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# Production Efficiency of Community Forestry in Nepal : A Stochastic Frontier Analysis

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A thesis
submitted in partial fulfilment
of the requirements for the Degree of
Doctor of Philosophy

at
Lincoln University
by
Narendra Bahadur Chand

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Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy.

# Production efficiency of community forestry in Nepal: A Stochastic Frontier Analysis

by

Narendra Bahadur Chand

During the past three decades, 1.2 million hectares of Nepal's forests have been transferred to community management with the twin objectives of supplying forest products and addressing local environmental problems. Community forests provide a range of benefits, from direct forest products such as timber, fuelwood, fodder, litter and grasses to ecosystem services such as soil protection and wildlife conservation. However, there is limited information on the relationship between the environmental and the community welfare effects of entrusting forests to communities. This study has analysed the production of natural environmental and direct forest product benefits in CFs, and identified the relationships between the outputs.

Community Forest User Groups were surveyed to measure the flow of products from their community forests. Environmental benefits were measured using a novel application of the Analytic Network Process (ANP). The ANP is generally executed by taking expert opinions; however, this study has taken forest user member's opinions. The stochastic frontier production analysis indicated that the production of direct forest product benefits per hectare was influenced by various socioeconomic and forest related factors, most prominently forest size, group heterogeneity, forest product dependency, size of community and links to the market. In addition, forest product benefits and environmental benefits were complementary to each other. Likewise, the production efficiency analysis showed that communities were not producing forest products efficiently. It also showed that factors such as social capital, support from the government and the longevity of CF management, contributed positively to the production efficiency, whereas caste heterogeneity in the executive committees of community forest user groups was negatively associated. It is anticipated that these findings will contribute to better implementation of community forestry programmes in Nepal and consequently will improve the welfare of communities by increasing direct forest product benefits and environmental benefits.

**Keywords**: Community forestry, production efficiency, stochastic frontier, Nepal.

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# Acronyms

| | |
|---|---|
| ACI | average consistency ratio |
| AHP | analytic hierarchy process |
| ANP | analytic network process |
| CA | community attributes |
| CD | Cobb-Douglas |
| CE | choice experiments |
| CFM | community forest management |
| CF | community forest |
| CFUGs | community forest user groups |
| CI | confidence interval |
| CI | consistency index |
| COLS | corrected ordinary least square |
| CR | consistency ratio |
| CV | contingent valuation |
| DEA | data envelopment analysis |
| DFO | district forest office |
| ES | environmental services |
| FA | forest attributes |
| GP | global priorities |
| HM | High Mountains |
| MAUT | multi attribute utility theory |
| MCDA | multi-criteria decision analysis |
| MH | Middle Hills |
| ML | maximum likelihood |
| MOLS | modified ordinary least square |
| MRTS | marginal rate of technical substitution |
| NMV | non-market valuation |
| OLS | ordinary least square |
| PPF | production possibility frontier |
| RP | Range Post |
| SFM | stochastic frontier model |
| SFA | stochastic frontier analysis |
| SFM | Sustainable forest management |
| TE | technical efficiency |
| TL | Translog |

# Chapter 1
# Introduction

## 1.1 Background

The paradigm of sustainable forest management (SFM) is emerging as a prime objective of forest management. The main features of SFM are recognition of social, environmental and economic values. However, maximisation of all three values together is impossible, as there is a trade-off amongst them. For example, management practices focusing on production of marketed products such as timber may have negative impacts on environmental services. In order to maximise the utility from the forest, all three forest values should be at optimal levels. Optimal level of economic, environmental and social values of forests can be attained only if the relationship amongst these values is known. Society chooses the level of these values based on the relationship amongst them.

SFM is the main thrust of forest policy in Nepal, particularly for community forest management (CFM). Under CFM a part of the government managed forest is handed over to the community for protection, management and utilization. CFM was introduced to supply forest products for basic needs and to halt environmental degradation. However, now the main focuses of CFM are to supply ever increasing demands for direct forest products and to maintain forest ecosystem services. Producing an optimum mix of forest environmental benefits and direct forest products is crucial for SFM (Misra & Kant, 2005).

To meet the increasing demand for direct forest products, productivity of forests ought to be improved and available resources should be utilised efficiently. A community forest (CF) producing high direct products and generating high environmental benefits is not necessarily utilising resources efficiently (Misra & Kant, 2004). The impact of increased resource use on the flow of environmental benefits is a matter of great concern (Adhikari et al., 2004). Increased direct forest products may come at the expense of environmental benefits. On the other hand, long term protection of a forest, without harvesting direct forest products in order to maintain the environmental benefits, might reduce the opportunities for needy people. Therefore, understanding the relationship between the production of direct forest products and environmental benefits is necessary.

In neo-classical economics it is believed that only conventional factors such as land, labour and capital contribute to the production process. However, North (1990) has demonstrated the role of non conventional factors claiming that factors such as social, economic and cultural factors also influence the production process. Understanding these social, economic and cultural factors, which may be beneficial or detrimental to the production process, is essential to improve production. A majority of CF studies have focused on production of a single output at a time, either forest product  or environmental benefits (Gautam et al., 2002; Malla, 2000). In CFM, production of both direct forest products and environmental benefits are important.

Identifying the factors of production and examining the relationship between direct forest product benefits and environmental benefits, is not sufficient to improve production outcomes. In recent years, production efficiency estimates of individual production units and their determining factors has received increasing attention (Binam et al., 2004; Ogundari et al., 2010; Rahman, 2003). Assessment of production efficiency variation among production units and investigation of associated factors, is essential from a policy perspective (Bravo-Ureta & Pinheiro, 1997; Lindara et al., 2006). Knowledge of associated factors which affect the level of production efficiency can be useful to improve the production efficiency of individual units. Policy makers may use information about the factors associated with production efficiency variation to design programmes that result in optimal production (Lien et al., 2007; Lindara et al., 2006).

## 1.2 Statement of the research problem

The Nepalese government's policy statement has emphasised the effective role of CFs in poverty reduction, through its positive impact on the local level economy and environmental conservation. In order to reduce poverty, efficiency in production, equity in distribution of forest product benefits and ecosystem sustainability, are essential (Agrawal & Ostrom, 2001). Efficiency improvement contributes to poverty reduction by 'making the overall cake bigger' (Adhikari, 2005; Binam et al., 2004). Ecosystem sustainability is a prerequisite to maintaining a continuous supply of forest product benefits (Chakraborty, 2001) and this is maintained through conservation of environmental benefits (Bengtsson, 1998; Lyons & Schwartz, 2001). Equity ensures the benefits are distributed according to the contribution of the members.

Existing studies on the production aspects of community forestry have either focused on individual products or distributional aspects of these forest products (Adhikari et al., 2004; Kanel & Varughese, 2000). Sakurai et al. (2004) for example, have compared the efficiency of timber production in plantation forests managed under three different ownerships; community, private and government. Efficiency was assessed in terms of costs of protection, inputs for forest management and overall profitability. The study solely analysed timber production and ignored the production of environmental benefits. Assessment of productivity in terms of multiple outputs of CFs is warranted and worthwhile for policy intervention (Liu & Yin, 2004).

From a distributional perspective, studies have shown that poor households have less access to forest products and income (Malla, 2002; Chakraborty, 2001; Iversen et al., 2005). This discrepancy in benefit distribution is mainly attributed to elite dominance and private endowment of households in a community (Adhikari, 2005; Agrawal & Gupta, 2005). Similarly, some studies have attempted to analyse the biological output of CFs and have revealed that the biophysical condition of forests has improved since they became CFs. For example, Karna et al. (2004) and Chakraborty (2001) claimed that crown coverage and growing stock of the CFs have improved after handover to communities. However, none of these studies have explored the condition of environmental benefits in these CFs.

Using case studies in two CFs, Achraya (2003) showed that the environmental benefits of the forests are declining. However, the study could not identify determinants which could enhance the environmental benefits and increase forest product benefits to communities. Branney and Dev (cited in Goverment of Nepal, 2006) claimed that forest users in CFs are managing forests for multiple forest products (timber, fuelwood and fodder). Therefore, the environment is conserved; however, no empirical study to justify their claim has been carried out yet. It is essential to understand which management model of forestry would address the twin problems of benefiting local people and conserving the environment.

Shrestha & McManus (2007) and Gautam et al. (2004a), stated that supply of forest products has decreased despite an increase in forest cover and stock volume. This was claimed to be due to the lack of distribution rules within forest users group. These studies attempted to address the relationship between two outputs; forest cover and supply of forest products, but were still unable to study the relationship between environmental benefits and forest product benefits, because, forest cover does not entail the entire range of environment benefits. Examination of the relationship between the production of tangible and intangible benefits of forests, is essential to manage a forest for a particular community, and for society as a whole (Zhou & Gong, 2005). That is, Pareto-efficient management of forests requires knowledge of the relationships between different benefits of the forest.

It is essential to understand whether the resources of CFs are being used efficiently or not. Are there possibilities for increasing the supply of direct forest products and forest environmental benefits within given resources? Or, are there possibilities for increasing the production of one of these benefits while maintaining the other benefit unchanged. Taking this point into account, the evaluation of production efficiency in terms of forest products and environmental benefits is essential (Viitala & Hanninen, 1998). In addition, identification of factors of production and factors explaining production efficiency, are essential for identifying opportunities for Pareto-improvement in terms of economic benefits and environmental conservation. None of the previous research has tried to identify the factors that are beneficial or detrimental to CF production efficiency.

This study addresses the following research questions to fill this knowledge gap and to contribute to informed policy decisions:

- What factors determine the production of direct forest product benefits in community forests?
- What is the relationship between CF environmental and direct forest products benefits?
- Are community forest user groups (CFUGs) equally efficient in producing direct forest product benefits and environmental benefits?
- What factors explain production efficiency of CFUGs?

## 1.3 Objectives

The purpose of this study is to examine the productivity of CFs that would enhance the environmental benefits as well as meet the forest product needs of the local people in Nepal. This purpose will be achieved by focusing the study on the following specific objectives:

- To estimate how the benefit from direct forest products is affected by forest attributes and socioeconomic attributes;
- To examine the relationship between environmental benefits and direct forest product benefits;
- To estimate the production efficiency of CFUGs in terms of direct forest product benefits;
- To determine factors explaining the variability in production efficiency among CFUGs, and
- To draw some policy implications.

## 1.4 Contributions

This study focuses on estimation of a production possibility frontier (PPF) concept in CFs of Nepal. The major contribution is identification of socio-economic and forest related factors, which contribute to the production process in CFs. Other contributions are:

- Identification of the relationship between direct forest product benefits and environmental benefits.
- Determination of the relationship between direct forest product benefits and environmental benefit value.
- Identification of exogenous factors that explain differences in production efficiency levels.
- Identification of policy implications for improving production in CFs in Nepal

Several other small contributions are made, which are noted in appropriate chapters.

## 1.5 Structure of thesis

This chapter has provided the background to this study and the study's objectives.

Chapter 2 explains CFM in detail, including: (i) the concept of community based management, (ii) the current status of CFs in Nepal, (iii) the kinds of benefits from CFs, (iv) issues in CF management and (v) a theoretical framework for analysis.

Chapter 3 explains the production possibility frontier, and reviews the literature related to different techniques of PPF estimation which includes parametric and non parametric techniques, and different functional forms.

Chapter 4 reviews different methods used to assess CF environmental benefits. The review mainly includes; (i) Analytic Hierarchy Process, and (ii) Analytic Network Process.

Chapter 5 explains the methods that have been used for conducting the research and analysis of the data. It describes the study sites and participants and operational procedures used for this study including, the instruments for data collection, selection of data for analysis, and the methods of analysis.

Chapter 6 presents the estimated environmental value of CFs and descriptive statistics of the variables used in this study. It also reports stochastic frontier analysis results.

Chapter 7 discusses the results presented in Chapter 6 with reference to findings of other studies and indicates implications of the findings.

Chapter 8 summarises the research findings, draws conclusions from the findings, discusses limitations and suggests opportunities for further research.

# Chapter 2
# Community Forest Management

## 2.1 Introduction

Chapter one identifies gaps and establishes a niche for a production performance study of Nepal's community forestry. This chapter reviews the literature regarding the performance of community forest management (CFM), particularly the performance of CFM in different circumstances. Factors which influence production performance in various studies are also identified. In addition, the chapter provides background information on Nepal's community forestry, including some cross-cutting issues related to the outcomes of community forestry.

## 2.2 Forestry management regimes

Four types of regimes have been appearing in forest management. These are open access management, community management, state management and private management regimes. In private management regimes, property rights are vested in the individual (Hanna et al., 1995; Heltberg, 2002). Although a perfect private management regime includes all entitlements of property rights such as access, use, management, exclusion and alienation, the owner is generally restricted from using resources in a socially unacceptable manner (Heltberg, 2002).

The open access management regime refers to the management situation in which there is lack of ownership and control over forest resources. In this management regime, access is free and unregulated, possibly because rights are only nominal and unenforced. Common management refers to forest management under communal ownership where access rules for community members are defined. In this management regime, property rights may be vested with individuals or with a group of people such as a tribe, a village, user committees, cooperatives, or local government (Heltberg, 2002). This type of management regime is mostly appropriate in a situation where the resources are indivisible and the enforcement cost of regulations is very high.

Under state management ownership, the control of resources resides in the state. The state formulates rules and regulations to control access and conservation (Heltberg, 2002). However, if a government fails to enforce the rules, state property can turn into *de facto* open-access property. Sometimes under state management, politicians and bureaucrats may manage the property so as to maximise their own interests (Cole, 2000).

## 2.3 Community forest management

In recent years, community management of forest resources has emerged as the main policy agenda in various developing countries (Adhikari et al., 2004; Agrawal, 2001; Heltberg, 2002). There are three main advantages for adopting community management in place of state management; (1) lower implementation and monitoring costs, (2) higher incentive for local people to get involved in management activities, and (3) adequate information related to natural resource management (Adhikari, 2005). Heltberg (2002) claims that successful management of the forest resource depends on the property rights assigned to the community and its members, and is only possible if the community has full ownership over the resources (Perman et al., 1999). For full ownership, it is mandatory to have exclusion, management, use, and alienation rights over an entity. Some authors (such as Poteete & Ostrom, 2004; Varughese & Ostrom, 2001) however, argue that different institutional, socioeconomic and cultural settings of communities decide the success or failure of community management.

Thus, the question arises; why do some communities become successful and others do not. Knowledge of what makes some forest management units more successful than others could help to improve the overall performance of CFM. At the same time, it is necessary to define what criteria are appropriate to evaluate the success of CFM.

## 2.4 Measuring success of community forest management

Varieties of success criteria have been reported in CFM studies. For example, Agrawal & Chhatre (2006) have regarded improvement in forest condition as the criteria for the success of CFM. They identified contextual factors, such as economic and demographic characteristics of the community as determinants of successful CFM. The study identified a relationship between forest condition and contextual factors such as distance to market, population change and fodder supply. Similarly, Varughese & Ostrom (2001) have used qualitative improvement in forest condition as an indicator of the success of CFM. Again, improvement in forest condition does not necessarily guarantee the fulfilment of local forest needs (Thoms, 2008). It is possible that a forest may have improved due to restrictions on the use of forest resources, which reduces forest benefits to local communities.

Adhikari (2005) has considered forest product benefits to individual households as a measure of success of CFM. Forest product benefits as the sole criteria of success, however, overlook the forest condition. To obtain higher forest product benefits, the forest condition may have been sacrificed. Adger & Luttrell (2000) and Heltberg (2002) have suggested three main criteria - economic efficiency, ecological sustainability and social equity - to measure the success of CFM. A CFM unit is said to be more economically efficient than others, if it generates more benefits than other units using the same inputs. Ecological sustainability relates to resource quality and maintenance of natural capital to ensure the continuous flow of goods and services. Social equity is concerned with the fair distribution of benefits and costs among the members of a community (Hanna et al., 1995).

Following Heltberg (2002), Adger & Luttrell (2000) and Misra & Kant (2004) have examined the success of joint forest management in India, measuring production efficiency in terms of forest product supply, forest crown coverage and social empowerment of the community. The approach of measuring success in terms of production efficiency is favoured by many authors (Adkins et al., 2002; Méon & Weill, 2005). Production efficiency measures provide fundamental knowledge of causes contributing to slackness in production. This knowledge can suggest policy intervention strategies to enhance overall production performance (Helfand & Levine, 2004; Reinhard et al., 2002).

Albeit several success criteria have been reported in community management literature, the selection of particular criteria of success depends largely on the objectives of management. Pagdee et al. (2006) argued that whatever criteria are used, they should be integrated with the broad dimensions of sustainability; ecological sustainability, social equity and economic efficiency.

## 2.5 Factors influencing outcomes of CFM

Studies have reported a large number of factors that can influence the outcomes of CFM (Agrawal & Chhatre, 2006; Bardhan, 2001; Heltberg, 2002; Misra & Kant, 2004). The most notable outcomes include physical forest condition, forest product supply and the supply of forest services. For this discussion, these factors are broadly categorised into biophysical and socioeconomic, social capital and heterogeneity.

### 2.5.1 Biophysical and socioeconomic factors

According to Misra & Kant (2004) forest outcomes depend not only on transformation factors, but also depend on transaction factors. Land, labour and capital are transformation factors used to create outputs. On the other hand, transaction factors are related to the social, cultural and economic characteristics of the community or organisation (Misra & Kant, 2005). Types of property rights, community heterogeneity and CF dependency are some examples of transaction factors. Transaction factors influence the transaction costs of production processes (Adhikari, 2005; Kant, 2000). In a study of joint forest management in India, Misra and Kant

(2005) have found that both transformation and transaction factors contribute significantly to the social, economic and biological outputs. The transformation factors were area of forest, number of households, and condition of forest before handover, whereas transaction factors were growing stock of forest, forest dependency, community's knowledge of government orders, distance to market and community leadership.

Many studies have demonstrated the influence of group size, access to market and forest dependency on collective actions in community based management. Ostrom (1990) found that group size is a determinant of outcomes and argued that smaller group size is more effective for collective action. Smaller groups reduce the transaction costs involved in organising activities related to resource management, such as developing rules and monitoring each other. Likewise, according to Poteete & Ostrom (2004), as group size drops trust among the group members increases because of increased interaction. Gautam (2007) observed a significant negative relationship between group size and number of trees per hectare.

While small size is beneficial for interaction, Agrawal (2000), in a study of CFs in northern India, found that communities having a small number of people were unable to collect enough funding to implement forest protection activities. As a result, the forest condition could not be improved. Likewise, Heltberg (2001) found that the collective action of common property owners is influenced by factors such as group size. However, findings of the relationships between group size and collective action were not consistent with the collective action theory, which states that the possibility of collective action is higher in small user groups. Heltberg (2001) found that large villages are more likely to have better collective action. This contradictory finding may be due to the small sample size or different social context as only 31 observations were used to establish the relationship.

Many studies have demonstrated the role of market access on outcomes of CFM, but the results are widely divergent. Some researchers (such as Agrawal, 2001; Gebremedhin et al., 2003) argued that better market access increases the value of resources and thus produces an incentive to the group members to produce more. Other researchers (such as Baland & Platteau, 1996; Pender & Scherr, 1999) have claimed that access to markets may lessen group members' contribution to resource management, since community members may have better 'exit' options. Thus, the effect of market access on common resource management is ambiguous and site specific.

Resource scarcity is another factor which influences the success of CFM. Heltberg (2001) has found that high level scarcity of resources, which was measured, by considering the village population relative to the area of forest, has a negative relationship with collective action. That is, shortage of resources makes people reluctant to accept collective management, because collective management may not provide their requirements. Therefore, instead of involving themselves in collective management, community members may defy resource use rules and they may over-exploit resources to fulfil their needs. Contrary to Heltberg (2001), Wade (1987) has claimed that scarcity of resources encourages people to form groups to achieve intensely felt needs which is not possible to do by individual action. Bardhan (1993) argues that medium levels of scarcity favour collective action. He argues that at high levels of scarcity, people struggle for survival and breaking of resource use rules is likely. Also, at low levels of scarcity, people need only a small amount of resources, which they easily obtain, and therefore are reluctant to cooperate for collective action.

### 2.5.2 Social capital

In recent years, the notion of social capital has emerged as one of the main determinants in the success of community management (Van Ha et al., 2004). Social capital is a multi-dimensional concept comprised of four components: associational activity, social relations, trust and reciprocity (Pretty & Ward, 2001; Van Ha et al., 2006).

Existence of social capital facilitates interactions among community members and builds trust and hence lowers transaction costs (Pretty & Ward, 2001). Lower transaction costs enhance efficiency of outcomes (Van Ha et al., 2006). Nepal et al. (2007) argue that social capital fills the information gaps between the community members, and as a result information flows smoothly at lower cost.

Evidence from several studies has indicated that social capital acts as an input factor and contributes positively to the production process. For example, Van Ha et al. (2006), found a role of social capital in production efficiency, in paper recycling mills in Vietnam. Interestingly, they found that social capital contributes more to the production process than physical capital. Sakuri (2001) analysed the effect of social capital on collective action in community forestry management, and found that structural social capital, which is measured in terms of frequency of governing rule change in CFs, contributes to collective action. On the other hand, cognitive social capital, which is measured in terms of the number of years since the handover of a CF, had no significant effect on collective action.

### 2.5.3 Group heterogeneity

The role of group heterogeneity on the performance of CFM is well documented in the literature. Economic and non-economic differences within a community generate heterogeneity (Dayton-Johnson & Bardhan, 2002). Three main types of heterogeneities have been distinguished in community management discourse; social heterogeneity, economic heterogeneity and spatial heterogeneity (Poteete & Ostrom, 2004; Varughese & Ostrom, 2001).

Theoretically, heterogeneity, whether it is economic, or social or spatial, generates diversity in knowledge, capacity and interest (Adhikari & Lovett, 2006). Diversity may impede consensus building and rule enforcement among community members, regarding management of common property resources. White & Runge (1994) and Cernea (1989) argued that heterogeneity among group members makes it costly to achieve consensus about a common goal.

In an empirical study on communally owned irrigation systems in Mexico, Dayton-Johnson (2000) demonstrated that group performance of irrigation systems which was measured by indicators such as the state of repair of field intakes and the degree of leakage around water canals, was significantly negatively associated with economic inequality and social heterogeneity. Using a theoretical model, Dayton-Johnson & Bardhan (2002) demonstrated a possible 'U' shaped relationship between economic heterogeneity and resource conservation. Increased heterogeneity up to certain limits does not support resource conservation. However, further increases in heterogeneity may produce more conservation of resources, because dominant users may bear the cost of externality and at the same time support small users to free ride on the former's contribution in order to conserve resources.

However, the effect of heterogeneity on resource management is not always the same, and its role is highly variable (Adhikari & Lovett, 2006; Gautam, 2007; Poteete & Ostrom, 2004; Varughese & Ostrom, 2001). For instance, Bardhan (2001) noticed that the maintenance of community managed irrigation canals is consistently lower in villages with higher social heterogeneity. Somanathan et al. (2007), reported evidence of a relationship between land equality and collective action in pine forests in the Himalayan district of India. In contrast, Adhikari & Lovett (2006) and Varughese & Ostrom (2001) found that there were no consistent relationships between social, economic heterogeneity and outcomes in CFM. Along the same line, Gautam (2007) noticed that there is no relationship between social heterogeneity and various biological variables of a forest, such as basal area and the density of trees.

## 2.6 Forest management in the Nepalese context

### 2.6.1 Forest dependency

Nepalese people are highly dependent on forest resources for their livelihoods. Forests mainly provide timber, fuel wood, fodder and grasses. More than two thirds of fuel wood requirements and more than 50% of fodder for livestock are extracted from forests (Acharya et al., 2004). In addition to forest product supplies for livelihoods, forests contribute to agricultural production. Forests provide grazing and fodder for livestock which in turn, supply manure to fertilize agriculture fields (Dougill et al., 2001; Nepal et al., 2007).

Forestry is also indirectly linked with agriculture. Some studies have shown a link between accessibility to forest products, and agricultural production (Amacher et al., 1996). It has been observed that when forest products such as fuel wood or fodder become scarce or costly to collect, the households spend considerably more time in the collection of forest products (Cooke, 1998). Spending more time in activities other than agriculture negatively affects agricultural production.

### 2.6.2 Forest classification

Five categories of forest are recognised in Nepal. These are (1) government managed forest, (2) leasehold forest, (3) religious forest, (4) protection forest, and (5) community forest. Table 2.1 depicts categories of forest, their management objectives and agencies responsible for their management. Among these forest categories, CF has received the highest priority within the forestry sector, because large numbers of people are directly involved in this forest category (Iversen et al., 2006; Thoms, 2008).

**Table 2.1 Forest classification, management objectives and responsible institutions**

| Forest category | Management objectives | Responsible agencies |
|---|---|---|
| *Government managed* | *Production of forest products* | *Government* |
| *Leasehold* | *Rehabilitation of forest, production of forest products* | *Leasehold group, industries* |
| *Religious* | *Protection of religious site* | *Religious institutions* |
| *Protected* | *Protection of wildlife, biodiversity and environment* | *Government* |
| *Community* | *Production of forest products and multiple purpose use* | *Forest user groups* |

Source: GN (2002)

### 2.6.3 Community forestry

Though communities have been managing forests for decades formal handing over of forests to communities began with the promulgation of the National Forest Plan 1976 (Gautam et al., 2004b). Prior to 1976, forests were managed by local communities according to their customary rules and regulations, ownership of forests remaining with the state (Nightingale, 2010). During the inception of the community forest policy, the forests were handed over to local bodies called *Panchayat* under two schemes, *Panchayat* forests referring to planted forests and *Panchayat* protected forests referring to natural forests. After the restoration of multiparty democracy in 1990, a new Forest Act (1991) and Forest Regulation (1993) were enacted giving greater property rights related to forest to local community forest user groups (CFUG[1]s).

Under CFs, parts of the government managed forest are handed over to the community for protection, management and utilization. The community is entitled to conserve, manage and use the forest and to sell forest products outside the community by independently fixing the price in the market (Agrawal & Ostrom, 2001). Although forest management is handed over to a community, ownership of the land remains with the government (Khadka & Schmidt-Vogt, 2008). The government can take the CF back if the CFUG works against provisions stated in the CFUG's constitution and forest operational plan.

Each CFUG prepares its own constitution for day-to-day functioning of the group, and a forest operational plan to manage the forest. The forest operational plan and the constitution are the main legal documents of mutual agreement between the local community and the government. The CFUG executes small scale development projects such as trail repair, support to schools and also forest related activities such as thinning, pruning and monitoring as specified in these two documents.

CFs supply both direct and indirect forest benefits. Directly consumable forest products such as timber, fodder and fuel wood provide direct benefits, and forest products such as watershed protection and soil erosion control which are not directly consumable provide indirect forest benefits (Chaudhary, 2000; Thoms, 2008). The government mandates that while supplying the direct forest benefits there should not be significant adverse effect on the supply of indirect benefits.

[1] CFUG is the group of people living near a particular forest area and which is registered at the District Forest Office. It is an independent and self governing entity (Kanel, 2006)

CFUGs are entitled to carry out development activities in their communities from the income obtained from various sources, such as donations from non-governmental organisations and income from selling forest products. Recent CF policy documents have emphasised the role of poverty reduction through CFs (Government of Nepal, 2008), suggesting that equitable distribution of forest products among community members and increased community income-generating activities, can help to reduce poverty.

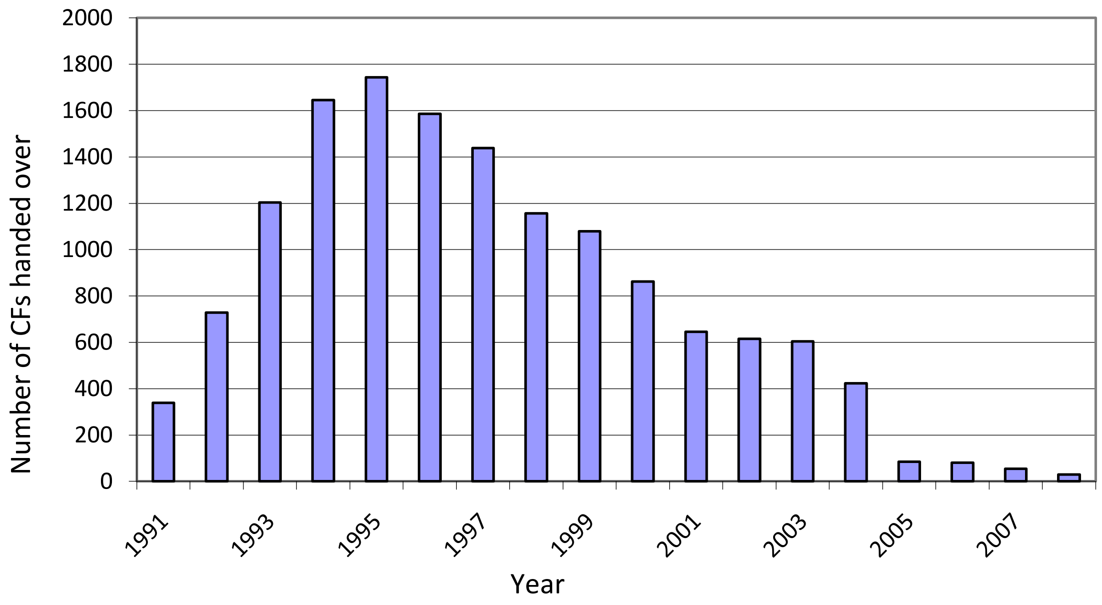
The Forest Act 1993 and the Forest Regulation 1995 identify criteria for the handover of national forests to a community, as follows:

- Accessibility - the forest should not be too far from the community.
- Traditional use rights - the community should have been using the forest for a long time.
- Willingness to manage the forest as a CF - the community should be interested in taking responsibility for management.
- Capacity of users to manage the forest size – the size of forest should be manageable for the community.

#### *2.6.3.1 Status of community forests*

Although the government has recognised CFs as a prioritised programme in terms of volume of activities (Chaudhary, 2000; Thoms, 2008), the CF hand-over rate is falling every year. This trend is mainly because most of the accessible forests located in the Middle Hills (MH)[2] and the High Mountains (HM) have already been handed over, and partly because governments have restricted handing over CFs in the Terai (Kanel, 2004). When the CF programme was first implemented during the 1990s, the hand-over rate was high. Figure 2.1 depicts hand-over of CF from 1991 to 2008. A considerable number of CFs were handed over to communities between 1994 and 1997, possibly because a new Forest Act was promulgated in 1993 with provisions for more user rights.

[2] Nepal is divided into three physiographic regions; High Mountain, Middle Hills and Terai (Government of Nepal, 2006). The High Mountain region lies in the north above 4000m. Middle Hills is the region between 1000m-4000m. Terai refers to the southern low land of Nepal, which lies below 1000m from msl.




Source: DoF (2009)

**Figure 2.1 Number of CFs handed over between 1991 to 2008**

Even though the hand over rate of CFs is declining, the accumulated area and the number of CFs have increased substantially from 1991 to 2008. Some figures related to CFs are shown in Table 2.2. Out of a total area of 5.5 million hectares, 2 million hectares are categorised as potential CFs, and the remaining 3.5 million hectares are categorised as leasehold forests and government managed forests. Twenty two percent of Nepal's forest area has been handed over as CF. Up until 2009, 14,569 forest patches have been handed over to communities. Approximately 1.67 million households, which constitutes about 35 % of the total population, are involved in CFM (Sharma, 2009).

**Table 2.2 Status of CF in Nepal as of 2009**

| | | |
|---|---|---|
| Total land area of Nepal | 14.7 million ha | ———— |
| Total forest area | 5.5 million ha | 37 % of total land area |
| Potential CF area | 3.5 million ha | 64 % of total forest area |
| Forest area under CF | 1.2 million ha | 22 % of total forest area |
| Number of forest patches handed over | 14,569 | |
| Households involved | 1.67 million | 35 % of total population |

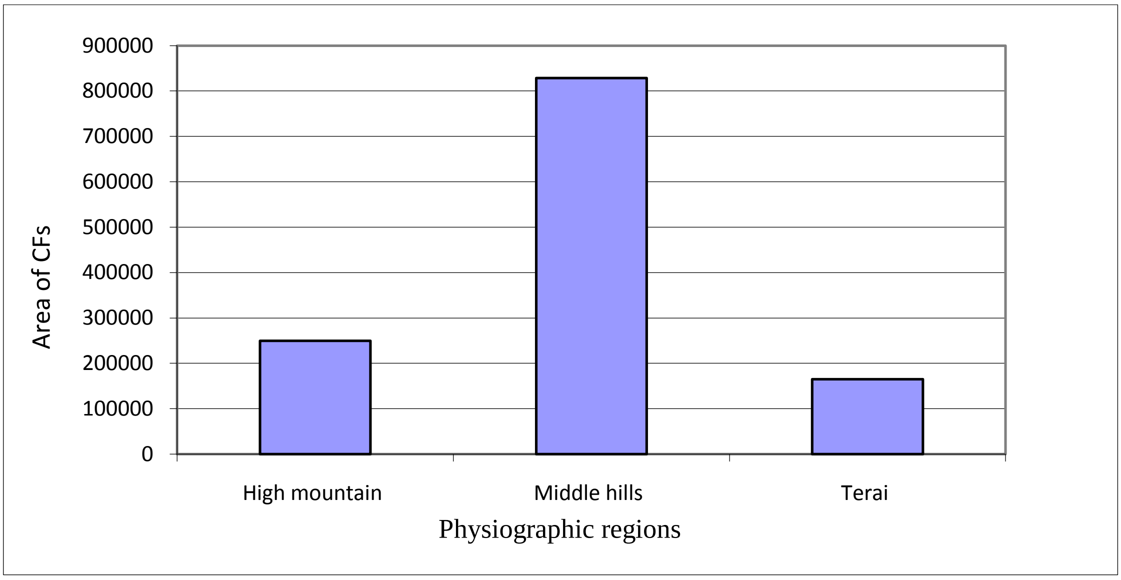
Source: Sharma (2009)

#### *2.6.3.2 Spatial distribution of CFs*

Although an identical CF model has been implemented throughout the country, there is great variation in the distribution of CFs between physiographic regions (Chakraborty, 2001).

Figure 2.2 demonstrates that a large proportion of the CF area is located in the MHs. Only small areas of CF are located in the High Mountains and the Terai (Sharma, 2009). According to Sharma (2009), about 67 % of the total area of CF is located in MH followed by HM (20%) and the Terai (13%).

A more homogeneous society, the sporadic nature of forests and the existence of traditional forest users in the Middle Hills and the High Mountains, are the reasons for more CFs in these areas than in the Terai (Chakraborty, 2001). The possibility of negotiation for forest management is high for groups who are homogeneous and who are managing forests traditionally. In addition, sporadic forest patches are generally characterised by clear boundaries. If a forest has a clear boundary, conflicts among the forest users are less likely to occur and this makes the hand-over process easier. The Terai region is characterised by a heterogeneous society (Chakraborty, 2001), and many Terai forest users live far from forests, which makes the forests difficult to protect (Iversen et al., 2006).




Source: Sharma (2009)

**Figure 2.2 Area of community forests by physiographic regions**

#### *2.6.3.3 Benefits from CFs*

CFs provide numerous types of benefits, which can be broadly categorised into economic, environmental and social benefits.

***Economic benefits***

The main objective of CFUGs is to fulfil daily requirements of forest products. However, many CFUGs produce more than their daily requirements, hence they sell surplus products in the market. Several authors claim that most CFUGs are becoming economically better off by selling a variety of forest products (Chakraborty, 2001; Chaudhary, 2000). Kanel (2004) has estimated a monetary value of forest products for all CFs in Nepal in 2002 and found that CFUGs earned NRs 1.8 billion (equal to US$ 24 million) based on the market prices of forest products. In addition to the benefits from forest products, CFUGs receive monetary benefits from various sources, such as membership fees and donations from government and non-government organisations.

The monetary benefits generated from all sources have been spent largely on forest and community development activities (Kanel, 2006; Thoms, 2008). Various studies have shown that development activities carried out in the community have been supporting the livelihoods of rural people. A study by Dev and Adhikari (2007) carried out in 14 CFUGs in different parts of Nepal found that the contribution made by benefits generated from CFs is helping to build infrastructure. Table 2.3 illustrates some examples of infrastructure developments in CFs. Though CFs have been contributing to infrastructure development, their impact, particularly on poor people, depends on the type of infrastructure. For example, infrastructure for irrigation may provide more benefits to the rich than poor, because in rural Nepal, rich people have larger land holdings that benefit more from irrigation, while poor people often have little or no irrigable land.

**Table 2.3 Contribution of CFs to infrastructure development (1994 – 2004)**

| Types of infrastructure | No of CFUGs | Quantity | Contribution of CFs | | Main beneficiaries |
|---|---|---|---|---|---|
| | | | US$ | % of cost | |
| Village trail | 8 | 45 Km | 3228 | 50 | All |
| Temple | 1 | One | 928 | 85 | All |
| School support | 9 | Nine schools | 7528 | 25 | Wealthy and some poor |
| Electricity | 1 | One village | 4285 | 30 | Wealthy |
| Health facility | 1 | One building | 442 | 20 | All |
| Irrigation channel | 5 | 20 Km | 2857 | 35 | Wealthy |

Source : Dev and Adhikari (2007)

Although CFs have been generating benefits from different sources, distribution of benefits at the household level is a big policy issue. In this regard, it has been demonstrated that benefits are asymmetrically distributed among different economic classes of households. A study by

Thoms (2008) in the MHs has shown that the rich members receive higher net benefits than the poor members of CFUGs. Adhikari (2005) presented an econometric analysis of the impact of private endowments (such as land and livestock) and household characteristics on benefits from CFs, and showed that rich and poor have asymmetric opportunities to benefit from CFs. Poorer members have been receiving fewer net benefits compared to rich and middle income members. In addition, these studies concluded that forest product benefits are determined by private endowments and household characteristics such as land holdings, livestock, education and caste, all of which are attributes of rich households.

A study by Malla (2000) concluded that the poor have less access to forest products for subsistence use and incomes, than the rich households. Brown (2003b) showed that local elites dominate the CFUGs and have a high level of decision making ability and decision influence. The elite in a community is usually determined by landholdings, political affiliation, education and caste (Thoms, 2007). The elite support a management strategy which gives priority to timber production rather than fuel wood and fodder production. This kind of decision deprives poor households from obtaining forest products which they need (Thoms, 2008).

The studies so far carried out related to benefits from CFs are focused at the household level. However, the study of benefits at the community level may have policy implications. Knowledge of the extent of benefits and the determining factors at the community level could assist in improving the community welfare.

***Environmental benefits***

The CF programme has been successful in restoring degraded forests in Nepal (Chaudhary, 2000; Thoms, 2008). Many studies related to CFs report forest improvement. For example, Gautam et al. (2002) carried out a study of land use changes associated with CF implementation in the MHs and found that CF activities have contributed to restoration of the forests. The area of forest has increased, due to forest regeneration on lands which were previously barren. Adhikari et al. (2004), Nightingale (2003) and Thoms (2007) have also reported improvements in forest condition due to the CF programme.

The CFs have also been providing a variety of environmental benefits with the improvement in forest condition. For example, Gautam et al. (2004a) carried out a study of land use changes in the MHs of Nepal, by comparing satellite images from 1976, 1989 and 2000. The study has shown that the number of forest patches decreased and forest area increased significantly from 1976 to 2000, because of the merging of patches in the latter period due to regeneration and plantation in open places. Jackson et al. (1998) undertook a land use change study in two MHs districts using aerial photographs from 1978 and 1993. They identified that scrublands and grasslands were converting into more productive categories of forest where communities were managing the forests. Gautam et al. (2002) and Gilmour et al. (2004b) claimed that improved soil erosion control and water conservation is significantly noticeable in the area where communities have been able to regenerate forest cover on previously degraded land.

However, these findings only revealed the ecological outcomes and ignored the economic outcomes. Pagdee et al. (2006) argued that improvement in forest condition provides too narrow a measure for judging CF success. An improvement in forest condition does not necessarily improve the supply of forest products (Dougill, 2001). Existing studies have been concerned only with improvement in forest condition and have overlooked the impact on the flow of forest ecosystem services, such as soil erosion control and wildlife habitat improvement. Pagdee (2006) claimed that forest management is successful if it supplies the local forest products needed, along with improvement in forest condition.

***Social benefits***

Besides economic and environmental benefits, CFs have created local organisations in the form of CFUGs. These groups help to form social capital (Dev et al., 2003; Nepal et al., 2007). The CFUGs have created forums where many interactions related to forest management as well as other development activities, occur. These interactions build trust among the community members, which helps to implement development activities both within and outside the CFs (Dev & Adhikari, 2007).

After institutional assessment in eleven CFUGs, Dev et al. (2003) have concluded that even the least organised CFUGs produce a certain level of social capital. The study has further shown that CFUGs have established new local organisations, which have been creating a forum for planning and implementing development activities. In many places, it has been observed that CFUGs are going beyond the management of forests and becoming a medium for village development and district development planning activities.

#### 2.6.3.4 The next step forward

The review of previous studies shows that they are either focused on the supply of direct forest products or are focused on the change in the biophysical conditions of the CFs. The combined production of environmental benefits and direct forest product benefits at the community level, has not received adequate attention from researchers. However, multiple objectives for CF management require information on all outcomes. There is a possibility that some communities have been more concerned with producing direct forest products, disregarding environmental benefits, or have been more concerned with environment benefits, overlooking the supply of direct forest products. There is also a possibility of producing more of both outputs. These possibilities in production show a need for a study which analyses the production of direct product benefits along with environmental benefits in CFs.

The production possibilities analysis between these two broad classes of outputs, and the examination of production efficiency, which measures the ability of producers to convert input factors into outputs, is crucial in community managed forests, especially in developing countries like Nepal, where input resources may have been used excessively (Misra, 2004). Examination of production efficiency differences among CFs and their determinants, could be useful for improving the performance of CFs.

A study of the production possibilities, in terms of forest product benefits and environmental benefits, can indicate whether forest product benefits under the present conditions can be increased without degrading environmental benefits. The production possibilities can provide useful insights into potential improvements in CF management. This study uses production analysis to investigate whether or not CFs are producing direct forest benefits and environmental benefits efficiently using the available resources. The production analysis of two outputs involves two components – the relationship between the two outputs and the relationships between outputs and the input factors. This can be carried out using the production possibilities frontier models (Coelli et al., 2005; Misra & Kant, 2004).

## 2.7 Summary

This chapter reported the rationale for implementing community management of forest resources instead of government management. Lower transaction costs, higher incentives to get involved in management activities, and adequate management information with the community people, are reasons for the effectiveness of community management. The effectiveness of forestry initiatives is measured on the basis of management objectives, using criteria such as improvement of forest condition, household welfare change due to forest management, production efficiency, and the social empowerment of people. Socioeconomic factors, such as group size, group heterogeneity and links to the market, influence the success of community management of forest resources.

As in other countries, the CF programme in Nepal has been regarded as a successful initiative for managing forest resources. Although community forestry has been successful in halting deforestation in Nepal, its economic impact favours rich people. Studies undertaken so far have dealt only with the consumption of forest products at the household level and have provided limited information on changes in environmental conditions. The relationship between community welfare from consumption of forest products, and the condition of the natural environment in CFs, has not been addressed. It is essential to investigate the relationship between these two outputs, to identify the sustainability implications of CFs. Knowledge of socioeconomic factors which influence the production of forest outputs can help predict future changes and the design of policy responses. The next Chapter presents the theoretical framework for the production possibility frontier model, which conceptualises relationships between outputs and between outputs and socioeconomic factors. The Chapter then discusses the concept of the production function and production possibility frontier models.

# Chapter 3

# Theoretical Framework and Production Function

## 3.1 Introduction

Maximisation of community welfare requires efficient allocation of resources. This chapter identifies criteria for the measurement of resource allocation efficiency and how those criteria can be examined empirically. This chapter first presents the theoretical framework for analysis, then introduces the production function and production possibility frontier concepts and criteria for efficient allocation of resources before discussing different ways of measuring efficiency and their advantages and disadvantages.

## 3.2 Theoretical framework for analysis

According to Ng (2004), social welfare (or good) is the aggregation of welfare of individuals or communities. Welfare of individuals depends on the utility derived from the consumption of different goods and services. If $W_i$ is the welfare of an individual *i*, then social welfare is ;

$$SW = f(W_1, W_2, W_3 \ldots\ldots\ldots\ldots W_I) \qquad (3.1)$$

where *SW* is the welfare of society as a whole. If $U_1$, $U_2$ , $U_3$ *…………..,* $U_n$ are the utilities derived from the consumption of different goods and services, then the welfare function for an individual $W_i$ can be written as ;

$$W_i = f(U_1, U_2 \ldots\ldots\ldots\ldots\ldots, U_n) \qquad (3.2)$$

According to the utilitarian concept of welfare, welfare is regarded as improved if the sum of individuals' or communities' welfare is better in the alternative situation than in the original situation (Dolan, 1998; Ng, 2004). The utilitarian social welfare function is;

$$W = W_1 + W_2 + W_3 + \ldots\ldots\ldots\ldots + W_n = \sum_i W_i \qquad (3.3)$$

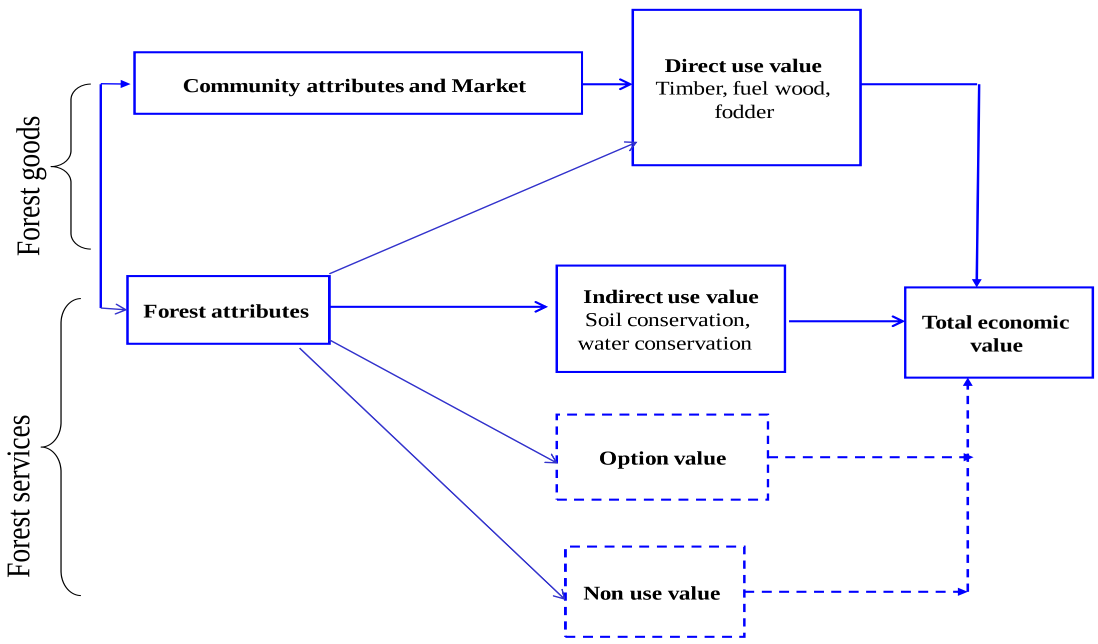
Social welfare is maximised when the sum of welfare of the individuals is maximised, irrespective of how welfare is distributed. However, the utilitarian concept of social welfare claims that society as a whole may achieve welfare improvement, even if some communities or individuals happen to decrease their welfare (Dolan, 1998).

For this study, it is postulated that the welfare of a society as a whole is the aggregation of the welfare of individual CFUGs. The welfare of an individual CFUG, on the other hand, depends on the utility derived from the consumption of forest goods (timber, fuel wood and fodder etc.) and services (water quality, flood control, biodiversity etc.). The total value of forest goods and services is split into direct use value, indirect use value, option value and non-use value, and the utility function of a CFUG can be expressed as ;

$$U_i = f(U_{FP_i}, U_{O_i}, U_{IU_i}, U_{NU_i}) \qquad (3.4)$$

where, $U_i$ is the utility of the $i^{th}$ CFUG, $U_{FP_i}$ $U_{O_i}$ $U_{IU_i}$ and $U_{NU_i}$ represent the utilities derived from the consumption of direct forest products, option, indirect use and non-use values respectively of the $i^{th}$ CF.

Utility derived from direct forest product values (*FP*), indirect use value (*IU*), option values (*O*) and non-use values (*NU*) is determined by various input factors. A hypothesised framework is shown in Figure 3.1.




Modified from Edwards & Abivardi (1998)

**Figure 3.1 Diagrammatical representation of theoretical framework**

Forest attributes, community attributes and markets are the key input factors, which affect the production of forest goods and services. Specifically, the framework postulates that production of direct use value of a forest is influenced by forest attributes (*FA*), market attributes (*M*) and community attributes (*CA*). Production of indirect use value, option value and non-use value are largely determined by *FA*. Thus, the welfare function can be expressed in terms of utility given by the Equation (3.5) - (3.10).

$$U_{FP_i} = f_2(FP_i) \tag{3.5}$$

where $FP_i = f_3(FA_i, M_i, CA_i)$

hence, $U_{FP_i} = f_4(FA_i, M_i, CA_i)$ (3.6)

$$U_{IU_i} = f_5(FA_i), \tag{3.7}$$

$$U_{O_i} = f_6(FA_i), \tag{3.8}$$

$$U_{NUi} = f_7(FA_i) \tag{3.9}$$

$$U_i = f(U_{FP_i}, U_{O_i}, U_{IU_i}, U_{NU_i})$$

$$= f_8(FA_i, M_i, CA_i) \tag{3.10}$$

Maximum utility is obtained only if a CF produces optimum amounts of direct usable forest products and indirect usable services (Misra, 2004). However, according to the framework, the quantities of the different outputs depend on forest attributes, market and community characteristics. Hence, maximisation of the utility of a community requires identification of the relationship between the multiple outputs and their relationships with market attributes, forest attributes and community characteristics. Although, the framework conceptualises four types of benefits from a forest, this study considers only direct use benefits and indirect use benefits. Non-use benefits are not included in this study because of the practical complexity in valuation and time constraints.

Production analysis is generally employed to analyse the relationship between outputs and outputs and inputs. The following section reviews different production models, their merits, demerits and estimation methods.

## 3.3 Concept of production function

A production function is a mathematical expression of relationships between outputs and inputs for given technology, and indicates the maximum amount of output attainable with given inputs (Battese, 1992; Nicholson, 2002).

Assume two inputs $(x_1, x_2)$ are used to produce one output (*y*) then the production function is:

$$y = f(x_1, x_2) \tag{3.11}$$

In Equation (3.11), y is the maximum quantity of output that can be produced with different quantities of the inputs $x_1$ and $x_2$. Sometimes the term ‘production frontier’ is used instead of ‘production function’ (Coelli et al., 2005).

Figure 3.2 represents the production function graphically. The surface OS represents the boundary of maximum output that can be obtained from inputs $x_1$ and $x_2$.

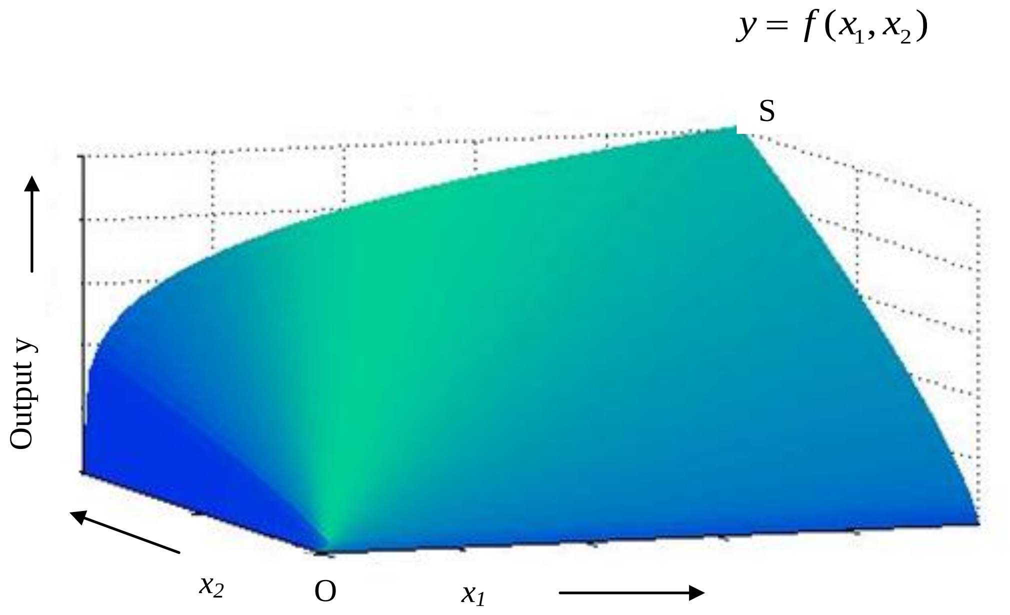



**Figure 3.2 Production frontier**

## 3.4 Production possibility frontier

The production possibility frontier (PPF) represents the different combinations of outputs that can be produced with given levels of inputs. The PPF describes the various quantities of different goods that can be produced simultaneously using available resources (Figure 3.3). In other words, the PPF is the boundary between those combinations of outputs that can be produced and those that cannot be produced. The combinations of outputs inside the frontier are possible. Points beyond the frontier are desirable but are not obtainable. The combination of outputs lying inside the frontier are considered productively inefficient (McCoy, 2003).

Following Coelli et al. (2005), assume that a firm is producing two outputs $y_1$ and $y_2$ using one input $x_1$, then the input requirement function is given by;

$$x_1 = f(y_1, y_2) \Rightarrow y_2 = f(y_1, x_1) \qquad (3.12)$$

The function defined in Equation (3.12) can be illustrated in a PPF (Figure 3.3).

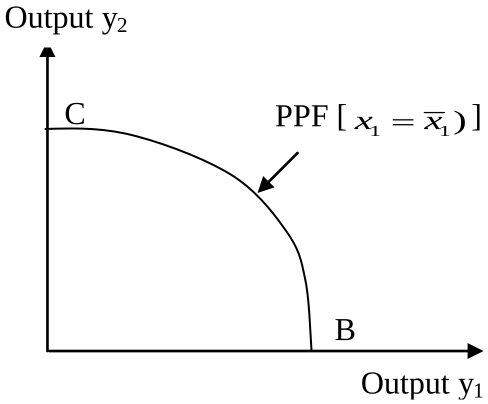



**Figure 3.3 Production possibility frontier**

In Figure 3.3, BC represents the PPF and shows all the maximum possible combinations of two products $y_1$ and $y_2$ that can be produced when all the given resources and technology is used at a given time. The slope of the PPF at any given point measures the marginal rate of transformation, which is the rate at which one output can be transformed into another output (Varian, 2006). In other words, the PPF shows the opportunity cost of one output as measured in terms of the other output (Mankiw, 1997).

The PPF in Equation (3.12) is the case of a firm producing two outputs. However, production schemes may entail different combinations of outputs and inputs. Some of them are: 1) producing one output using one input, or 2) producing two outputs using two inputs, or 3) producing one output using two inputs, or 4) producing multiple outputs using multiple inputs. Except for the production of multiple outputs using multiple inputs, the other production schemes can be illustrated with a two dimensional graph. For instance, the one input/one output PPF is illustrated in Figure 3.4.

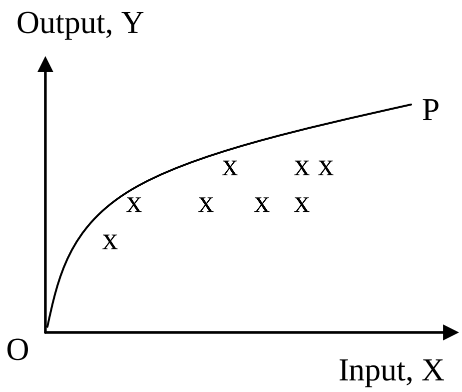



**Figure 3.4 Production possibility frontier with one input/one ouput**

In Figure 3.4 each ‘x’ represents the observed input-output values of different producers. The curve (OP) enveloping the highest of these input-output values, depicts the PPF. Production units operating below the PPF are producing less than their potential.

Likewise**,** Figure 3.5 represents the two inputs and one output PPF. A firm uses two inputs of production, $X_1$ and $X_2$, to produce a unit of output Y. Under the assumption of constant returns to scale, efficient technology is represented by the unit isoquant, which is obtained by enveloping the lowest combinations of inputs per unit of output.

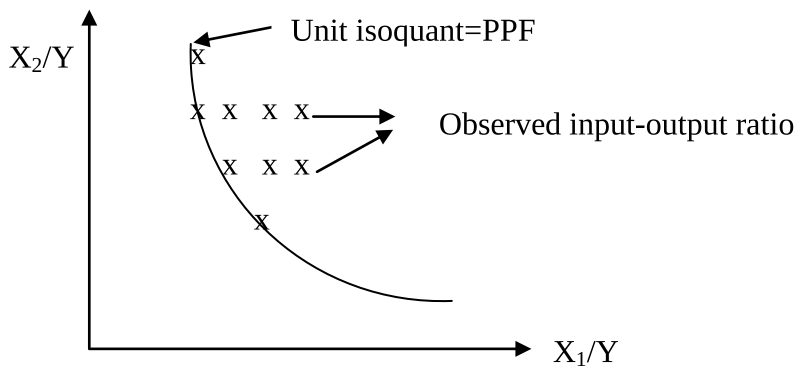



**Figure 3.5 Production possibility frontier with two inputs/one output**

The PPF model has been used frequently to help allocate resources efficiently by examining the trade-offs among different goods and services produced using limited resources (Lichtenstein & Montgomery, 2003; McCoy, 2003; Rohweder et al., 2000; Zhou & Gong, 2005). Zhou and Gong (2005) applied the PPF model to examine the trade-offs between the different uses of forest, such as the monetary value of timber, preservation of biodiversity, reindeer grazing and recreational value. Their model examined the tradeoffs between two uses at a time with fixed levels of the other two uses. Similarly, Nalle et al. (2004), have used a PPF model to examine trade-offs between endangered species protection and timber production in forested landscapes over a 100 year planning horizon. The study has shown a competitive as well as a complementary relationship between timber production and endangered species protection, over the range of possibilities of both outputs.

### 3.4.1 Properties of production possibility frontiers

If the production technology is defined by output sets and represented by $P(x)$ then: $P(x) = \{y$: $x$ can produce $y\}$. Kumbhakar & Lovell (2000) summarise the properties of this set as follows.

$P_1$: $P(0) = \{0\}$.

$P_2$: $P(x)$ is a closed set.

$P_3$: $P(x)$ is bounded for $x \in R_+^N$.

$P_4$: $P(\lambda x) \supseteq P(x)$ for $\lambda \geq 1$

$P_5$: $y \in P(x) \Rightarrow \lambda y \in P(x)$ for $\lambda \in [0, 1]$.

$P_6$: $P(x)$ is convex.

$P_1$ states that non-zero output levels cannot be produced from zero levels of inputs. Since $P(x)$ is a closed set, its value cannot exceed certain limits. The highest value of $P(x)$ indicates the maximum value of output that is possible. Therefore, $P_2$ guarantees the existence of technically efficient output vectors. $P_3$ implies that finite input cannot produce infinite outputs. $P_4$ and $P_5$ demonstrate the feasibility of radial expansions of feasible inputs and radial contractions of feasible outputs. These properties indicate the possibility of improving production by changing inputs and outputs. Finally, convexity ($P_6$) implies that if two combinations of outputs can be produced from given inputs then any weighted average of these outputs can also be produced. Convexity ensures the possibility of production between two possible outputs. However, this assumption requires that the outputs are continuously divisible in nature (Coelli et al., 2005).

## 3.5 Concept of *Pareto optimality*

Public policies can be implemented to obtain an efficient allocation of resources (Just et al., 2004). In public policy analysis discourse, policies are analysed based on whether the policy improves social welfare or not (Glahe & Lee, 1989; Kaplow & Shavell, 2001). To assess the welfare change, the criterion of *Pareto optimality* is often used (Adhikari, 2005; Dolan, 1998; Kumar, 2002). An allocation of resources is said to be *Pareto optimal* if it is impossible to make some-one better off, without at the same time making any-one worse off (Just et al., 2004; Riera et al., 2007). The *Pareto optimality* criterion is often replaced by the efficiency concept (Boadway & Bruce, 1984; Riera et al., 2007). *Pareto optimality* requires efficiency in production, efficiency in consumption and product-mix efficiency (Glahe & Lee, 1989; Ng, 2004; Nicholson, 2002). This study addresses efficiency in production.

### 3.5.1 Efficiency in production

Efficiency in production requires that the production process generates as much output as possible from given inputs (Glahe & Lee, 1989; Rowley & Peacock, 1975). If this condition is not satisfied, then someone can be better off without making anyone else worse off simply by increasing the output being produced by rearranging the inputs already in use (Ng, 2004).

In order to attain production efficiency, the marginal rate of technical substitution[3] (MRTS) between the inputs must be the same (for each output) for all production units using the inputs (Just et al., 2004; Ng, 2004). If these conditions are not satisfied, it is possible to reallocate inputs to increase the production of some products, without reducing the production of any other products. Assume an economy consists of two persons A and B, assume that A produces X and B produces Y, using two inputs (L and K). Then production efficiency is said to be attained if the marginal rate of substitution of inputs (L and K) is equal for both outputs (X and Y) and for all production units (A and B) or producers (Just et al., 2004; Nicholson, 2002). That is,

$$MRTS_x = MRTS_y.$$

## 3.6 Applications of the efficiency concept

The efficiency concept is widely used in different fields of study, including natural resources management, health and information technology (Adhikari, 2005; Dolan, 1998; Misra & Kant, 2004; Riera et al., 2007). Adhikari (2005) has used the efficiency concept to analyse the consumption of forest products at the household level in the CFs of Nepal. Likewise, Misra & Kant (2005) have analysed production in the Joint Forest Management system of India using the production efficiency.

## 3.7 Approaches to efficiency measurement

Efficiency consists of two components; technical efficiency (TE) (or production efficiency) and allocative efficiency (Misra & Kant, 2004; Murillo-Zamorano & Vega-Cervera, 2001). Two main approaches are used to measure efficiency; input-oriented and output-oriented, and are based on whether the measure adopts an input conserving or output expanding strategy (Coelli, 1995; Coelli et al., 2005; Murillo-Zamorano, 2004) .

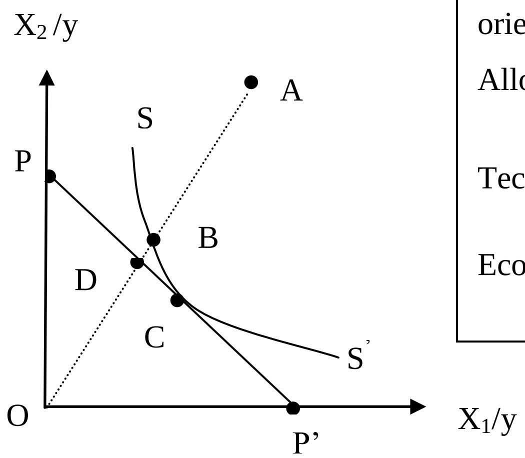
### 3.7.1 Input-oriented approach

The input-oriented TE approach is concerned with how much contraction in inputs is possible in order to produce a given level of output. Mathematically, TE is the ratio of the minimum feasible inputs to actual inputs required to produce the actual level of outputs (Battese, 1992). Allocative efficiency measures the ability of a firm to use inputs in optimal proportions, given

[3] MRTS shows the rate at which one input is substituted for another input while keeping the output constant (Nicholson, 2002).

their respective price and production technology. It is concerned with choosing between different technically efficient combinations of inputs that are used to produce maximum feasible outputs (Siry & Newman, 2001). Technical and allocative efficiency combined are economic efficiency (Coelli et al., 2005), defined as the ability of a producer to produce a given quantity of output at minimum cost for a given level of technology (Worthington & Dollery, 2000). Economic efficiency is also known as cost efficiency in the input-oriented case. Thus when a producer uses its resources allocatively and technically efficiently then the producer is said to be economically efficient or cost efficient.

Input-oriented efficiency measures are illustrated graphically in Figure 3.6. Two inputs, $X_1$ and $X_2$, are used to produce a single output 'y' under the assumption of constant returns to scale. Assume curve SS' represents a unit isoquant of a fully efficient producer. If the producer is using quantities of inputs defined by Point A to produce a unit of output, then TE is given by the ratio OB/OA. The ratio indicates the proportional reduction in inputs to maintain the same quantity of output (lies along the unit isoquant). If PP' represents the input price ratio, then allocative efficiency is given by the ratio OD/OB. The ratio represents the potential reduction in cost if production were at Point C, which is allocatively and technically efficient. Economic efficiency is obtained by multiplying the technical and allocative efficiency, or the ratio OD/OA. Box 3.1 shows the mathematical expressions for technical, allocative and economic efficiencies.




Box 3.1 Mathematical expressions for input oriented efficiencies

Allocative efficiency = $\frac{OD}{OB}$

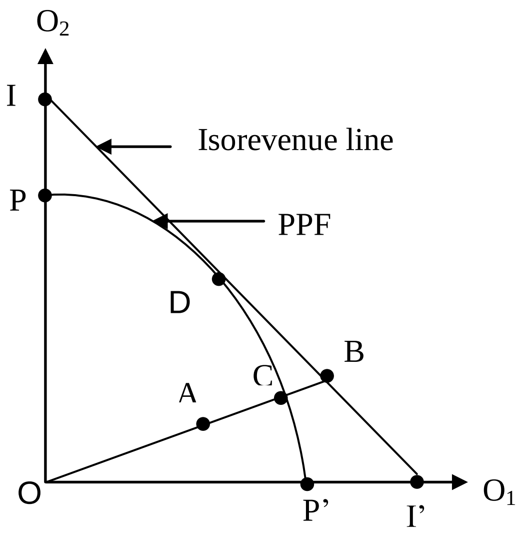
Technical efficiency = $\frac{OB}{OA}$

Economic efficiency = $\frac{\mathrm{OD}}{\mathrm{OB}} \times \frac{OB}{OA} = \frac{OD}{OA}$

**Figure 3.6 Input-oriented efficiency**

### 3.7.2 Output-oriented approach

The output oriented approach to efficiency measurement is concerned with expanding the outputs, for a given level of inputs and production technology. The definitions of efficiency components based on an output-oriented approach are illustrated in Figure 3.7. Assume production involves two outputs ($O_1$ and $O_2$) and a single input (X). Assuming constant returns to scale, the technology is represented by a unit (of input) production possibility frontier, PP'. Take a point (A), which is operating below the PPF. The distance AC represents output-oriented technical inefficiency, which is the amount by which output could be expanded without adding extra input (Battese, 1992). Output oriented TE is given by OA/OC (see Box 3.2), which indicates the deviation from the PPF. II' depicts the isorevenue line, which is the different combination of quantities of outputs for a given amount of revenue. Then, for Point A, distance BC represents allocative inefficiency, which is the amount by which revenue could be increased if the producer at A was on the PPF at Point D. Thus, output-oriented allocative efficiency is = OC/OB. Output-oriented economic efficiency (also called revenue efficiency) is measured in terms of deviation from the isorevenue line which is obtained by multiplying technical and allocative efficiency. Hence in Figure 3.7, economic efficiency = TE x allocative efficiency = OA/OB (Box 3.2).




Box 3.2 Definitions of output oriented efficiencies

Technical efficiency = $\frac{OA}{OC}$

Allocative Efficiency = $\frac{OC}{OB}$

Economic efficiency = $\frac{OC}{OB} \times \frac{OA}{OC} = \frac{OA}{OB}$

**Figure 3.7 Output-oriented efficiency**

### 3.7.3 Selecting efficiency approaches

There is no clear theoretical distinction between the two efficiency measures. However, selection of a particular efficiency estimation approach depends on the nature of inputs and outputs. Output-oriented measures of efficiency are appropriate if the producer has limited control over inputs. On the other hand, input-oriented measures of efficiency are suitable when the producer has limited control over output usage (Coelli et al., 2005). Coelli & Perelman (1999) and Puig-Junoy (2000) argue that the input-oriented approach of efficiency is not applicable if input prices are not available. They also argue that the output-oriented approach may not be appropriate if the aggregating weights are either unavailable or inappropriate. Aggregating weights are used to change multiple outputs into a single output. For example, price can be used as a weight to aggregate outputs.

Although the existing nature of inputs and outputs determines the choice between the two efficiency measures, an empirical study of European railways carried out by Coelli & Perelman (2000) has reported that there are no serious consequences on the efficiency result, due to the different approaches. The correlation coefficient between efficiency estimated using the two approaches is positive and significant. Tzouvelekas et al. (2001), in their study of TE of organic and non-organic olive farming in Greek agriculture, have found clear differences between the efficiencies estimated, in cases where the producers were operating under variable returns to scale. However, similar efficiencies were observed where the producers were operating under constant returns to scale. Thus returns to scale of a producer makes the difference in the efficiency result.

## 3.8 Characterising the production process

Even if a producer is technically and allocatively efficient, the producer may be experiencing a suboptimal scale of operation (Coelli et al., 2005). Three types of scale of operation have been defined in economics (Glahe & Lee, 1989; Nicholson, 2002). A producer is functioning under constant return to scale if any proportional increase in all inputs exhibits an equal proportion increase in output. A producer exhibits decreasing return to scale if any proportional change of inputs leads to less than proportional change in output. If a proportional increase in inputs results in more than a proportional increase in output then a producer is functioning under increasing return to scale (Glahe & Lee, 1989).

Economies of scale can be generalised with a production function with '*n*' inputs.

$$y = f(x_1, x_2, x_3, \ldots\ldots\ldots, x_n) \tag{3.13}$$

If all inputs are multiplied by the positive constant term '*m*' then;

$$f(mx_1, mx_2, \ldots., mx_n) = m^k f(x_1, x_2, \ldots., x_n) = m^k y \tag{3.14}$$

In Equation (3.14) if $k = 1$ then the production function exhibits constant returns to scale. Decreasing returns to scale and increasing returns to scale correspond to the cases where $k < 1$ and $k > 1$ respectively. Assume that production is characterised by a Cobb–Douglas function;

$$y = f(K, L) = AK^a L^b \tag{3.15}$$

and $A$, $a$ and $b$ >0.

Equation (3.15) can exhibit any degree of returns to scale depending on the values of $a$ and $b$. Suppose all inputs were increased by a factor $m$. Then

$$\begin{aligned} f(mK, mL) = A(mK)^a (mL)^b &= Am^{a+b} K^a L^b \\ &= m^{a+b} f(K, L) \end{aligned} \tag{3.16}$$

Thus, if $a + b = 1$, the function reveals constant returns to scale, because the output is also increased by the factor $m$. If $a + b > 1$ the function has increasing returns to scale, and $a + b < 1$ corresponds to decreasing returns to scale.

Although the theory of scale of operation is postulated on the assumption that all the inputs are changed together, in practice this may not be always possible (Nicholson, 2002). For example, suppose agriculture land needs to be doubled, but it is not always possible to find twice as much land with the same fertility (Nicholson, 2002). Measurement of scale of operation is significant for policy, because it indicates the possibility of growth in production with an increase in inputs. Golany & Thore (1997) measured scale of operation in three groups of countries, to identify whether investment in education, health and social welfare is showing increasing, decreasing or constant returns and found that most of the developed countries showed decreasing returns to scale whereas developing countries showed increasing returns to scale. Siry & Newman (2001) using the Cobb-Douglas production function to identify that the Polish State Forests function under increasing returns to scale. The implication is that output (timber) can be increased more than the proportion increase in size of forests.

## 3.9 Estimation of the production frontier and technical efficiency

Broadly, two techniques are applied to estimate production frontiers; parametric and nonparametric (Figure 3.8) (Bravo-Ureta & Pinheiro, 1997; Diaz-Balteiro et al., 2006; Thiam et al., 2001). The parametric technique is further divided into the stochastic method and the deterministic method. The non parametric technique has only one method called data envelopment analysis (DEA) (Murillo-Zamorano & Vega-Cervera, 2001). Both statistical and non-statistical techniques are used to estimate deterministic models, whereas only statistical methods are used to estimate stochastic models. In the parametric technique a predefined functional form is imposed for the production frontier, but in DEA, no functional form is pre-established (Murillo-Zamorano, 2004).

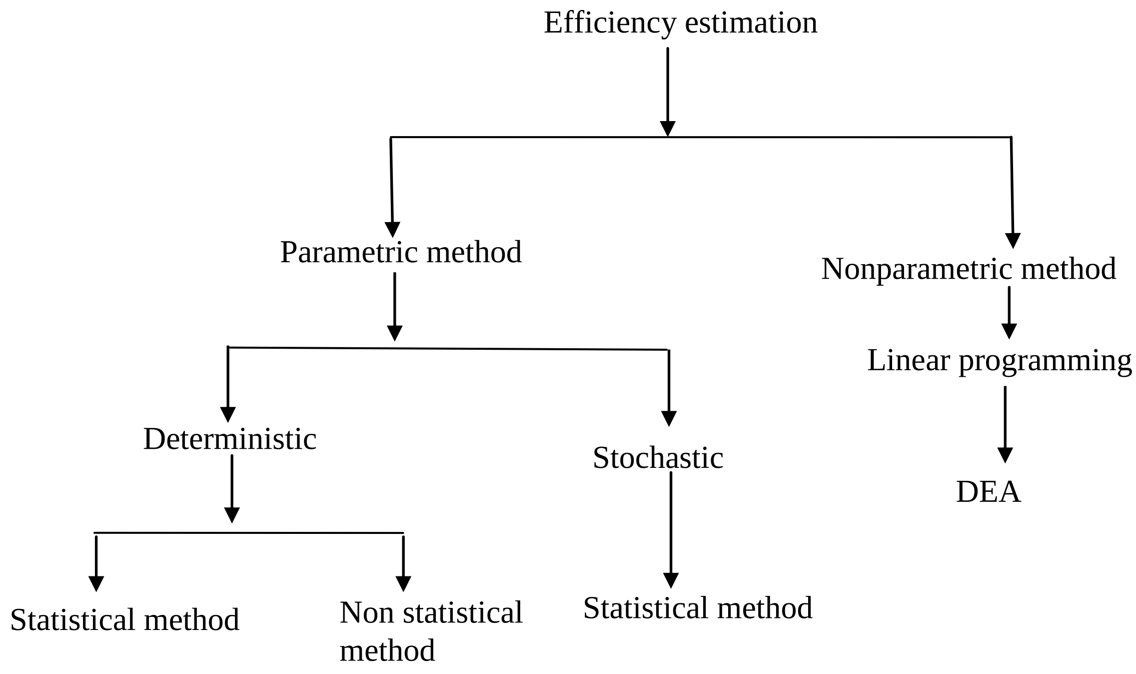



**Figure 3.8** Estimation **methods for production frontier and TE**

### 3.9.1 Nonparametric method

The nonparametric approach uses the set of observations of outputs and inputs to construct an isoquant diagram, as shown in Figure 3.9. The efficient isoquant is identified by joining observed points so that no point lies below or to the left of it. Efficiency is calculated with reference to the isoquant SS'. Farrell (1957) made two assumptions for this isoquant to be a valid reference frontier. First, the isoquant should be convex to ensure that if two points are attainable then any point representing a weighted average of them is also attainable. Second, no observed point lies between the isoquant frontier and the origin.

Following Farrell's input-oriented frontier model, Charnes et al. (1978), generalised the concept of two inputs and one output into the multiple outputs and inputs case and developed the DEA technique. DEA involves the use of linear programming to calculate the production frontier (Thiam et al., 2001). The DEA technique is illustrated in Figure 3.9, which considers a case of two inputs ($X_1$ and $X_2$) and one output (Y).

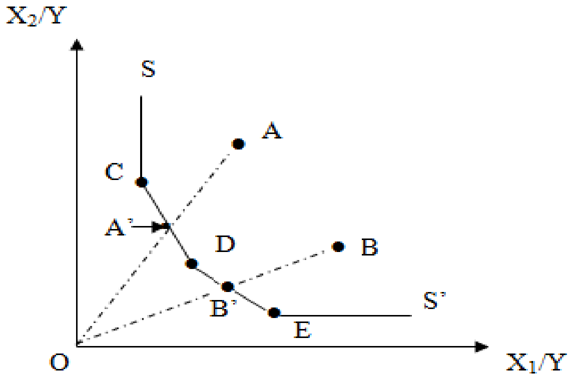



**Figure 3.9 Graphical representation of a DEA model**

A, B, C, D and E are five producers. The curve SS' represents the efficient frontier. Producers C, D and E are technically efficient, whereas producers A and B are away from the efficient frontier and, therefore these producers are inefficient. The level of inefficiency of A and B is determined by comparing the inputs ($X_1$ and $X_2$) used to produce a unit of output (Y), to the producer lying on the efficient frontier. The TE of producers A and B is given by their deviation from the efficient frontier, and hence,

TE of A = OA'/OA, and

TE of B = OB'/OB.

The efficiency of producer A is evaluated by comparing it with a composite producer indicated by A'. The composite producer is a hypothetical producer derived from other efficient producers. For example, composite producer A' is a weighted average of inputs of producers C and D.

The example used in Figure 3.9 has two inputs and one output. This makes it possible to illustrate the efficient frontier graphically. However, when multiple inputs and outputs are encountered in real world cases, linear programming is used to calculate the efficient frontier (Nyshadham & Rao, 2000).

### 3.9.2 Advantages and disadvantages of the nonparametric method

The main advantage of DEA is that it does not require any initial assumption about specific functional form linking inputs and outputs (Cooper et al., 2006; Forsund et al., 1980), therefore alleviating potential discrepancies due to assumptions regarding the use of specific functional forms (Coelli, 1995). Efficiency is measured along the ray from the origin to the observed point, which has the advantage that results are consistent even if the unit of measurement is changed (for example, measuring labour in terms of hours instead of days). This property of DEA is called units invariance (Cooper et al., 2006). Also, the DEA can handle multiple inputs and outputs together (Ondrich & Ruggiero, 2001).

The DEA method has several disadvantages. First, efficiency estimated by the DEA method is not absolute, since it is only with respect to other producers. Hence, by adding an extra producer into the analysis, the efficiency score may change if the added producer is on the frontier (Harper et al., 2001).

Second, efficiency scores calculated using DEA are sensitive to outliers (Nyshadham & Rao, 2000; Simar, 2007). The frontier is developed from the set of efficient producers, therefore existence of an outlier producer may severely distort efficiency scores for the remaining data set. This distortion is serious if the outliers are added or removed from the efficient frontier (Brown, 2006).

Third, when using the DEA method, it is difficult to identify the correct set of inputs and outputs. This problem especially appears when a producer is using multiple inputs and outputs (Diaz-Balteiro et al., 2006). Use of a large number of inputs may shift the compared units towards the efficient frontier, resulting in a large number of units with high efficiency scores (Wagner & Shimshak, 2007). However, Sun (2002) has suggested the use of statistical tools, such as multiple regression analysis, to examine the relationship between inputs and outputs. Similarly, Nasierowski & Arcelus (2003) and Zhu (1998) have advised the use of the principal component analysis to reduce the number of inputs and outputs.

Fourth, the DEA method assumes that the entire deviation of a producer from the production frontier is due to inefficiency and that there is no random error such as measurement error or error due to weather conditions (Coelli, 1995; Latruffe et al., 2005). This assumption has enormous implications in efficiency calculations. For example, if there is sampling variation and the input-oriented model is used, then the efficiency estimates are likely to be biased towards higher scores (i.e. towards 1) (Lee, 2005). This bias will further increase if more efficient producers are not contained in the sample and only inefficient producers form the frontier (Latruffe et al., 2005).

Fifth and finally, parameters are not estimated in the DEA method. Parameters are important for the economic interpretation of a production process, by calculating economic characteristics such as elasticity of substitution, marginal products and returns to scale. In addition, since non- parametric methods make no assumption about the distribution of the underlying data, it is difficult to make any statistical inference about efficiency. Statistical inference is possible using bootstrapping procedures (Brummer, 2001).

#### *3.9.2.1 Application of nonparametric model*

The DEA method has been extensively used to calculate TE. For example, Diaz-Balteiro et al. (2006) have employed the DEA method to analyse the relationship between innovative activities and productive efficiency of Spain's wood-based industries. The method includes a two stage analysis. In the first stage, the DEA was used to develop an envelope by using several inputs and outputs related with financial and economic data. In the second stage, a logistic regression method was used to estimate the relationship between efficiency and innovative activity indicators. The study found that there was no significant relationship between efficiency and innovative activities in Spain's forest based industries.

Sun (2002) applied DEA to measure the relative TE of 14 police precincts in Taiwan. He followed two steps. In the first step, the relative efficiency of the police precincts was measured and in the second step, multiple regression analysis was employed to identify the factors for efficiency. The study indicates that differences in the operating environment, such as residential population and location factors, do have a significant effect on efficiency.

Shafiq & Rehman (2000) employed the DEA technique with multiple regression, to measure the relative technical and allocative efficiencies and factors of efficiency, of individual cotton production farms in Pakistan's Punjab. The use of DEA shows that the technique reveals both the extent and sources of inefficiency in cotton production.

### 3.9.3 Parametric model

The concept of the parametric models of efficiency estimation was developed by Aigner & Chu (1968). As discussed earlier, parametric models are subdivided into deterministic and stochastic models.

#### *3.9.3.1 Deterministic model*

Following the introduction of the TE concept by Farrell (1957), Aigner and Chu (1968) pioneered the deterministic model to estimate the production function. Aigner and Chu (1968) accepted the theoretical influence of random error and TE on the production process. However, empirically, they assumed that random error, such as measurement error, is negligible and attributed all deviations from the production frontier to inefficiency. Deterministic models have been used with a variety of functional forms, even though Aigner and Chu (1968) only developed linear and quadratic methods (Coelli & Perelman, 1999;

Misra & Kant, 2005). A basic deterministic production function is given by the following expression:

$$Y_i = f(x_i;\beta)\cdot \exp(-u_i) \quad i = 1, 2, \qquad (3.17)$$

where $Y_i$ represents the output for the $i$ th producer, $f(x_i;\beta)$ is a suitable functional form (Cobb Douglas or translog), $\beta$ is a vector of parameters to be estimated, $x_i$ represents the input vector for producer $i$ and $u_i$ is a non negative random variable associated with firm specific factors, which contribute to the $i$ th firm not attaining maximum efficiency in production, and $u_i \geq 0$. $u_i$ is associated with the technical inefficiency of producer $i$, and the random variable exp $(-u_i)$ varies between zero and one (Battese, 1992). Thus it follows that the possible production $Y_i$ is bounded from above by the deterministic quantity $f(x_i;\beta)$ (Coelli et al., 2005). Hence, Equation (3.17) is a deterministic production function.

Following is the definition of the output oriented TE (the ratio of observed output to maximum possible output)

$$\begin{aligned} \text{TE} &= f(x_i;\beta)\cdot \exp(-u_i) / f(x_i;\beta), \\ &= \exp\{-u_i\} \end{aligned} \qquad (3.18)$$

The deterministic model is represented graphically in Figure 3.10. Assume a simple case of one input ($x$) and one output ($y$). In this two dimensional representation, suppose input $X_i$ is used to produce output $Y_i$ (Point A). If producer $i$ utilized inputs in the best possible way, then production would have been at Point B. The points corresponding to producers who use their resources in the most productive way, forms the deterministic production frontier SS'. AB indicates inefficiency, which is a deviation from the deterministic frontier SS'.

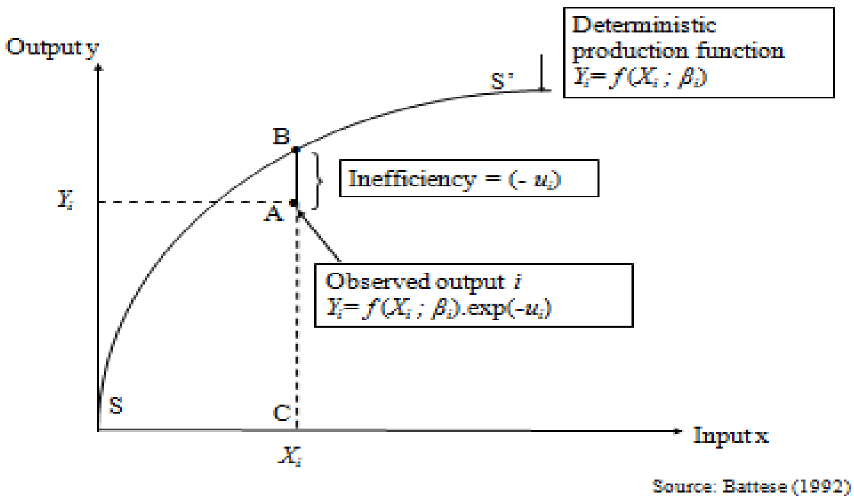



**Figure 3.10 Deterministic production frontier**

Whatever the methods used in the deterministic frontier model, their objective is to identify the frontier and thereby estimate the distance of a particular producer from the frontier. Estimation of efficiency from Equation (3.18), requires estimates of the $\beta$ vector, which describes the structure of the production frontier and the values of $u_i$. Various methods are used to estimate the deterministic production frontier and as discussed earlier these methods are broadly classified into two groups; non-statistical and statistical.

***Non- statistical method***

The non-statistical method includes goal programming and is solved by linear and quadratic linear programming approaches. Aigner & Chu (1968) first used linear programming and quadratic programming to calculate TE. The linear programming approach, calculates the values of $\beta$s such that the sum of the proportional deviation of the observed output of each producer from the maximum feasible output, is minimised (Hailu & Veeman, 2000; Kumbhakar & Lovell, 2000). The resulting deviations are then used to calculate the efficiency of each producer. The linear programming model is,

$$\text{Min} \sum u_i \quad \text{subject to} \quad f(x_i;\beta) \geq Y_i \quad \forall\ i = 1, 2, \ldots\ldots\ldots, N \qquad (3.19)$$

On the other hand, the quadratic programming approach calculates the values of βs such that the sum of the squares of deviations of the observed output of each producer from the maximum feasible output, is minimised. The quadratic programming model is given by,

$$\text{Min } \Sigma u_i^2 \quad \text{subject to} \quad f(x_i;\beta) \geq Y_i \qquad \forall \; i = 1, 2, \ldots\ldots, N \qquad (3.20)$$

Once the parameters are calculated from Equation (3.20), then the TE of each producer is calculated by slack in the functional constraints. Slack is the difference in calculated output from Equation (3.20) and observed output. If $f(x_i;\beta)$ takes the Cobb-Douglas form, then by rewriting Equation (3.17), the deterministic production frontier model is yielded,

$$\ln Y_i = \beta_0 + \sum_j \beta_j \ln x_{ji} - u_i, \quad i = 1, 2, \ldots\ldots, N \qquad (3.21)$$

where $i$ indicates producers, $j$ represents the inputs, $Y_i$ represents outputs, $\beta_0$ is the intercept, $\beta_j$ are input parameters and $x_{ji}$ are input vectors. The term $u_i$ is the error term, which represents technical inefficiency. TE is calculated as; TE = exp ($-u_i$), where,

$$u_i = \left[ \beta_0 + \sum_j \beta_j \ln x_{ji} \right] - \ln Y_i \qquad i = 1, 2, \ldots\ldots, N \qquad (3.22)$$

Several studies have used the goal programming methods to calculate TE. For example, Hailu & Veeman (2000) employed the goal programming method to calculate the input-based TE of the paper and pulp industry in Canada. Misra & Kant (2005) used linear programming to calculate the TE of joint forest management in India. Coelli & Perelman (1999) used linear programming techniques to calculate the TE of European railways.

Even though goal programming has been widely used, it has some shortcomings. Statistical tests regarding the value of parameters are limited because the parameter vectors ($\beta$) do not come with standard errors (Hailu & Veeman, 2000; Kumbhakar & Lovell, 2000).

***Statistical methods***

In an attempt to give the deterministic model statistical validity, Schmidt (1978) added a disturbance term and used statistical methods to estimate the parameters and the disturbance terms. The methods used included corrected ordinary least squares (COLS) and modified ordinary least squares (MOLS). COLS and MOLS have been superseded by more advanced methods and are not analysed further here.

Parametric deterministic frontier models have some drawbacks. The main drawback arises from the assumption that all departures from the best practice frontier are due to inefficiency, ignoring the effect due to random error (Worthington & Dollery, 2000). Random errors may contribute to the variation in production and errors may be negative or positive. This drawback may have significant implications in empirical efficiency studies, especially if data associated with any producer is an outlier (Aigner et al., 1977; Schmidt & Knox Lovell, 1979). Outliers may result in either high efficiency or low efficiency estimates if random error effects are not removed. Considering the drawbacks of the parametric deterministic approach, a model is required that takes into account, variations due to both random error and technical inefficiency. That requirement is fulfilled by stochastic models.

#### 3.9.3.2 Stochastic frontier model

Aigner et al. (1977) and Meeusen & Broeck (1977) developed stochastic frontier models that assume that the output of a firm is a function of a set of inputs, inefficiency and random error. In the stochastic frontier model (SFM), inefficiency is identified with a disturbance terms in the functional equation (Greene, 1993a). A general stochastic production function with a single output is given by;

$$\begin{aligned} Y_i &= f(x_i;\beta)\cdot \exp(\varepsilon_i) \\ \varepsilon_i &= v_i - u_i \end{aligned} \qquad (3.23)$$

Where $Y_i$ denotes output, $x_i$ denotes a set of inputs, $\beta$ is a set of parameters to be estimated and $i$ denotes producers. $\varepsilon_i$ is a composed error term consisting of two elements, $v_i$ and $u_i$ , where $v_i$ represents random error (also called statistical noise) and $u_i$ is a non-negative random variable, which accounts for technical inefficiency.

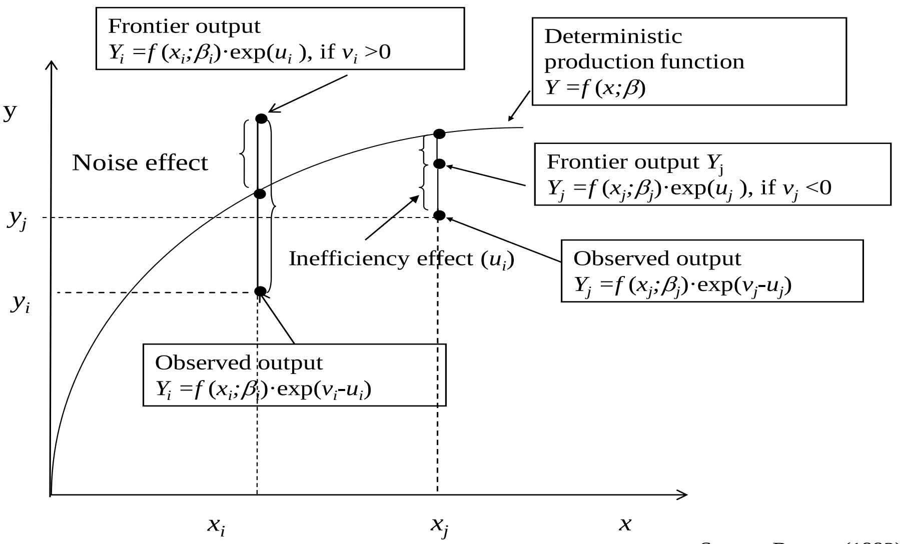
***Graphical representation of the stochastic frontier model***

The SFM is illustrated in Figure 3.11. Two producers ($i$ and $j$) are considered for illustration. Producer $i$ uses inputs $x_i$ and produces output $Y_i$. If production had been under favourable conditions for which the random error $v_i$ is positive, and had been utilizing the inputs in an efficient way ($u_i$ =0), production would have been $Y_\mathrm{i}$ = [$f(x_i;\beta)\cdot\exp(v_i)$], which lies above the deterministic frontier $f(x;\beta)$. However, producer $i$ is not utilizing inputs efficiently, hence production is $y_{i,}$ which is below the deterministic frontier.

On the other hand, producer $j$ is producing output $Y_j$ using inputs $x_j$, which is less than the value on the deterministic frontier $Y_=$ [$f(x;\beta)$] because its productive activities are associated with unfavourable conditions, for which the random error is negative ($v_j$<0). In addition, producer $j$ is not utilizing its inputs efficiently ($u_j \geq 0$). Observed production is $Y_j$ which is given by $f(x_j;\beta_j)\cdot\exp(v_j - u_\mathrm{j})$, and reflects both random error and inefficiency.

In both cases, the observed production values are less than the corresponding frontier output values, and the frontier production values lie below or above the deterministic production function. Thus, the frontier itself is stochastic because of the presence of the 'exp($v$)' stochastic component in the function [$f(x;\beta)\cdot\exp(v)$] (Aigner et al., 1977; Schmidt & Knox

Lovell, 1979). Observed outputs lie below the deterministic frontier in both cases presented here, and there is the possibility that the observed output lies above the deterministic frontier [$f(x;\beta)$] if $v_i > u_i$ (Battese, 1992).




Source: Battese (1992)

**Figure 3.11 Stochastic frontier model**

***Efficiency estimation using the stochastic frontier model***

When the SFM was first introduced by Aigner et al. (1977) and Meeusen & Broeck (1977), they assumed two distinct distributions for $u_i$ and $v_i$. They assumed a one-sided distribution for $u_i$ and two-sided normal distribution for $v_i$ with mean 0 and variance $\sigma_v^2$. TE was estimated using Equation (3.24),

$$\text{TE} = E(\varepsilon) = E(u) = \sigma_u \sqrt{\frac{2}{\pi}} \qquad (3.24)$$

where $\sigma_u$ is standard deviation associated with inefficiency term ($u_i$).

Although Aigner et al. (1977) and Meeusen & Broeck (1977) introduced a technique to estimate the average value of $u_i$ from the value of $\varepsilon_i$, and thereby average the TE of producers in a sample, they were unable to estimate the TE of individual producers. To estimate the TE for individual producers, Jondrow et al. (1982) estimated $u_i$ by considering the conditional distribution of $u_i$ given $\varepsilon_i$. The process of estimating the TE based on the conditional distribution of $u_i$ can be explained by assuming a Cobb-Douglas functional form in logarithmic transformation to estimate the stochastic frontier model

$$\ln Y_i = \beta_0 + \sum \beta_n \ln X_{ni} + (v_i - u_i)$$

(3.25)

$$v_i - u_i = \varepsilon_i . \quad (3.26)$$

The term ($v_i$-$u_i$) is a composed error term, where $v_i$ represents random error (statistical noise), assumed to be symmetrically distributed, and $u_i$ is a non-negative random variable which accounts for technical inefficiency, assumed to be asymmetrically distributed and non-negative.

In order to estimate the TE using the SFM, the error components are required to follow three assumptions. The first assumption is that $v_i$ has a normal distribution [$v_i$ ~N (0, $\sigma_u^2$)] and that $u_i$ has an asymmetrical distribution (Jondrow et al., 1982). The commonly used asymmetrical distributions include half normal [$u_i$~|(0, $\sigma_v^2$)|], truncated normal and exponential (Aigner et al., 1977; Jondrow et al., 1982). The second assumption is that the two components $v_i$ and $u_i$ are independent of each other. The third assumption is that the inefficiency component is independent of explanatory variables and the input vector.

Since $v_i$ and $u_i$ follow two different distributions, ($v_i$ - $u_i$) is asymmetrically distributed and negatively skewed. Following Jondrow et al. (1982), the maximum likelihood (ML) estimation of stochastic Equation (3.25) yields consistent estimators for β, λ and $\sigma^2$, where β is a vector of unknown parameters, $\lambda = \sigma_u/\sigma_v$ and $\sigma^2 = \sigma^2_u + \sigma^2_v$. Based on the estimated parameters, the TE of an individual producer *i* is given by the conditional mean of $u_i$ for given $\varepsilon_i$ , as defined by Equation (3.27) (detailed derivation is in **Appendix A**):

$$E(u_i \mid \varepsilon_i) = \sigma_* \left[ \frac{f(\varepsilon\lambda/\sigma)}{1-F(\varepsilon\lambda/\sigma)} - \left( \frac{\varepsilon\lambda}{\sigma} \right) \right] \quad (3.27)$$

and the mode is:

$$M(u_i \mid \varepsilon_i) = -\varepsilon_i \left( \frac{\sigma_u{}^2}{\sigma^2} \right) \quad (3.28)$$

Where *f* (.) and *F* (.) represent the standard normal density function and cumulative density function respectively, and $\sigma_* = \sigma_u \sigma_v / \sigma$. Once point estimates of $u_i$ from Equation (3.27) or (3.28) are obtained, estimates for the TE of each producer can be calculated from Equation (3.29)

$$TE_i = \exp(-\hat{u}_i) \quad (3.29)$$

where $\hat{u}_i$ is either $E(u_i \mid \varepsilon_i)$ or $M(u_i \mid \varepsilon_i)$.

Equation (3.29) estimates point efficiency, based on E($u_i$|$\varepsilon_i$). However, Battese & Coelli (1988) claimed that point efficiency should be based on E[exp(-$u_i$)|ε]:

$$TE_i = E(\exp(-u_i) \mid \varepsilon_i) = \left[\frac{1-F(\sigma_* - \mu_{*i}/\sigma_*)}{1-F(-\mu_*/\sigma_*)}\right] \cdot \exp\left\{-\mu_{*i} + \frac{1}{2}\sigma_*^2\right\} \qquad (3.30)$$

This equation is based on the derivation of the untransformed output, where $Y_i$ is used instead of ln$Y_i$. The point estimators given in Equation (3.29) and Equation (3.30) may yield different results because $E(\exp(-u_i) \mid \varepsilon_i) \neq \exp\{-E(u_i \mid \varepsilon_i)\}$. Kumbhakar & Lovell (2000) support the use of Equation (3.30) instead of Equation (3.29), especially when $u_i$ is not close to zero, because $E(u_i \mid \varepsilon_i)$ contains only the first term [1-$u_i$] in the power series expansion of $E(\exp(-u_i))$.

***Methods for parameter estimation***

Under various assumptions related to error components and explanatory variables, several statistical methods can be used to estimate parameters of the stochastic production frontier. One of them is ordinary least squares (OLS), but the intercept estimated by this method is less than the true value (Coelli et al., 2005). Thus the inefficiency estimated using OLS method only represents the departure from the average production frontier (Coelli et al., 2005).

Hill et al. (1997) argued that maximum likelihood (ML) techniques reveal very "consistent[4], normally distributed and best" estimates of the parameters. Wooldridge (2002) asserts that ML is the most preferred method because it uses information on the distribution of the independent variables given the dependent variables. The ML technique has been extensively used in stochastic frontier estimation (Adkins & Moomaw, 2003; Binam et al., 2004; Chen, 2007; Rahman, 2003).

***Explanation of parameters in the stochastic frontier model***

If the data does not follow the assumptions, then problems in estimating efficiency may result. For example, considering Equation (3.25 and 3.26), if the distribution of $\varepsilon_i$ is symmetric or positively skewed instead of negatively skewed, efficiency estimation using the SFM through ML estimation is unrealistic. In this situation ML and OLS both result in biased parameter estimates (Kumbhakar & Lovell, 2000). Therefore, before estimating efficiency using the stochastic frontier model, it is essential to test the skewness of the OLS residuals and the distribution of $u_i$. Aigner et al. (1977) use alternative parameters to indicate the nature of

[4] An estimator is consistent for a scalar parameter if the estimated value is close to the true parameter value, and as the sample size increases the variance gets smaller (Coelli et al., 2005).

distributions of inefficiency, and the random error term corresponding to the stochastic functional form under consideration. The following bullet points describe definitions and appropriate values of the different parameters.

- $\lambda = \sigma_u / \sigma_v$ is the ratio of the standard deviation of inefficiency and standard deviation of random error terms. $\lambda$ indicates the relative variability of the two sources of error ($v_i$ and $u_i$) in the composed error ($\varepsilon_i$) (Kumbhakar & Lovell, 2000). The value of $\lambda$ exhibits the nature of the inefficiency and random error terms. $\lambda > 1$ ($\sigma_u > \sigma_v$) implies that there is a high degree of inefficiency (Chakraborty et al., 2001). Specifically, $\lambda$ reveals the total variation of output from the frontier which can be attributed to TE. If $\lambda \rightarrow \infty$ the production function is deterministic, and if $\lambda=0$ then there is no inefficiency disturbance in the model (Greene, 1993b).
- Some literature has used $\delta$ (= $\sigma_u^2 / \sigma_v^2$) instead of $\lambda$ (Sharma & Leung, 1998). $\delta$ also measures the amount of variation stemming from inefficiency relative to random noise for the sample (Chen, 2007). $\delta$ is used to compare the sizes of variances of two error terms $u_i$ and $v_i$ (Aigner et al., 1977). Values of $\delta$ greater than 1 indicate that production is dominated by technical inefficiency. On the other hand, values of $\delta$ close to zero indicate output is dominated by random error (Squires & Tabor, 1991). When $\delta=0$ SFM turns out to be an average production function (Sharma & Leung, 1998). The average production function is estimated by minimising the sum of the squares of deviations of each data value from the mean value.
- $\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$ is the ratio of the variance of the error due to the inefficiency to the combined variance of random error and error due to inefficiency. By definition, the value of $\gamma$ lies between 0 and 1 (Kompas, 2004; Rahman, 2003). A value of $\gamma = 0$ implies that $\sigma_u^2 = 0$ which indicates that there is no variation in production due to inefficiency (Kompas, 2004). That means all firms are equally efficient and the expected value of TE is one. On the other hand, $\gamma = 1$ indicates $\sigma_v^2=0$, which implies that there is no random noise in the variables, and variation in production is attributed solely to the variation in inefficiency. In this condition the production model collapses to a deterministic frontier (Binam et al., 2004). Values of $\gamma$ greater than 0 (but less than 1) indicate that both inefficiency and random error effects are in the stochastic frontier model. Although $\gamma$ is used to test the existence of error in the production model, $\gamma$ is not equal to the ratio of the variance of the efficiency effects to the total residual variance. In fact variance of $u_i$ is equal to $[(\pi-2)/ \pi]\ \sigma^2$ and the relative contribution of

the inefficiency effect to the total variance (denoted by $\gamma^*$) is $\gamma^* = \gamma / [\gamma + (1-\gamma)\pi/(\pi-2)]$ (Rahman, 2003).

- Another variance term which measures the contribution of the two error terms is σ, which is the square root of the sum of the variance of errors due to random noise and inefficiency:

$$\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}\ .$$

Although the literature describes the four parameters explained above, only λ and γ test the appropriateness of functional form and the existence of (in)efficiency in the production process (Anderson et al., 1999; Bravo-Ureta & Pinheiro, 1997).

***Estimation of confidence intervals***

Various sources of uncertainty make point estimates of TE unreliable. Brummer (2001) argues that sampling error and different sets of assumptions which are made in order to estimate the stochastic frontier, are the main sources of uncertainty. One way to understand the uncertainty associated with point estimates of efficiency is to construct a confidence interval (CI) around each point estimate (Horrace & Schmidt, 1996). A wide CI indicates there is not much information in the sample about the population parameter (Black et al., 2007), whereas a narrow CI estimate indicates details have been learnt about the population parameter (Hill et al., 1997). Kim & Schmidt (2000) claimed that policy makers should rely less on estimated efficiency levels that are less precise.

Many techniques have been reported to estimate the CI for efficiency. For example, Simar (1992) suggests bootstrapping to construct the CI around point efficiency estimates using the non-parametric model. Horrace & Schmidt (1996) recommend a technique called multiple comparisons with the best (MCB), and Kim & Schmidt (2000) suggested a very similar technique called marginal comparison with the best. Horrace & Schmidt (1996) explain a technique to construct CIs under different distributional assumptions for the inefficiency term. This technique is particularly appropriate when cross sectional data are used to estimate efficiency. Only the technique suggested by Horrace & Schmidt (1996) is explained in this section because this study is also using cross sectional data to estimate efficiency under different distributional assumptions for efficiency.

The CI estimation technique is explained by Bera & Sharma (1999) by considering the basic SFM

$$y_i = f(x_i, \beta) + \varepsilon_i \qquad (3.31)$$

$\varepsilon_i = v_i - u_i$ and $u_i \geq 0$,

The terms in this equation are the same as Equation (3.23).

The technique follows the concept suggested by Jondrow et al. (1982) that the estimate of the inefficiency term ($u_i$) is conditional on the value of the composed error term ($\varepsilon_i$). According to Jondrow et al. (1982), under the assumptions $v_i \sim N(0, \sigma^2_v)$ and $u_i \sim N(\mu_i, \sigma^2_u)$ the conditional distribution of $u_i|\varepsilon_i \sim N(\mu^*_i, \sigma_*^2)$ is a random variable truncated (from the left) at zero, where $\mu^*_i = \sigma^2_u \varepsilon_i / (\sigma^2_u + \sigma^2_v)$ and $\sigma_*^2 = \sigma^2_u \sigma^2_v / (\sigma^2_u + \sigma^2_v)$. Following the distributional assumptions for $u_i$ and $v_i$, Bera & Sharma (1999) have suggested that if the conditional mean [$E(u_i|\varepsilon_i)$] and variance [var $E(ui|\varepsilon_i)$] of $u_i$ for given $\varepsilon_i$ are known, the confidence intervals for $u_i|\varepsilon_i$ at a confidence level of (1- α) are given by

Upper Bound ($UB_i$) = $\mu^*_i + \sigma_* \Phi^{-1}\left[1 - \frac{\alpha}{2}\Phi(\mu^*_i / \sigma_*)\right]$ (3.32)

Lower Bound ($LB_i$) = $\mu^*_i + \sigma_* \Phi^{-1}\left[1 - (1 - \frac{\alpha}{2})\Phi(\mu^*_i / \sigma_*)\right]$ (3.33)

where $\Phi$ is the standard normal cumulative density function.

Based on Equations (3.32) and (3.33) the CI for technical inefficiency would be [$LB_i$, $UB_i$]. Battese and Coelli (1988) use the expression $E[\exp(-u_i)|\varepsilon_i]$ as a measure of efficiency. Hence the lower limit and upper bounds for $u_i | \varepsilon_i$ translate directly into upper and lower bounds on $E[\exp(-u_i)|\varepsilon_i]$, because $E[\exp(-u_i)|\varepsilon_i]$ is a monotonically decreasing function of $u_i$ (Horrace & Schmidt, 1996). The CI for efficiency following Battese & Coelli (1988) is given by;

TE (lower bound) = $E(\exp(-u_{iU}) | \varepsilon_i)$ (3.34)

TE (upper bound) = $E(\exp(-u_{iL}) | \varepsilon_i)$ (3.35)

***Scope of estimation of confidence intervals for efficiency***

CI estimation is not free from criticism. Brummer (2001) pointed out that CIs estimated by Equations (3.34) and (3.35) ignore any uncertainty due to parameter estimation, because the unknown parameters are replaced by their sample estimates in Equations (3.34) and (3.35). Furthermore, since only uncertainty induced by the non-negative error term is considered, the interval shows a 'minimal' width of the confidence interval for the TE estimate (Brummer, 2001).

Only a few studies have estimated CIs for TE (Bera & Sharma, 1999; Brummer, 2001; Horrace & Schmidt, 1996; Jensen, 2000). Bera and Sharma (1999) illustrated that the most efficient firms yield the smallest CIs. They claim that as a firm moves towards its production frontier, both efficiency and production certainty increases. However, CIs for the least efficient producers show different results when using the two different definitions of TE given by Equations (3.29) and (3.30). Following the definition by Jondrow et al. (1982), relatively inefficient producers have wider CIs. On the other hand, the Battese and Coelli (1988) definition shows even the most inefficient producers have narrow CIs relative to middle level efficient producers. Bera and Sharma (1999) claim that when firms operate at the most and least efficient levels they show the least uncertainty in their production. Even when a firm is least efficient production is at such a low level that there is little variation in production (Bera & Sharma, 1999).

Brummer (2001) estimates CIs around the TEs estimated by two methods; DEA and SFA. He observes that CIs for SFA are four times wider than for DEA. Brummer (2001) argues that the narrower interval width in the case of DEA is attributed to the exclusion of statistical assumptions such as random error and functional form of estimation.

Horrace & Schmidt (1996) report wide CIs for the TE of rice farms using the SFA method. Their Cobb-Douglas functional form shows that variance due to random error ($\sigma_v^2$) is larger than variance due to inefficiency ($\sigma_u^2$). The relatively large value of random error variance, indicates variation in production is mainly attributed to factors such as sampling and measurement variations. Their small value of $\sigma_u^2$ implies large uncertainty is associated with inefficiency.

Jensen's (2000) study on the effects of personal characteristics on individual wages using stochastic and non stochastic models, observes wide and overlapping CIs around TEs. Jensen (2000) claims that wide confidence intervals occur largely because of sampling error. To overcome this dilemma, Jensen suggests the use of a membership function which indicates the probability that individual producer *i* is the most efficient in the sample. He used a Monte-Carlo simulation to identify the group of most efficient producers in the sample. Monte Carlo simulation involves calculating the probability that a producer *i* is more efficient than the others, based on multiple iterations.

***Advantages and disadvantages of the stochastic frontier model***

The SFM has several advantages for estimating efficiency. First, it allows estimation of both (in)efficiency and random error components (Binam et al., 2004; Cummins & Zi, 1998). In other words, SFM allows separation of the shortfall in production due to random factors (such as variation in weather conditions and variations in measurement), from variations due to technical inefficiency. Second, since this model applies statistical theory for estimating TE, further validity testing regarding the parameters of SFM is possible (Chen, 2007). In addition to this, SFM allows construction of CIs around point estimates of efficiency to measure uncertainty in the efficiency estimate (Lee, 2005).

SFM is however, not without disadvantages. The main disadvantage is the prior assumption of a probability distribution for the inefficiency term for which there is no theoretical justification (Murillo-Zamorano, 2004). The distributional assumption influences the measure of efficiency (Coelli et al., 2005). For example, since half normal and exponential distributions have modes at zero, assuming inefficiency is distributed either half normally or exponentially, it implies that most of the producers are efficient and most efficiency values would be near one (Kumbhakar & Lovell, 2000; Murillo-Zamorano, 2004). Assuming gamma or truncated normal distributions whose modes are non-zero, it may furnish wider ranges of efficiency values, which may better reflect the real world situation (Coelli et al., 2005), but these distributions involve more parameters to be estimated, creating computational complexity (Murillo-Zamorano, 2004). The gamma and truncated normal probability distributions involve estimation of two parameters, whereas half normal and exponential distributions involve one parameter only (Kumbhakar & Lovell, 2000). Coelli et al. (2005), and Ondrich & Ruggiero (2001) argue that although various probability distributions are available for the inefficiency term, the selection of a particular probability distribution is largely governed by computational ease and model fit. Following the principle of parsimony, a considerable number of studies have used half normal and exponential models (Bravo-Ureta & Pinheiro, 1997; Chen, 2007; Coelli et al., 2005; Cubbin & Zamani, 1996; Estache & Rossi, 2002). Schmidt & Knox Lovell (1979) suggest trying models with alternative probability distributions and selecting a distribution which fits the best with the given functional model.

Finally, the SFM method is not applicable for the study of multiple outputs, particularly when outputs are jointly produced (Avkiran, 2001; Lindara et al., 2006). However, SFM can be applied by transforming multiple commodities (if possible) into a single output index (Coelli & Perelman, 2000).

#### *3.9.3.3 Stochastic output distance function*

When multiple inputs are used to produce multiple outputs, a simple production function may not be appropriate to describe the production technology. Under multiple output cases the stochastic output distance function is commonly applied to estimate production technology (Coelli et al., 2005; Kumbhakar & Lovell, 2000). The stochastic output distance function has complications in estimating production technology. One complication is the endogeneity of regressors, because all except one output are placed in the right side of the production function as ratios of outputs (in order to impose homogeneity). Also, the stochastic output distance function is not appropriate for all functional forms, such as the Cobb-Douglas functional form because of 'its curvature nature' (Kumbhkar & Lovell, 2000).

## 3.10 Functional forms in production analysis

Specification of functional form has a significant role in the estimation and interpretation of the efficiency and structure of production technology (Murillo-Zamorano, 2004). The two most popular forms are the Cobb-Douglas (CD) and Translog (TL) functional forms (Alauddin et al., 1993; Lindara et al., 2006).

### 3.10.1 Cobb-Douglas functional form

Logarithmic transformation of the CD functional form (see Equation 3.25) makes the model linear in inputs, making econometric application easy (Coelli, 1995; Lindara et al., 2006). However, this attractive feature imposes a number of restrictions. The most notable is that the CD functional form imposes constant elasticity of substitution that is equal to one. That is, inputs are assumed to be perfect substitutes, which is not always true (Coelli & Perelman, 2000; Newman & Wear, 1993). In addition, the CD functional form assumes the same value of returns to scale for all firms in a sample (Coelli, 1995; Coelli et al., 2005).

In the CD model, individual input related parameters ($\beta_i$s) are partial elasticities, which measure the responsiveness of output for 1% change in the *i*th input (Nicholson, 2002). The sum of the parameters exhibits the production structure of technology.

### 3.10.2 Translog functional form

The translog functional form is a direct generalisation of the CD functional form (Nicholson, 2002). The TL functional form is more flexible (Bigsby, 1994; Lien et al., 2007; Parikh et al., 1995). Flexibility arises due to inclusion of second order terms, including interaction and cross multiple terms. Interaction and cross multiple terms provide an opportunity to explain the structure of production explicitly (Samoilenko & Osei-Bryson, 2008). For example, a positive coefficient on an interaction term indicates a complementary relationship between the two factors. The TL function has other desirable properties for example no prior restrictions being imposed such as for elasticities of substitution, or the assumption of identical returns to scale (Bigsby, 1994; Coelli, 1995). Hence, this functional form is more appropriate than CD when the structure of the production technology, (such as elasticity of substitution and returns to scale) are the prime concern of analysis.

The TL functional form is not free from limitations. There is a risk of multicollinearity when many parameters need to be estimated and numbers of observations are few (Siry & Newman, 2001). Therefore, this functional form is most likely to be of use if the numbers of inputs are few. In addition, some authors (such as Sharma & Leung, 1998) argue that parameters associated with interaction and cross multiple terms do not have straightforward interpretation. Following Coelli (2005), a general TL production function is given by Equation (3.36);

$$\ln Y_i = \beta_0 + \Sigma\beta_i \ln X_i + \frac{1}{2}\Sigma\Sigma\beta_{ij} \ln X_i \ln X_j \tag{3.36}$$

where i and j = 1, 2,………..,n.

$Y_i$, $\beta_0$, and $\beta_i$ are the same as the CD model, and $\beta_{ij}$ are parameters to be estimated associated with interaction terms. The TL function can exhibit any degree of returns to scale depending on the values of the parameters (Nicholson, 2002). If $\sum\beta_i = 1$ and $\sum \beta_{ij} = 0$ then the TL function exhibits constant returns to scale, otherwise it exhibits variable returns to scale. The CD form is nested in the TL form and when all $\beta_{ij}$s are zero the CD form results.

### 3.10.3 Choice of functional form

Since both functional forms have advantages and disadvantages, careful selection of a functional form is essential. The functional form is selected largely on practical consideration and specific objectives of the research (Binam et al., 2004). If description of the structure of production technology along with efficiency estimation is the main concern, then the TL functional form is appropriate (Paul et al., 2000). The Cobb Douglas functional form is also appropriate for analysing the production structure and estimating efficiency of a firm (Siry & Newman, 2001; Ogundari et al., 2010). However, it is restrictive, because the Cobb Douglas functional form imposes constant elasticity of substitution equal to one (Barrell & Te Velde, 2000; Sidhu & Baanante, 1981). A study carried out by Kopp & Smith (1980) has concluded that functional specification has a noticeable but small impact on estimated efficiency. Coelli et al. (2005), suggest following the principle of parsimony and selecting the simplest functional form which accomplishes the objective of the study, and this favours the CD form.

## 3.11 Summary

Efficient allocation of resources requires efficiency in production, efficiency in consumption and efficiency in the product-mix. To achieve efficiency in production the marginal rate of technical subsitution of inputs should be equal.

The two main approaches used to measure production efficiency are input and output oriented. Production efficiency is estimated using the production function or frontier. Various techniques are applied to estimate the production frontier and thereby production efficiency, including DEA, the deterministic frontier model and the SFM. The SFM is the most appropriate technique to estimate efficiency because it allows estimation of the inefficiency component, the random error component and the role of input factors. In addition to this, the SFM allows further statistical testing, such as confidence intervals of efficiency estimates and validity of parameters.

The most common functional forms used to estimate efficiency are the TL form and the CD. The TL form is more flexible because of the inclusion of interaction and cross multiple terms and prior restrictions. However, there is the risk of multicollinearity when many parameters are to be estimated and the number of observations are few. On the other hand, logarithmic transformation of the CD functional form makes the model linear in inputs, which makes econometric application easy. However, this functional form is comparatively less flexible and a number of restrictions are imposed. For example, the CD functional form reveals constant elasticity of substitution equal to one.

The purpose of this study is estimation of the production efficiency of CFs, considering the effect of environmental conditions of CFs. However, measurement of environmental conditions of CFs is not straight forward, which will be inputs or outputs in the production system. Therefore, the next chapter evaluates different environmental valuation techniques, and identifies a technique which is applied in CFs in Nepal.

# Chapter 4
# Valuation of Forest Ecosystem Services

## 4.1 Introduction

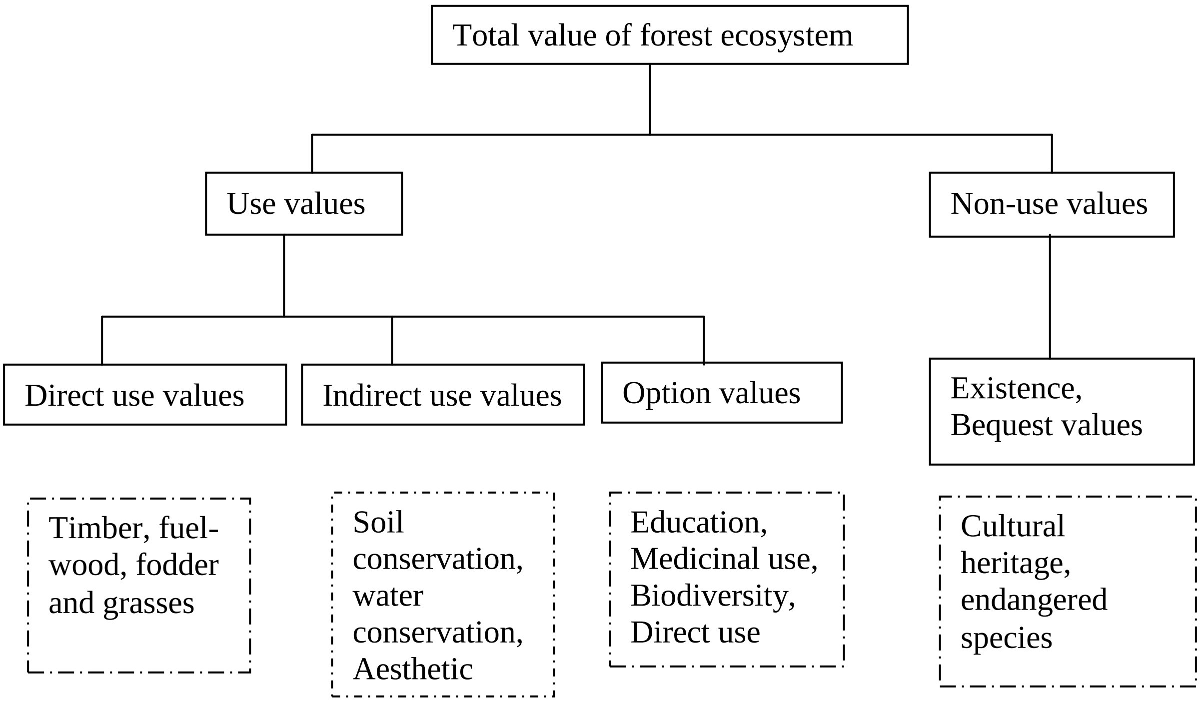
Chapter Two identified that the relationship between community welfare from consumption of forest product benefits and the environmental benefits from CFs has not been addressed. The theoretical framework of Section 3.2 conceptualises the dependency of community welfare on socio economic, market and forest related factors. Chapter Three identifies various potential estimation methods to address the study of relationships between forest product benefits, environmental benefits and socioeconomic factors.

Examination of production possibilities between forest products benefits and environmental benefits requires measurement of both. However, direct measurement of environmental benefits is often difficult, because environmental benefits are not directly exchanged in markets or have limited market exchange (Bennett & Blamey, 2001). Various indirect methods are used for measurement of environmental benefits. This chapter reviews some key environmental benefit valuation methods, including revealed preference, stated preference and multi-criteria decision analysis. Specifically, this chapter reviews the advantages, disadvantages and applications of a number of methods. The chapter begins with classification of forest ecosystem goods and services, and then reviews different methods of ecosystem service valuation.

## 4.2 Forest ecosystem goods and services

Forests provide many important functions and these functions are grouped in various ways. One way groups forest functions into goods and services (Xu et al., 2003). Forest goods refer to directly consumable forest products such as timber, fuel wood, fodder and grass. Forest ecosystem services (ESs) refer to indirectly consumable forest products. Some of the important forest services include soil conservation, water quality maintenance, climate regulation, pollutant decomposition, aesthetics, biodiversity and wildlife conservation (Christie et al., 2006; Xu et al., 2003).

As an alternative, Barbier (1994) classified forest functions into use and non-use value. Figure 4.1, shows Barbier's classification. Use values are further classified into direct use, indirect use and option values. Direct use value of forests includes consumptive uses of its resources such as timber, fuel wood, fodder and grasses (Barbier, 2000). Indirect use value includes non-consumptive uses of forest such as soil conservation, water conservation, flood control, and wildlife habitat conservation (Barbier, 1994). Option values relate to the option of using forest resources for future benefits, even though there is no current use (Edwards & Abivardi, 1998). Examples of option values of forests include future educational benefits, use of forest resources for future medical purposes and biodiversity conservation (Yang et al., 2008). Non-use value, sometimes also called passive use value (Pearce, 2002), is related to the value of services when the respondent does not experience its use directly or when the respondent is not directly participating in its use (Pagiola et al., 2004). Non-use values of forests are commonly divided into existence value and bequest value. Existence value is associated with value people may experience simply by knowing that resources exist, though some of those people never expect to use those resources directly for themselves (Pearce, 2002). Bequest value relates to the value people obtain from conserving forest resources for future generations (Kumar & Kumar, 2008; Poudel & Johnsen, 2009). Cultural heritage value and value for endangered species are some examples of non-use values of forest ecosystems (Hutchinson et al., 2008; Yang et al., 2008).




Source: Barbier (2000)

**Figure 4.1 Grouping of total value of forest ecosystems**

## 4.3 Valuation of forest goods and services

Forest goods such as timber and fuel wood are either exchanged in a market or are directly consumable. Values of goods which are exchanged in markets are computed from market prices. Values of goods which are not exchanged in markets are computed using other indirect methods, such as the barter method and the opportunity cost method (Adhikari, 2005; Chopra, 1993). The barter method of valuation involves setting up an imaginary situation in which a forest good is bartered with a good which has a well known market value (Gunatilake, 1998). The opportunity cost approach considers the cost of the closest substitute as a value of forest goods (Croitoru, 2007; Gunatilake, 1998). Chopra (1993) claimed that if labour time is the major input required in the collection of a forest good, then opportunity cost of labour time can be used as the value of the good. Value of forest goods such as grasses, fuelwood and fodder can be derived by using cost of labour to collect them.

Valuation of forest services is complex because of the complex nature of a forest ecosystem. Many services are produced jointly and most of them overlap - producing one service may influence the availability of other services (de Groot et al., 2002). In addition, valuation is complicated by the fact that various forest services, such as soil conservation and recreation, are not exchanged in markets, so they are often without any prices (Chee, 2004; Chopra, 1993; Xu et al., 2003). The public good nature of many forest services creates free riding opportunities. As a result the forest services are prevented from being exchanged in market (Loomis et al., 2000).

Various indirect methods have been used to value forest services, including non-market valuation (NMV) methods and multi-criteria decision analysis (MCDA) methods (Hein et al., 2006). NMV methods include revealed preference and stated preference methods. The key MCDA methods include multi-attribute utility theory, analytic hierarchy process and analytic network process.

### 4.3.1 Revealed preference non-market valuation methods

Revealed preference methods evaluate the value of goods and services based on the actual behaviour of consumers (Boyle, 2003; Chee, 2004) . The relation of non-marketed goods or services with marketed goods is used to estimate the values of non-marketed goods or services (Boyle, 2003). Although revealed preference methods have been widely applied in ecosystem valuation studies, their application is relevant in certain cases only (Brown, 2003a; Font, 2000; Shrestha et al., 2002). Valuation by revealed preference methods is based on existing circumstances. Therefore this method is unable to value new or hypothetical circumstances. In addition, revealed preference methods cannot value non-use values, such as existence value, because non-use values are not related to any market goods and services (Bennett & Blamey, 2001; Carson et al., 2001). Stated preference methods are used where revealed preference methods are not applicable, such as to estimate non-use values (Baral et al., 2008; Carlsson et al., 2003; Mekonnen, 2000).

### 4.3.2 Stated preference non-market valuation methods

Stated preference methods involve asking people to state choices on different hypothetical scenarios of allocation of resources (Bennett & Blamey, 2001). The two main stated preference methods are the contingent valuation (CV) and the choice experiments (CE). CV involves asking respondents to state their choice or preference in terms of money about a new environmental condition (Veisten, 2007). The condition may be improved or worse than the status quo. CV is the most widely used technique in the non-market valuation literature because it can be applied to the valuation of both use and non-use values (Loomis et al., 2000; Venkatachalam, 2004; Yang et al., 2008).

CE is an extension of the CV method. The CE technique involves asking respondents to make choices between different alternatives (Adamowicz et al., 1998). Each alternative is described by a number of attributes and their different levels (Rolfe et al., 2004). This technique is more useful in cases where attributes of a resource change simultaneously (Adamowicz et al., 1998).

Albeit many studies have used CV and CE techniques to value forests goods and services, these methods have some common limitations (Adamowicz et al., 1998; Carlsson et al., 2003; Hanley et al., 1998a; Hanley et al., 1998b; Taylor, 2003). These methods are criticised for using money as the value measure (Ananda & Herath, 2003). Many of the forest's services, such as soil conservation, have no direct market, so valuation in monetary terms may be hypothetical (Ludwig, 2000).

CV and CE are based on hypothetical scenarios for the respondents (Hall et al., 2004). Thus in the absence of markets for the service, the estimation of a monetary value will not be trustworthy and will have little validity in the conclusion drawn from the responses. The issue of hypothetical questions is more severe in developing countries. Various authors (such as Mekonnen, 2000; Shrestha et al., 2007) have argued that posing hypothetical questions often encounters high rates of non-response or reports of zero value of resources (Shrestha et al., 2007). To overcome the limitations associated with stated and revealed preference methods, alternative techniques, such as MCDA techniques, may be more appropriate to estimate the value of forest services (Colombo et al., 2009; Hill & Zammit, 2000).

## 4.4 Multi-criteria decision techniques

The MCDA is an evaluation framework which can be used to rank or score the performance of decision alternatives against multiple objectives measured in different units (Ananda & Herath, 2003; Herath, 2004). The objectives may be attributes or criteria. Within the framework of MCDA, various techniques have been developed and they have their specific advantages and disadvantages. However, in general, authors such as Herath (2004) and Chee (2004) have argued that the MCDA technique has advantages compared with NMV methods. The most important advantage is that it takes into account multiple criteria of assessment, rather than the single criterion of monetary value. Preferences over various alternatives or objectives are expressed in terms of cardinal and ordinal values. MCDA is simpler than NMV because the attributes or alternatives are compared in pairs and a ratio scale is used to express the preference of one attribute or alternative over other attributes or alternatives.

MCDA is a general approach of decision making and includes various techniques. The most widely used techniques are Multi Attribute Utility Theory (MAUT), the Analytic Hierarchy Process (AHP) and the Analytical Network Process (ANP) (Duke & Aull-Hyde, 2002; Rehman & Romero, 1993). Although all three methods require subjective and objective judgments to derive preferences for criteria and alternatives, their theoretical assumptions, procedures and applications are not similar.

### 4.4.1 Multi attribute utility theory

The MAUT technique derives a preference score for each alternative based on the utility derived from its attributes. Preference scores are derived from a preference function or utility function (Løken, 2007). A utility function is derived for each criterion. By aggregating the utility functions of criteria, an overall utility function for an alternative is determined (Russell et al., 2001). The criteria of decision making are variables of the utility function, and the parameters indicate the relative importance of each of the criteria.

A general MAUT model is given by;

$$U(A) = \sum w_i u_i(x_i) \qquad i = 1, 2, \ldots\ldots n, \qquad (4.1)$$

where *U(A)* represents the overall utility from option A and is the weighted sum of the utility derived from each of the criteria $x_i$, with $w_i$ being the weight applied to criterion *i* and $u_i(x_i)$ is the utility function for criterion *i* (Kangas, 1993).

The main advantage of MAUT is that it takes into account the risk and uncertainty embedded in the selection of alternatives (Løken, 2007; Russell et al., 2001). In Equation (4.1) *U* (*A*) includes the values of risk and uncertainty, because the utility function for each criterion is determined by the decision makers' risk attitude. For example, risk-averse decision maker will select the criterion with high utility. On the other hand, a risk-prone decision maker will select the criterion with lower utility (Yoo, 1998).

This technique is useful for assessing multi criteria decision problems, particularly when decision makers do not have enough information regarding the occurrence of alternatives. Many authors (such as Yoo, 1998) prefer the MAUT technique because it is based on a strong utility theory foundation. Despite being theoretically strong, the MAUT technique is not very suitable for practical uses because of the strict assumption of independence among criteria (Duke & Aull-Hyde, 2002; Rehman & Romero, 1993). This assumption may not always hold true in practical cases, and as a result the technique may result in false rankings (Rehman & Romero, 1993).

The majority of studies applying the MAUT technique have used an additive functional form (Kangas & Kuusipalo, 1993; Min, 1994; Vacik & Lexer, 2001; Yoo, 1998). However, Rehman and Romero (1993) claimed that the assumption of an additive functional form for utility is too restrictive for many decision problems. In addition, Løken (2007) argued that establishing a utility function is a difficult and lengthy process, which may restrict the MAUT's application. Overall utility function derivation involves derivation of multiple sub-utility functions based on the numbers of criteria and decision alternatives (Kangas & Kuusipalo, 1993).

Despite its disadvantages, MAUT is used in many studies. Kanagas (1993) applied the MAUT technique to estimate the preference model of a private non-industrial forest landowners for choosing reforestation alternatives in a forest stand. Yoo (1998) applied the MAUT technique to decision making, in environmental planning of the Korea Electricity Power Corporation. The study concluded that MAUT is a feasible technique in major decision making in environmental planning.

MAUT furnishes preferences and relative ranking of alternatives, based on the probable outcomes of the alternatives. However, if decision alternatives are not probabilistic in nature then other MCDA methods such as analytic hierarchy process (AHP) and analytic network process (ANP) may be more appropriate (Duke & Aull-Hyde, 2002).

### 4.4.2 Analytic hierarchy process

AHP is another MCDA technique. It is a method based on the theory of ratio scale measurement, in which a mathematical technique is used to obtain quantitative values from qualitative comparisons (Alphonce, 1997; Duke & Aull-Hyde, 2002; Herath, 2004). The AHP method decomposes the decision problem into a hierarchical decision schema and decision elements (Alphonce, 1997; Herath, 2004). Elements may be criteria, sub-criteria or alternatives, and these elements are judged qualitatively, and criteria are the factors which affect the decision making.

#### *4.4.2.1 Steps for the application of AHP*

The use of AHP involves various steps. Broadly, the steps are problem decomposition and hierarchy construction from the decision problem, pairwise comparison, weight calculation, consistency check and priority determination of alternatives (Ananda & Herath, 2003). Figure 4.2 shows the main steps in AHP.

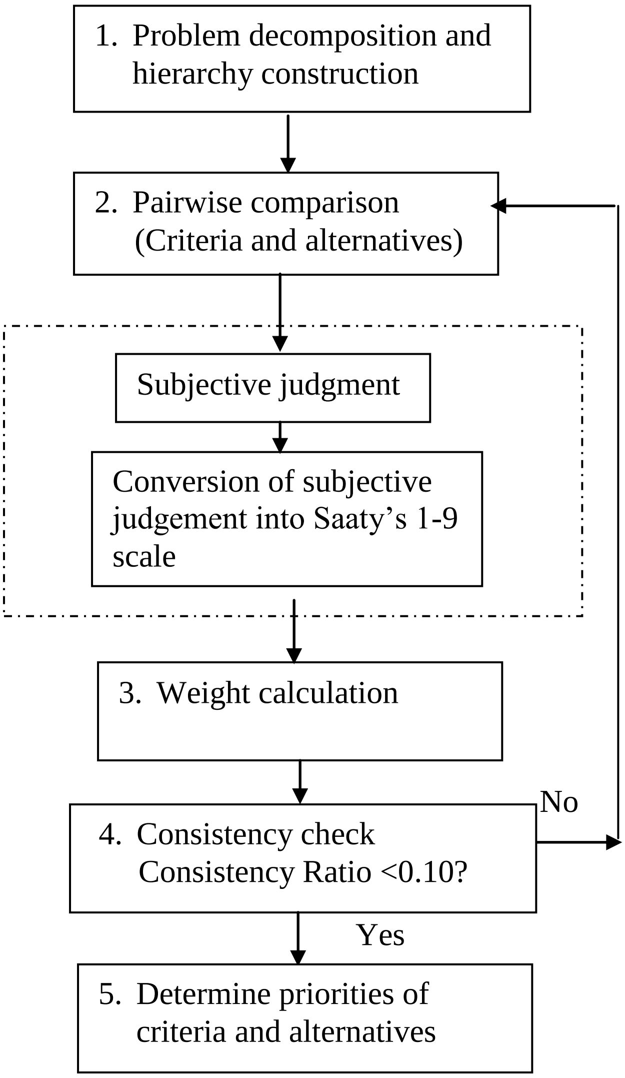



**Figure 4.2 Steps in the AHP method**

*Problem decomposition and hierarchy construction*

This step includes breakdown of the decision problem into overall objective, criteria and alternatives. The overall objective of the decision process lies at the top of the hierarchy and the criteria and decision alternatives are on the successive lower levels of the hierarchy (Alphonce, 1997). Figure 4.3 shows a three level hierarchical model with one overall goal, one set of choice criteria and one set of choice alternatives. Each level in the hierarchy corresponds to common characteristics of the elements in that level. The number of levels can be varied depending on the decision problems under consideration.

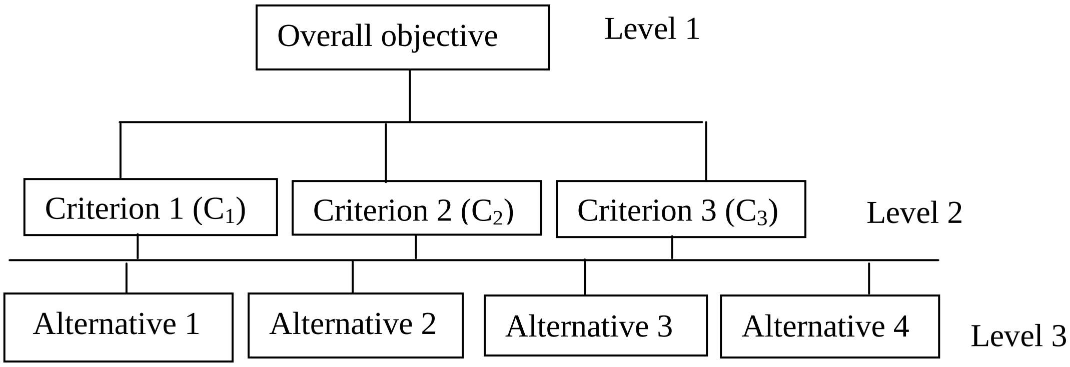



**Figure 4.3 Decision hierarchy model in AHP**

*Pairwise comparison*

In this step elements of each particular level are pairwise compared with respect to specific elements in the immediate upper level (Alphonce, 1997). In the first part of the pairwise comparison, the respondent is asked to prioritise between two elements at a time and is then asked to quantify the relative importance. The degree of importance of one element over the other element is expressed on a nine point scale developed by Saaty (2001). Use of a nine point scale is based on research by psychologist George Miller (1956) which showed that "decision makers were unable to consistently repeat their expressed gradations of preference finer than seven plus or minus two". Table 4.1 shows the nine point scale and score definitions. A value of '1' indicates the two elements are of equal importance and the value '9' indicates the absolute importance of one element over the other.

**Table 4.1 Measurement scale of AHP**

| Degree of relative importance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Weak importance of one over the other |
| 5 | Essential or strong importance |
| 7 | Demonstrated importance |
| 9 | Absolute importance |
| 2,4, 6 and 8 | Intermediate values between two adjacent judgements |

Source: Ananda & Herath (2003)

Pairwise comparison is executed in various steps. First, criteria are pair-wise compared with respect to the overall objective of the decision problem. Subsequently**,** elements in the sub criteria level are pairwise, compared with respect to each element in the criteria level. In this way priority matrices are formed at each level. Equation (4.2) depicts one example of a priority matrix, corresponding to level 2 in Figure 4.3. It is formed by comparing criteria $C_1$, $C_2$ and $C_3$ with respect to the overall objective. $a_{ij}$ represents the degree of importance of element $i$ relative to element $j$, and $n$ is the number of decision elements to be compared (Duke & Aull-Hyde, 2002). $a_{ij}= 1/a_{ji}$, thus when i = $j$, $a_{ij}$ = 1. This implies the value of importance when comparing an element with itself that is 1 (Alphonce, 1997). A similar process is followed for level 3 (Figure 4.3), four alternatives are pairwise compared with respect to each criterion at level 2. Thus three pair-wise comparison matrices are formed at level 3.

$$A = \left[a_{ij}\right] = \begin{bmatrix} a_{11} & a_{12}\ldots\ldots & a_{1n} \\ a_{21} & a_{22}\ldots\ldots & a_{2n} \\ a_{31} & a_{n2}\ldots\ldots & a_{nn} \end{bmatrix} \qquad (4.2)$$

***Weight calculation by analysing pairwise comparison matrix***

The next step is the analysis of pairwise comparison data, in order to calculate priority weights for the criteria and alternatives. The most common techniques for calculating the priority weights are the eigenvalue technique and a technique suggested by Saaty and Kearn (1985 in Haung et al., 2002). In the eigenvalue technique, reciprocal matrices are constructed from pairwise comparisons. The right eigenvector of the largest eigenvalue of matrix $A$ constitutes the estimation of relative importance of elements [Equation (4.3)], where $w$ is the eigenvector of matrix $A$. When the vector $w$ is normalised, it becomes the vector of priorities of the elements in a level which is under consideration.

$$Aw = \lambda_{max} w \qquad (4.3)$$

where $\lambda_{max}$ is the maximum eigenvalue of matrix $A$. Computing eigenvectors by using the eigenvalue method can be time consuming (Haung et al., 2002). An alternative method suggested by Saaty and Kearn (1985 in Haung et al., 2002) can also be used. The method includes calculating the geometric mean of each row, and normalising these by dividing by the sum of geometric means for each row. Mathematically, the geometric mean of each row (which also represents the weight of the element corresponding to that row) is given by

$$c_i = \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} \qquad (4.4)$$

where $c_i$ is the geometric mean of each row and $n$ is the number of elements in each row. After calculating the geometric mean, normalisation is carried out to get the priority weights which are calculated as:

$$x_i = c_i \, / \sum_{j=1}^{n} c_j \qquad (4.5)$$

where $x_i$ is priority weight for the $i^{th}$ row and $c_j$ is the sum of the $i^{th}$ row. The priority weights so calculated at each level are also called local priority weights (Haung et al., 2002).

Due to the subjective judgment embodied in Equation (4.5) and inconsistent judgement by respondents, the estimated degree of importance may not be consistent with underlying preferences (Duke & Aull-Hyde, 2002). Therefore, a consistency check of the coherence of respondent's judgments is essential before estimating the final priority weights of elements (Kangas, 1994). For example, if element A is 4 times more important than element B, then element B should be 1/4 times more important than A. A certain degree of inconsistency often exists while making subjective pair-wise comparisons of the elements (Duke & Aull-Hyde, 2002). As a rule of thumb, a consistency ratio value of 10% or less is considered to be satisfactory (Herath, 2004; Kangas, 1994). Alphonce (1997) defined the consistency ratio (CR) as the ratio of the inconsistencies of the results being tested, to the inconsistencies obtained from randomly generated preferences.

$$\text{CR} = \text{CI}/\text{ACI} \qquad (4.6)$$

where, CI is the consistency index and measures the inconsistencies of pairwise comparisons, and ACI is the average consistency index of randomly generated comparisons. The ACIs developed by Saaty (1980 in Ramanathan, 2001) up to size 10 x 10 matrices is given in Table

4.2. CI is given by the expression; CI = $\frac{\lambda_{max} - n}{n - 1}$ where, $\lambda_{max}$ is the largest eigenvalue and $n$ is the number of elements being compared. If the pairwise comparisons do not involve any inconsistencies then $\lambda_{max} = n$ (Ananda & Herath, 2003). The more consistent the pairwise comparisons are, the closer the value of computed $\lambda_{max}$ is to $n$ (Kangas & Kuusipalo, 1993), the smaller CI is, and consequently the smaller is CR .

**Table 4.2 The average consistency index table**

| Size | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| ACI | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

Source: Ramanathan (2001)

If the consistency ratio is more than 10% then all or some of the comparisons must be reconsidered to resolve the inconsistency (Fong & Choi, 2000; Kangas & Kuusipalo, 1993). Obtaining improvement in the consistency ratio is difficult if the numbers of criteria and alternatives are high. However, Duke & Aull-Hyde (2002) noted that if there are sufficient numbers of comparison matrices, then an acceptable overall level of consistency is possible even if some of the comparison matrices have unacceptable levels of inconsistency. Computer software such as Expert Choice (2000) and Superdecisons (Saaty, 2000) can be used to calculate the value of inconsistency (Alphonce, 1997; Matta et al., 2007; Mau-Crimmins et al., 2005).

***Determination of weights of criteria and alternatives***

Once the weights of elements in each level of the hierarchy are available, they are aggregated to find the final priorities of the alternatives or elements. These are global priorities (GP) with respect to the overall objectives of the decision problem. The sum of the GPs at each level is one (Kangas & Kuusipalo, 1993). The GPs of alternatives or elements in the particular level are obtained by multiplying local priority weights of elements, by the priority weight of corresponding elements, in the level immediately above (Kangas, 1994). Equation (4.7) is used to calculate $GP_i$ (Haung et al., 2002):

$$GP_i = \sum_{i=1}^{n} v_i z_i \tag{4.7}$$

where $v_i$ is the priority or weights of the $i^{th}$ criteria with respect to the goal, and $z_i$ is the local priority or weight of the $i^{th}$ alternative with respect to each criterion in the matrix. Equation

(4.7) is a simple weighted summation of local priorities. The GPs thus obtained represent the importance of the alternatives to achieve the goal.

#### 4.4.2.2 Theoretical assumptions of AHP

The validity of the AHP method is based on four assumptions (Duke & Aull-Hyde, 2002).

- Reciprocal condition: For two given alternatives *i* and *j*, if the preference score of *i* over *j* is given by *x* then the preference score of *j* over *i* is the reciprocal of preference score of *i* over *j;* if $a_{ij}= x$, then $a_{ji}= 1/x$ where, $x \neq 0$.
- Homogeneity: Elements of a particular hierarchy are comparable. There should not be a large disparity among the elements in any particular level. If such a situation exists there is no choice, one element will be absolutely selected. For example, a particle of sand cannot be compared with an apple.
- Independence: When stating preferences under each criterion, each criterion is assumed to be independent of the properties of the decision alternatives. That is, the weight of a higher level element is independent of the elements in the lower level.
- Expectations: When proposing a hierarchical structure for a decision problem, the structure is assumed to be complete. Adding or dropping any element from the hierarchy may change the preference ordering.

#### 4.4.2.3 Advantages and disadvantages of AHP

The AHP method mostly uses qualitative criteria for ranking of alternatives. Therefore it is particularly useful when quantification of attributes is unlikely to form a basis for comparison (Ananda & Herath, 2003; Duke & Aull-Hyde, 2002). Since AHP takes into account many attributes together, it is useful when the decision problem consists of many criteria.

The most notable advantage of AHP is its ability to incorporate the consistency check for preferences making the preferences more reliable and valid (Boucher & MacStravic, 1991; Mau-Crimmins et al., 2005; Ramanathan, 2001). Since opinions of many stakeholders are included in decision making (Mau-Crimmins et al., 2005), AHP is useful for environmental problems which often involve many stakeholders (Ananda & Herath, 2003; Duke & Aull-Hyde, 2002).

AHP has been used in various fields that include strategic planning, public policy, programme selection, resource allocation and natural resource management (Ananda & Herath, 2003; Duke & Aull-Hyde, 2002; Haung et al., 2002; Kangas & Kuusipalo, 1993; Matta et al., 2007). Vaidya & Kumar (2006) mention 150 applications of AHP in their literature review.

Applications include ‘selection’, ‘evaluation’, ‘benefit-cost analysis’, ‘allocations’, ‘planning and development’, ‘priority and ranking’ and ‘decision making’.

In spite of AHP’s immense popularity in decision making, it has some shortcomings. First, authors such as Belton and Gear (1983), Dyer and Wendell (1985) and, recently, Mau-Crimmins et al. (2005), argue that since there is no theoretical basis for the formation of hierarchies, decision makers under similar situations may have different preferences and as a result, outcomes may be different. Saaty (2001) has introduced four axioms to validate the theoretical basis of AHP; reciprocity, homogeneity, dependency and expectation. Therefore, the validity of AHP depends on whether the decision problem under consideration complies with these axioms.

Second, AHP is criticised for lack of statistical theory (Duke & Aull-Hyde, 2002; Herath, 2004) - it ignores uncertainty embedded in preference scores. This disadvantage prohibits statistical tests for the validity of preference scores. However, a large sample size can minimise uncertainty to some extent (Mau-Crimmins et al., 2005). Duke & Aull-Hyde (2002) have used a sample of 129 respondents to identify public preferences for land preservation, and have tested for statistical differences in mean pair-wise comparison ratings between two counties and found the preference difference was significant as well as consistent with the prior expectations.

Third, application of AHP can be cumbersome with a large number of alternatives. However, Bottani & Rizzi (2008) suggest reducing the number of alternatives by clustering the alternatives based on their similarities, and then executing pairwise comparisons. However, even if clustering lessens the burden of the large number of alternatives, the process of calculating priorities are still lengthy (Saaty, 2006).

Belton and Gear (1983) and Mau-Crimmins et al. (2005) claim that AHP’s ranking is arbitrary because if an alternative is added or dropped the ranking may change. Harker and Vargas (1987) claimed that variation in ranking occurs if an element similar to any elements under consideration is added. In order to alleviate the problem of rank reversal, Harker (1986) and Harker & Vargas (1987) suggested making a detailed analysis of the decision problem and to include only those alternatives which are really unique, into the decision hierarchy.

Finally, the AHP model assumes that elements within each level are independent (Cheng & Li, 2004; Neaupane & Piantanakulchai, 2006; Wolfslehner et al., 2005). However, this assumption is not always tenable in real world situations (Yüksel & Dagdeviren, 2007). Various decision problems involve the interaction and dependence of higher level elements on the lower level elements (Saaty, 1999). This disadvantage of AHP can be overcome by using the advanced MCDA technique called analytic network process (ANP) (Wolfslehner et al., 2005; Yüksel & Dagdeviren, 2007).

### 4.4.3 Analytic network process

The ANP technique is a generalisation of AHP. The technique assumes multidirectional relationships among the decision elements (Saaty, 1999). A group of elements (criteria or alternatives) having some common characteristics forms, a cluster. ANP involves interactions and dependencies between the clusters and between elements within clusters. Since ANP involves multidirectional relationships among decision elements, instead of a hierarchy, a network is used. Figure 4.4 illustrates the structural difference between AHP and ANP models. Figure 4.4 (b) illustrates a basic ANP model which involves multidirectional relationships and a network of clusters, which is distinct from an AHP model [Figure 4.4 (a)] which only involves vertical relationships between different hierarchical levels. A cluster consists of elements which have a synergic relationship. In Figure 4.4 an arrow (→) indicates a one way dependency, a two ended arrow (↔) indicates a two way dependency and an arced around represents an interaction within the elements of a cluster.

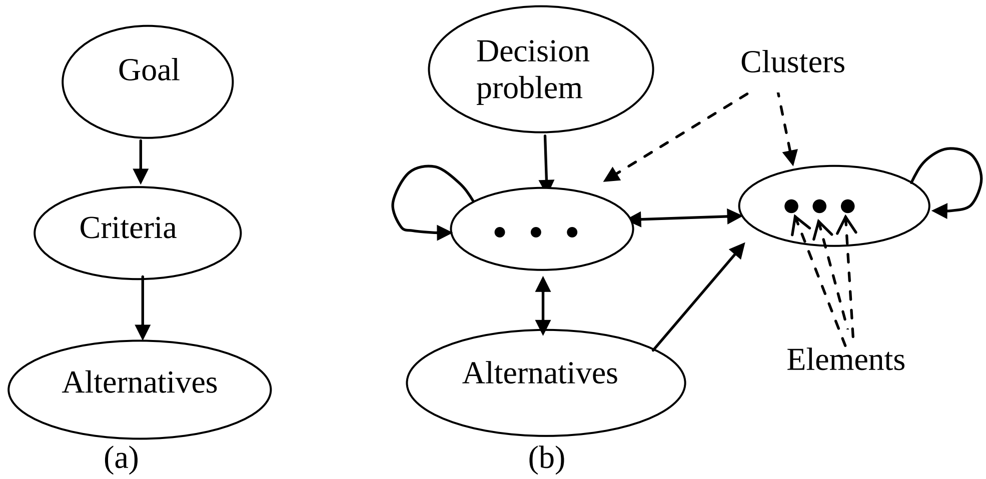



**Figure 4.4 Structural differences between a hierarchy and a network**

Like AHP, ANP uses ratio scales and pairwise comparisons to derive the priorities of the alternatives. ANP considers dependencies both within and between the clusters (inner dependence and outer dependence) (Saaty, 1999). As such, priorities between clusters and elements within each cluster are evaluated. To accommodate dependencies between and within clusters, a supermatrix is used instead of a simple matrix. Entering the priority vectors derived from pairwise comparison matrices, forms the supermatrix (Saaty, 2006). Broadly, ANP comprises four steps to calculate priority weights of elements (attributes).

Step 1. Model construction and problem structuring: The first step involves identifying and breaking down the decision problem into decision components. Next, relationships between different components of the system are established. The literature suggests two ways to structure an ANP model; either through literature review, or through discussions with experts or decision makers (Khan & Faisal, 2008; Lee & Kim, 2000; Yüksel & Dagdeviren, 2007).

Step 2. Pairwise comparisons: Pairwise comparisons are carried out at the cluster and element levels. Similar to AHP, a 9 point scale is used to measure the preference for one element relative to another element. Because of interaction relationships among the clusters and their elements, the question structure used in ANP is not as straight forward as that used in AHP. Questions are designed to reflect interaction relationships. The general question may be of the type: ‘Given an alternative and a criterion, which of the two alternatives influences the given criterion more and how much more than the other alternative?’ Pairwise comparison between elements at each level is conducted with respect to their relative importance towards the main objective. Priority matrices are constructed from pairwise comparison ratios. From priority matrices, priority vectors are calculated using the same process as is used in AHP.

Step 3. Formation of a supermatrix: The priority vectors obtained in Step 2 are put into the supermatrix that represents the interrelationships of the elements in the system. A general form of a supermatrix is shown in Figure 4.5 where $C_N$ denotes the $N$ th cluster, $e_{Nn}$ denotes $n$ th element in the $N$ th cluster, and $W_{ij}$ is a block matrix consisting of the priority weight vectors ($w$) of the influence of the elements in the $i$ th cluster with respect to the $j$ th cluster. If the $j$ th cluster has no influence to the $i$ th cluster, then $W_{ij} = 0$. The supermatrix obtained at this stage is called the unweighted supermatrix (Huang et al., 2005).

<table>
<tr><td></td><td></td><td colspan="4">$C_1$</td><td colspan="4">$C_2$</td><td rowspan="2">…</td><td colspan="4">$C_N$</td></tr>
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Source: Neaupane & Piantanakulchai (2006)

**Figure 4.5 General structure of supermatrix**

Step 4. Formation of the weighted supermatrix: The unweighted supermatrix obtained in Step 3 consists of several priority weights for elements of a cluster the sum of which is one. The unweighted supermatrix must be changed into a matrix in which the column sum is one (Gencer & Gürpinar, 2007). This is achieved by multiplying each element by the weight of each cluster, which produces the weighted supermatrix (Neaupane & Piantanakulchai, 2006). The weight of each cluster is obtained from cluster level pairwise comparisons with respect to the main objective and is sometimes called a control criterion. In other words, the cluster weight is an eigenvector of influence of the clusters on each cluster (Gencer & Gürpinar, 2007). Finally, the weighted supermatrix is raised to a power at which the weighted supermatrix's row values converge to the same value for each column of the matrix. The resulting matrix, called the limiting supermatrix (Huang et al., 2005), represents the final weights or priorities of the elements of the decision problem.

#### *4.4.3.1 Advantages and disadvantages of ANP*

ANP retains all the advantages that AHP possesses, and on top of those it allows dependencies among clusters (or criteria) and elements (or alternatives). ANP is a more powerful technique and is more useful in complex issues where factors of the decision problem interact (Gencer & Gürpinar, 2007). The two way dependencies among the clusters and elements, refine the measurement priority weights from the judgment and make predictions more accurate (Wolfslehner et al., 2005).

Since ANP is a generalisation of AHP, some of the methodological problems existing in AHP also apply to ANP (Huang et al., 2005). Dependencies among clusters and elements make ANP more computationally complex. However, computer software such as Super Decisions and Expert Choice™ have made calculation easy (Aragonés-Beltrán et al., 2008; Gencer & Gürpinar, 2007; Herath, 2004; Wolfslehner et al., 2005).

## 4.5 Applications of MCDA in natural resource management

Although MCDA and its variants such as AHP and ANP have been used extensively in various fields, its application in environmental management is still limited. For example, Duke & Aull-Hyde (2002) used AHP to compare the public's values for the attributes of preserved land that included; environmental, agricultural, growth control and open space. Herath (2004) used the AHP to compare the public's relative values for conservation, recreation and business attributes of the Wonga Wetlands on the Murray River of Australia. The study identifies the preferences of the attributes from three different stakeholders' perspectives and concludes that preferences among the stakeholders vary. Colombo et al. (2009) have applied the AHP and the choice experiment method to rank the attributes of public right-of-ways in Bedfordshire, England. The attribute ranking revealed by AHP was consistent with ranking revealed by the choice experiment.

Application of AHP in developing countries is not much explored except for a few. Soma (2003) has claimed that AHP is an appropriate technique for developing countries because it primarily uses qualitative information which is generally all that is available. In addition, AHP involves stakeholders and identifies their preferences over objectives, criteria and alternatives, making management of resources more likely to be a success (Soma, 2003). Huang et al. (2002) have used AHP to identify the effects of agro-forestry on biodiversity of a natural reserve in the East Usambara mountains of Tanzania. Likewise, Soma (2003) has used AHP to support decision making in the shrimp fishery sector in Trinidad and Tobago.

Although some studies have reported the use of AHP in a developing country, its application has some difficulties. Soma (2003) observed that rural people had difficulty understanding and interpreting the questions being asked in AHP. However, pre-tests of questions and detailed explanation of questions during interviews can solve this difficulty to some extent (Khan & Faisal, 2008; Soma, 2003). Duke & Aull-Hyde (2002) have suggested the use of posters or photographs to assist the understanding of AHP questions. Tiwari et al. (1999) observed that farmers, as well as government officials, have difficulty understanding pairwise comparison questions. However, detailed explanation of objectives, criteria and sub criteria of AHP helped respondents to answer the questions (Tiwari et al., 1999).

ANP has been used in only a few environmental management cases, including Neaupane & Piantanakulchai (2006), Khan & Faisal (2008) and Wolfslehner et al., (2005). Neaupane & Piantanakulchai (2006) applied ANP to a landslide hazard assessment, taking the case of eastern Himalayan districts of Nepal, and demonstrating the applicability of this method in the case study area.

In India, Khan & Faisal (2008) applied ANP to prioritise and select appropriate municipal solid waste disposal methods. Khan & Faisal’s (2008) study adopted some very desirable measures, such as sending a brief outline of the network model to the stakeholders before the discussion workshop and holding a brainstorming session with experts. These measures helped participants to understand the ANP model and the questionnaire.

Wolfslehner et al. (2005) compared the AHP and ANP methods in order to identify the differences between the two techniques, using four contrasting forest management strategies in south Austria. Even with the same inputs, AHP and ANP produced different rankings for the four management strategies, however the absolute differences in the priorities among the ranks were quite small. However, the authors suggest that to find the best alternatives, it is appropriate to apply the more sophisticated ANP method.

Aragonés-Beltrán et al. (2008) successfully applied the ANP technique to estimate the monetary value of land plots. Based on priority weights and monetary values of reference plots, the study demonstrates that the ANP technique can be used accurately to estimate the monetary value of entities, provided the monetary value of some reference entities is known.

## 4.6 Summary

Forests provide a variety of goods and services. Valuation of these goods and services is essential to optimally manage a forest. For goods and services which are exchanged in markets or are directly consumable, market prices provide value information. However, for goods and services which are neither exchanged in markets nor directly consumable, indirect methods of valuation are used. The most commonly used are non market valuation and MCDA methods. Non market valuation methods measure the value of goods and services in monetary terms, whereas MCDA measures the in tems of a ratio scale.

MCDA variants have been used in various empirical studies to overcome the criticisms of non-market valuation methods. The main variants include MAUT, AHP, and ANP. MAUT is criticised for its rigid assumption of independency among the criteria and restricted additive functional form for utility. These criticisms prevent the use of MAUT technique in environmental management cases. The AHP only deals with unidirectional vertical relationships and avoids any horizontal relationships among criteria and alternatives. However, many components of environmental management cases are related horizontally as well as vertically. Therefore, the application of AHP in environmental management cases is limited. To address the issue of horizontal and vertical relationships among criteria and alternatives, the ANP technique is useful. Some empirical studies have demonstrated the use of ANP in environmental management cases.

This research will apply ANP to calculate environmental benefits of CFs based on ecosystem services and forest attributes. Environmental benefit of a particular CF is estimated by summing relative preference values for forest attributes. Use of the ANP involves various steps including design of a questionnaire and interviews with stakeholders. The next chapter describes the methodology used to collect information related to communities and forests.

# Chapter 5
# Research Methodology

## 5.1 Introduction

This study investigates production efficiency of community forests (CFs) in terms of direct forest product benefits and environmental benefits. Chapters Three and Four have provided theoretical backgrounds for production efficiency analysis and environmental value estimation.

Production efficiency analysis requires several types of information related to forests and the communities that manage them. This chapter provides details of the methodology and fieldwork undertaken to collect data related to forests and communities. This chapter first presents the general methodology, followed by a detailed account of the specific research methods applied, sampling procedures, questionnaire and interview contents, and data analysis techniques.

## 5.2 Methodology

Three main research approaches are available; qualitative, quantitative and mixed approaches (Creswell, 2009). The qualitative approach of inquiry refers to the collection of information in the form of expressions of views or feelings. This approach is mainly concerned with generating theories and hypotheses by extending the topic from specific to general (Creswell, 2009; Punch, 2005). On the other hand, quantitative approaches of inquiry usually involve gathering statistical information and are more concerned with statistically testing hypotheses and theories (Punch, 2005).

Each approach has its own strengths and weaknesses. The qualitative approach is more flexible, is applicable to a wider range of situations and purposes, and can be modified in the course of its use if new situations appear (Punch, 2005). The qualitative approach involves an open ended type of inquiry, and a wide range of information may be available, which can be used for wider purposes (Rudestam & Newton, 2007). Taylor (2000) argued that since the qualitative approach of inquiry is more exploratory in nature, it is more relevant when precedents are difficult to find. In addition, Taylor (2000) asserts that the qualitative approach encourages the respondent to freely express their views instead of sticking to a subject area or response which has already been determined by the researcher. The qualitative approach is not without limitations. Because it typically involves interviewing a small number of respondents, extending the findings beyond the group may be unreliable. For the same reason, generating theory from a limited set of ideas can also be problematic (Taylor, 2000).

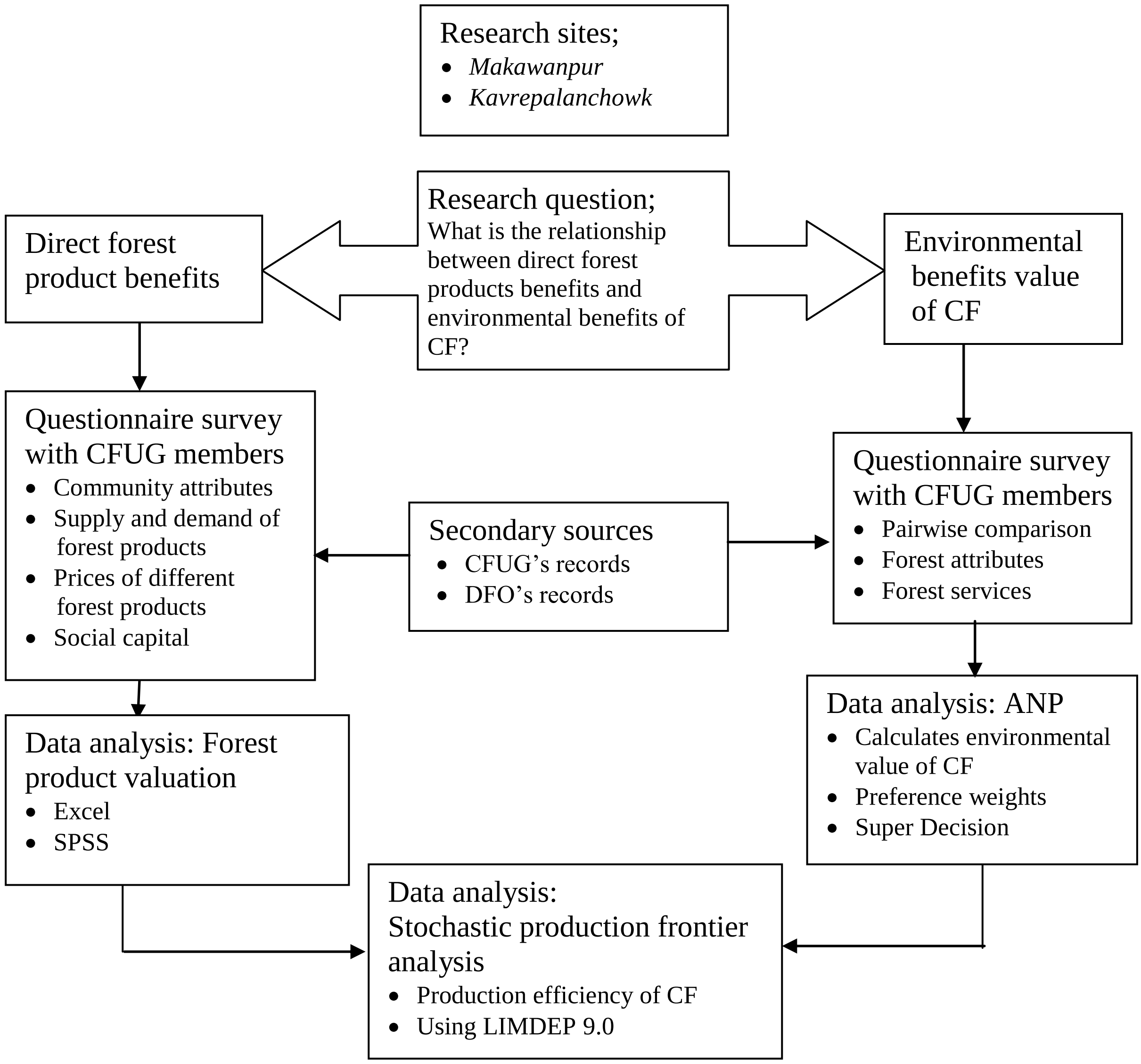
The quantitative approach of inquiry gathers information in the form of numbers. Hence, this approach enables description of the situation or phenomena in a systematic and comparable way (Punch, 2005). This approach is favoured especially when relationships among the different variables describing the research problem are needed. Punch (2005) has asserted that procedures for the analysis of quantitative data are well developed and codified, and hence produce objective results. Because of this objectivity, researchers have fewer chances to influence the result of the analysis.

Jennings (2001) argues that the two approaches of inquiry are based on specific paradigms which stand in opposite positions to each other, and therefore may result in 'mixing theoretical world views that are contradictory to each other'. Hence, it can be inferred that neither approach is always superior to the other approach. However, selection of any approach depends more on the research problem and the objective of the study, rather than on the underlying theory of the approach (Creswell, 2009; Punch, 2005).

This study is focused on the investigation of production possibilities of CF in terms of direct forest products benefits and environmental benefits. Also, the study involves interactions of various variables associated with forests and communities. Thus, the nature of the research requires adoption of a quantitative approach of inquiry. Many other analyses of production efficiency of firms, households, industries and communities have also employed the quantitative approach (Lee, 2005; Misra & Kant, 2005; Siry & Newman, 2001; Van Ha et al., 2006). Approaches to data collection and an overview of research procedure is explained in the next section.

## 5.3 An overview of the research procedure

Field work was undertaken to collect the two types of benefit information. One group of information was used to measure direct forest product benefits from CFs and the other group of information was used to calculate the environmental benefit value of CFs. For direct forest product benefits, two types of questionnaires were implemented. One questionnaire was used to collect information related to environmental benefits. In addition, some secondary sources was also used when information from primary sources were inadequate. Figure 5.1 depicts an overview of the entire data collection and analysis process. Each component of Figure 5.1 is detailed in the following sections.




*Note*. DFO is District Forest Office.

**Figure 5.1 An overview of data collection and analysis processes**

## 5.4 Research sites

This study was undertaken in *Makawanpur* and *Kavrepalanchwok* districts of the Middle Hills (MH) region of Nepal. Figure 5.2 depicts the location of the two districts. The MH region forms the major central belt and occupies about 30% of the country. A large number of the CFs so far handed over lie in the MH. According to Sharma (2009), about 74 % of Nepal's CFs are located in the MH.

*Makawanpur* and *Kavrepalanchok* districts were selected, firstly, because they have practiced CFM for more than two decades. The long practice of CFM provides a suitable site to analyse and to compare, the production performance of CFs. The two districts have similar social, cultural and economic characteristics and follow similar forest management practices. (Adhikari, 2006; District Forest Office, 2008).

Secondly, the researcher was previously involved in various CFM activities in these two districts. This helped to establish good rapport with CFUG members and government forestry staff, which facilitates easy accessibility to information. Many authors have also noted the positive role of a rapport between a researcher and participants in the data collection process (Glesne, 1989; Heltberg, 2001; Johnson & Turner, 2003).

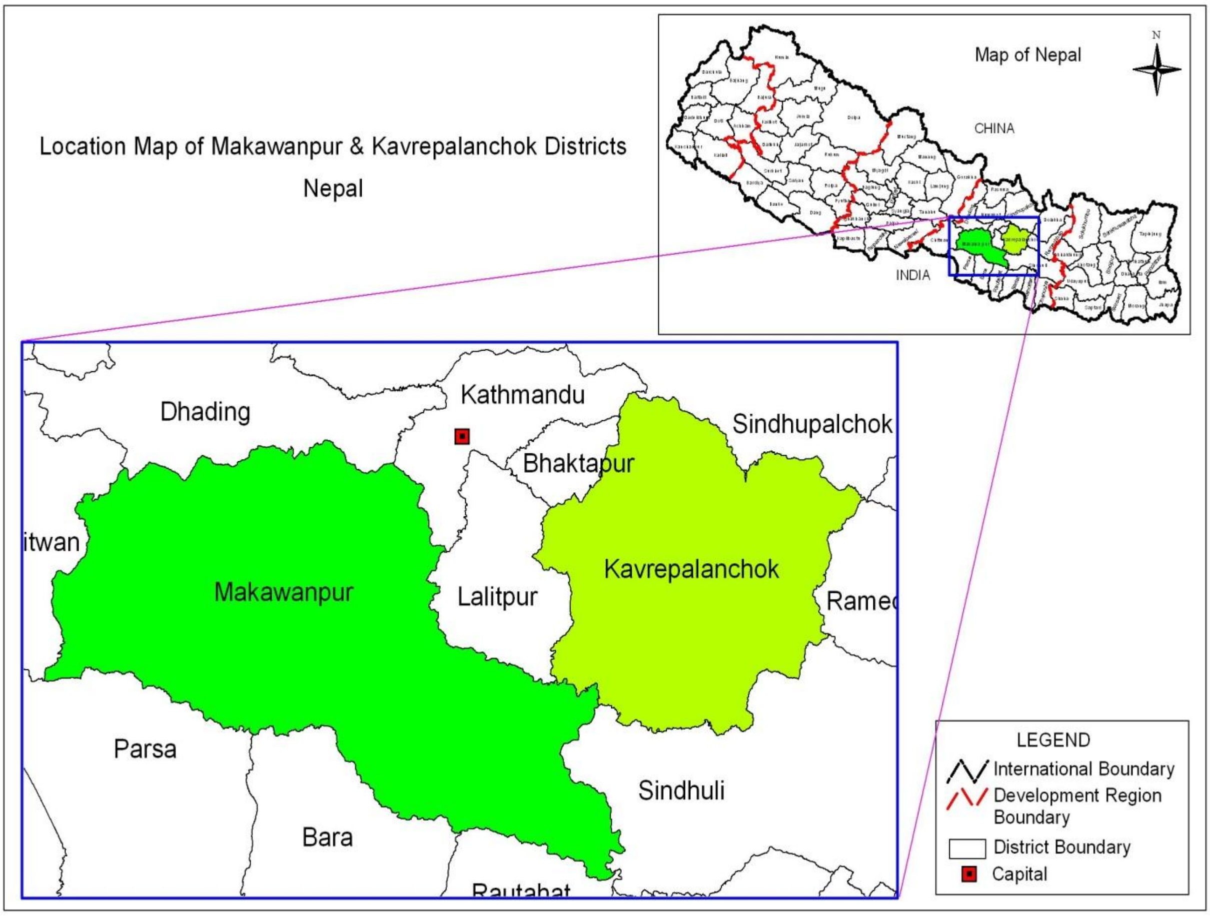



**Figure 5.2 Map of research sites**

## 5.5 Selection of sample community forests

Sampling is a process of selecting an appropriate specimen from an entire population. Broadly, there are two types of sampling design; random sampling and non-random sampling. Random sampling refers to the selection of specimens such that each specimen has an equal chance of being selected. Non-random sampling refers to the selection of specimens following pre-decided criteria, hence each specimen does not have an equal chance of being selected.

Quantitative research generally follows a random sampling design whereas qualitative research often follows a non random sampling design (Jennings, 2001). However, because of constraints, such as budget and time, even quantitative research often uses non-random sampling (Helfand & Levine, 2004; Sharma & Leung, 1998; Siry & Newman, 2001). According to Punch (2005), the choice of sampling method is largely decided by the research objective and research questions. If research questions require representativeness, some form of random sampling design can be used. On the other hand, if the research questions require comparisons between groups or relationships between the variables then some form of non-random sampling is more appropriate (Punch, 2005). This is because non-random sampling allows selection samples in a way that it increases the chances of observing relationships between the variables. There are various forms of non-random sampling, such as convenience sampling, snowball sampling, expert sampling, quota sampling and purposive sampling (Jennings, 2001).

In this study, non-random purposive sampling was used. Purposive sampling involves the researcher making a decision about what kind of sample units to include in the study (Jennings, 2001). There are two reasons for using purposive sampling for this study. First, the objective of the study is to examine the production performance of CFs and this involves an analysis of relationships between various kinds of theoretically relevant variables. Hence, it was essential to select a sample which contains the characteristics related to theoretically relevant variables.

Second, limited time and budget was available for the field work, so only a small number of samples was possible. With random sampling there is a chance of selecting samples that have a limited range of characteristics relevant to this research, weakening the validity of results. Agrawal (2002) suggested purposive sampling where common pool resources are involved, because it is easy to implement and it precisely looks at the theoretically relevant variables. Several studies have demonstrated that small sample size is justifiable if sample units are purposively selected. For example, Misra & Kant (2004) selected only fifty joint forest management units in India to analyse production efficiency.

Considering the budget and time available for fieldwork, sixty CFs were purposively selected to include a broad range of forest attributes and community characteristics such as forest type, number of households involved, link to the market and distance to the government office. In the first instance, sample CFs were selected based on information which was easily obtainable from district forest office documents. However, district forest office documents do not provide sufficient information regarding social capital. In that case, representation of CFUGs having different social capital was approximated using expert advice provided by government forest staff.

## 5.6 Data collection approaches

The first stage of the empirical data collection involved a questionnaire survey conducted across various CFUGs. The data were collected from different sources.

### 5.6.1 Data sources

Primary data were collected by the researcher. Secondary data are those data which were collected by other researchers (Jennings, 2001). In this study, both primary and secondary data were collected. Primary data were collected through structured questionnaires. If data could not be obtained through these questionnaires, then data were collected from secondary sources. The secondary data were largely collected from CFUG forest management plans, CFUG constitutions, CFUG office records, and district forest office records. Two types of data – one related to the community and the other related to the forest were collected from both sources.

### 5.6.2 Data related to community

Many techniques are used to collect quantitative information. The key techniques include informal discussion, observation, semi structured questionnaires and structural questionnaires (Dhungana et al., 2004; Misra & Kant, 2004). In this study, structured questionnaires were mainly used to collect community related data. There are various reasons for choosing the structured questionnaire technique. Structured questionnaires yield better results than observations, if quantitative information is needed (Punch, 2005). Observation is preferable to gather information related to behavioural activities, and a semi-structured approach is more suitable for qualitative in-depth inquiry (Jennings, 2001). In addition, structured questionnaires reduce the chances of collecting unnecessary information because pre-planned questions prevent the researcher, as well as the respondents from going off track. A large body of studies pertaining to productivity analyses of agriculture and forestry have used structured questionnaires to collect information. For example, Misra & Kant (2005) have employed structured questionnaires to collect the information related to outputs and inputs of joint forest management in India. Dhungana et al. (2004), and Battese et al. (1996) have employed structured questionnaires to collect information related to inputs and outputs of household agriculture production.

The structured questionnaire used for this study contained a number of sections. The sections were related to socioeconomic information, such as number of households, number of households in different economic, spatial and social classes, and demand and supply of different forest products. The full questionnaire appears in **Appendix B**. Some information, such as demand and supply of forest products, was difficult for CFUG members to recall from previous years. Therefore such information was gathered from CFUG forest management plans and office records. A separate questionnaire was used to collect information related to social capital and the full questionnaire is in **Appendix C**. The upper section of Table 5.1 provides a short description of the types of information related to communities and their sources gathered by using the both questionnaires which are in **Appendices B** and **C**.

**Table 5.1 List of information collected and sources**

| Information | Unit | Information sources |
|---|---|---|
| 1. Related to community: | | |
| Direct forest product benefits | NRs | Q |
| Time since CF establishment | Years | Q |
| Distance to the government forest office | Kilometres | Q |
| Link to the market | 0 or 1 | Q |
| CFUG status in terms of : | | Q |
| Trust and solidarity | Likert scale | |
| Collective action | ″ | |
| Stability | ″ | |
| Social cohesion & inclusion | ″ | |
| Number of households by; | Integer | Q/SS |
| Social classes | ″ | |
| Economic classes | ″ | |
| *Spatial classes* | ″ | |
| Number of households | Integer | Q/SS |
| Forest product dependency | 0 to 1 | Q/SS |
| Support from government staff | 0 or 1 | Q |
| Number of executive members in different caste classes | Integer | Q/SS |
| 2. Related to the forests | | |
| Area of CF | ha | SS |
| Growing stock | $m^3$/ha | FO/SS |
| Forest types | Conifer or broadleaf or mixed | Q/FS |
| Forest crown coverage | Percentage | Q/FS |
| Forest development stage | Mature or immature | Q/FS |
| Forest canopy layers | One or multiple layers | Q/FS |

*Note*; NRs= Nepalese rupees, Q = Questionnaire, FS= Field survey, SS= Secondary source.

### 5.6.3 Data related to forest attributes

Information related to forest attributes was collected using a questionnaire and direct measurement in the forests. Simple random sampling method was not adopted because establishing and measuring random plots in mountainous terrain is a difficult task. Sample plots were established systematically along a transect line chosen to represent different attributes of the forest. The number of plots varying from four to twelve was decided based on the variability of forest attributes. Forest attributes, such as forest crown coverage, development stage, forest type, and canopy layers were recorded in each plot. The bottom section of Table 5.1 shows the measured forest attributes and their sources.

### 5.6.4 Data to calculate environmental value of CF

The ANP is used to measure the environmental benefits of CFs. The ANP requires pairwise comparisons between forest services and forest attributes to derive their ratio-scale priorities. The services used here are soil conservation, water conservation, wildlife conservation and aesthetic value, and are referred to as ecosystem services (ESs). Further discussion of how these were selected is in Section 5.6.4.4. Based on the ratio scale priorities, the environmental benefits of a particular CF were able to be calculated. To implement the ANP method a separate questionnaire was used, which included questions for pairwise comparisons. Box 5.1 depicts a sample of ANP questions. The way the ANP questions were asked will be explained in a later section. A question such as 1 estimates priority weights for forest services. A question such as 18 measures interaction between forests attributes. Similarly, a question like 49 measures the dependency between the forest services. These priority weights are fit into a super matrix as explained in Section 4.4.3. The super matrix allowed calculating priority weights for each forest services and forest attribute, which are later used to calculate the environmental benefits of individual CF. The full ANP questionnaire appears in **Appendix D**.

**Box 5.1 Sample of ANP questions**

1. For environmental benefits of community, which of the following forest services is important, and what is the degree of importance?

| Benefits | Tick (√) one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Soil conservation<br>Wildlife conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wildlife conservation<br>Aesthetic value | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

18. Given that a forest is dense (> 70%), what number of canopy layers is more important for the soil conservation benefit of a forest, and what is the degree of importance?

| Canopy layer | Tick (√) one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

49. Given that water conservation is provided by a mixed forest, which of the following benefits is more important for the overall environmental value of a forest, and what is the degree of importance?

| Benefits | Tick (√) one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Soil conservation<br>Wildlife conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

#### *5.6.4.1 ANP questionnaire development*

After reviewing the literature on ANP method and forest ecosystem services, the ANP questionnaire was developed. Forest attributes and environmental services which are policy relevant and easily collectable were included. The questionnaire was first developed in English and later translated into Nepali to make it understandable for CFUG members. Initial pretesting of the ANP questionnaire was undertaken with the Lincoln University Nepalese community. Before administrating the questionnaire, pretesting was carried out in Nepal to ensure the questions were understandable to the subjects of the research (Collins, 2003; Hunt et al., 1982). Government staff and CFUG members participated in pretesting, resulting in modifications to make the questionnaire more understandable to community members.

#### *5.6.4.2 Data collection technique*

Several techniques can be used to gather ANP information such as Delphi, postal survey, personal interview and panel discussion (Erdogmus et al., 2006). All these techniques have some merits and demerits and preference over any technique is largely determined by appropriateness of a particular technique for the case under consideration. Table 5.2 depicts different survey techniques used in information collection for ANP studies and their merits and demerits.

**Table 5.2 Merits and demerits of different survey techniques**

| Techniques | Complexity | Time taken | Addresses inconsistency? |
|---|---|---|---|
| Delphi | Complexity may arise due to several rounds of iterations. | Takes a long time to reach a conclusion. | Iterative process enables panel members to change their opinions. |
| Postal survey | Easy to execute. | May take a long time if the postal service is poor. | Possibility of inconsistency in pairwise comparisons. |
| Personal interview | Difficulties for respondents in trading off criteria and alternatives instantly. | Takes a short time, but depends on number of interviewers required. | Possibility of inconsistencies while doing pairwise comparisons, but can be resolved. |
| Group discussion | Difficulty in gathering respondents for discussion with their busy schedule. | Takes a short time. | Inconsistencies in pairwise comparison among criteria and alternatives can be detected and resolved while having discussion. |

Sources: Chan et al., (2001), Duke & Aull-Hyde (2002) and Oddershede et al. (2007).

A Delphi survey is a group facilitation technique, which transforms individual opinions into group consensus (Powell, 2003). In the Delphi technique, questionnaires are sent to the participants, and a high level of response is desirable to reach a conclusion. A low response rate and any dropout in the middle of the process may make the process complex (Hasson et al., 2000). The iterative nature of the process generates new information and renders the opportunity for panel members to change their opinions. The use of several rounds of interaction among the panel members, needed to come to agreement, can make this technique time consuming (Chan et al., 2001).

In the postal survey technique, questionnaires are sent to the respondents but it does not involve interaction among the respondents. Postal surveys are not appropriate in places where the postal service is not reliable, such as in remote Nepal. Data gathered by postal survey may not be reliable if the respondents have no knowledge of the ANP process beforehand. Respondents need to have some understanding of the ANP network and priority scale before answering the questions (Khan & Faisal, 2008).

Personal interviews through questionnaires could be another possible technique to collect the information. However, this technique requires that the individual respondent be well acquainted with ANP. It has been noticed that respondents felt difficulties in trading off among criteria and alternatives when ANP questions related to pairwise comparisons were asked to individual respondents (Duke & Aull-Hyde, 2002; Lai et al., 2002). This problem could appear in this study if CFUG members were asked questions individually.

The group discussion technique involves interviewing several people simultaneously (Basch, 1987), and was used in this study for three reasons. First, this technique needs less time compared to Delphi, postal survey and personal interview techniques (Chung et al., 2005; Tran et al., 2004). Second, group discussion provides a forum to understand others' views and for participants to have a chance to review their own arguments and rectify them if desired (Oddershede et al., 2007). Hence, use of this technique can help to detect and resolve inconsistencies in pairwise comparison among forest attributes and services. Third, the variety of individuals in a group renders more valid outcomes than an individual provides, because different ideas are synthesised in group discussion (Saaty, 2005). Surowiecki (2005), after examining many cases, argued that a conclusion drawn from the combined views of the group is more accurate than a conclusion drawn from a single person's view. He further argues that "Under the right circumstances, groups of people can be remarkably intelligent and often smarter than the smartest people in them" (pp. xiii). However, a group works well only if there is good communication among the members, and there are rules to maintain order and coherence (Surowiecki, 2005).

#### *5.6.4.3 Selection of respondents*

Generally ANP seeks an expert's opinion to estimate the relative weights of decision alternatives, believing that the experts retain the systematic knowledge of the subject, and best judgments are likely to be revealed (Bayazit & Karpak, 2007; Gencer & Gürpinar, 2007; Leskinen & Kangas, 2005). However, Maharjan (2004) argued that selection of respondents should be based on the type of decision problem under consideration and the group of people likely to be affected by decision outcomes. For example, if the decision outcomes are likely to affect wider groups of people, such as policy makers, planners and farmers, then it is worthwhile to involve these groups of people in the decision making process (Matta et al., 2007; Oddershede et al., 2007).

Many ANP studies have involved a variety of stakeholders. For example, Khan & Faisal (2008) involved policy makers and managers in their study of solid waste disposal options. Duke & Aull-Hyde (2002) interviewed 149 *Dilware* residents to reveal their collective preference for agriculture and land preservation. Soma (2003) has involved stakeholders such as fisherman, inshore vessel owners, offshore vessel owners and managers to identify the priorities of relevant objectives, criteria and options for shrimp fishery management. These studies have involved stakeholders who would likely be affected by implementation of the policy.

Along the same line, in this study, groups of CFUG members were interviewed to carry out pairwise comparison between different forest attributes and forest services. There are two main reasons for choosing CFUG members as the source of opinion instead of forestry experts. First, CFUG members are the main actors of forest management and they are directly affected by forest management activities (Gilmour & Nurse, 1991). Second, Nepalese society is socially and economically heterogeneous and this has resulted in variation in forest management and perceptions toward the environment. Therefore, instead of interviewing only a few forestry experts, interviewing diverse groups of forest users incorporated CFUGs' opinions regarding values for forest attributes and forest services.

CFUGs were recruited for interviews through government staff. They were instructed to ensure representation from a broad spectrum of the community. Community members representing gender, executive committee, and ethnic classes and ordinary members, were present at the interviews. Numbers of CFUG members attending the interviews varied from six to fourteen. Figure 5.3 shows group discussions in two typical CFUGs.

**Figure 5.3 Principal researcher during group questionnaire**

#### *5.6.4.4 Selection of forest services and forest attributes*

This study calculates the environmental benefit value of each CF based on forest attributes and forest ESs. Table 5.3 shows the types of forest services, forest attributes and their corresponding levels which were used to calculate the environmental benefit value of CFs.

**Table 5.3 Forest services, forest attributes and levels of attributes**

| Ecosystem services | Forest attributes | Levels of attributes |
|---|---|---|
| Soil conservation<br>Water conservation<br>Wildlife conservation<br>Aesthetic value | Forest types | Broad leaf<br>Coniferous<br>Mixed |
| | Forest canopy coverage | Dense (> 70%)<br>Moderately dense (40-70%)<br>Open (10-40%) |
| | Canopy layers | One layer<br>Multi layers |
| | Development stages | Mature<br>Immature |

Even though a CF supplies a wide range of forest ESs, only four types of services were selected. The selected forest ESs were easily understandable to users and have livelihood impacts.

***Soil conservation service*** is related to the protection of top soil from erosion. In this study, the soil conservation service is protection of soil in CFs and areas surrounding, where forest user group members reside.

***Wildlife conservation service*** is the suitability of the CF for the wildlife which are known to the forest users. CFs are becoming favourable for wildlife habitat with the improvement in forest quality (Dongol et al., 2002). Wildlife habitat conservation value is measured from the forest user's perspective only.

***Water conservation service*** is related to the availability of water throughout the year from natural streams inside and around the CF. CFUGs are benefiting from water sources with improvement in crown coverage in CFs (Lawrence et al., 2007).

***Aesthetic value*** of a CF means the satisfaction that forest users derived from the beauty of a forest. CFUGs are taking advantage of CFs in the form of aesthetic value.

Likewise, based on the research literature and government documents, four types of forest attributes and their different levels were chosen (see Box 5.2 for description) (Maharjan, 1998; Ministry of Forests and Soil Conservation, 2000). Simplicity and policy implications were the main criteria for choosing forest attributes and their levels.

Box 5.2 Description of forest attributes

1. *Forest types*: Three types of forest were differentiated, and were based on the structural features.
   - *Broadleaf forest:* A forest containing more than 60% of broad leaf species.
   - *Coniferous forest:* A forest having more than 60% of coniferous species.
   - *Mixed forest:* A forest containing both broadleaf and coniferous trees is termed a mixed forest.
2. *Development stage:* It is difficult to estimate the exact age of the forest; therefore, the development stage of forest is classified into two stages; mature forest and immature forest.
   - *Immature forest:* A forest is called immature if the median diameter at breast height (dbh) is less than 40 cm for *Sal* forest and less than 30 cm for other forest.
   - *Mature forest:* A forest is called mature if the median dbh of the forest is more than 40 cm for *Sal* forest and 30 cm (at dbh) for other species.
3. *Crown coverage:* Percentage of the ground, which is covered by vertical projection of the outermost perimeter of the natural spread of the foliage of plant. It is measured for dominant trees only. In Nepal, crown coverage is classified into three groups: dense crown if crown coverage is >70%, moderately dense crown if crown coverage is in between 40-70% and open crown if crown coverage is < 40%.
4. *Canopy layers:* Layers of vegetation formed by trees of different ages or sizes. In this study canopy layers are classified into two types. Those are one layer and multi-layers canopies.

#### 5.6.4.5 *Analytic network process model*

The ANP model represented in Figure 5.4 was used to identify priority weights for ESs and forest attributes. The model indicates all dependencies and direction of influences among forest attributes and ESs. In Figure 5.3 "environmental value of CF' represents the overall objective of the network. The sets of ESs and forest attributes represent the two different clusters. Figure 5.4 shows that the environmental value of a forest depends on the value of four ESs. At the same time, four ESs are interdependent, which is represented by a loop. The value of an individual ES is determined by different forest attributes and their levels. The impact of an individual forest attribute depends on its combination with other attributes: that is, forest attributes are outer dependent. The outer dependency is represented by two headed arrows (Figure 5.4).

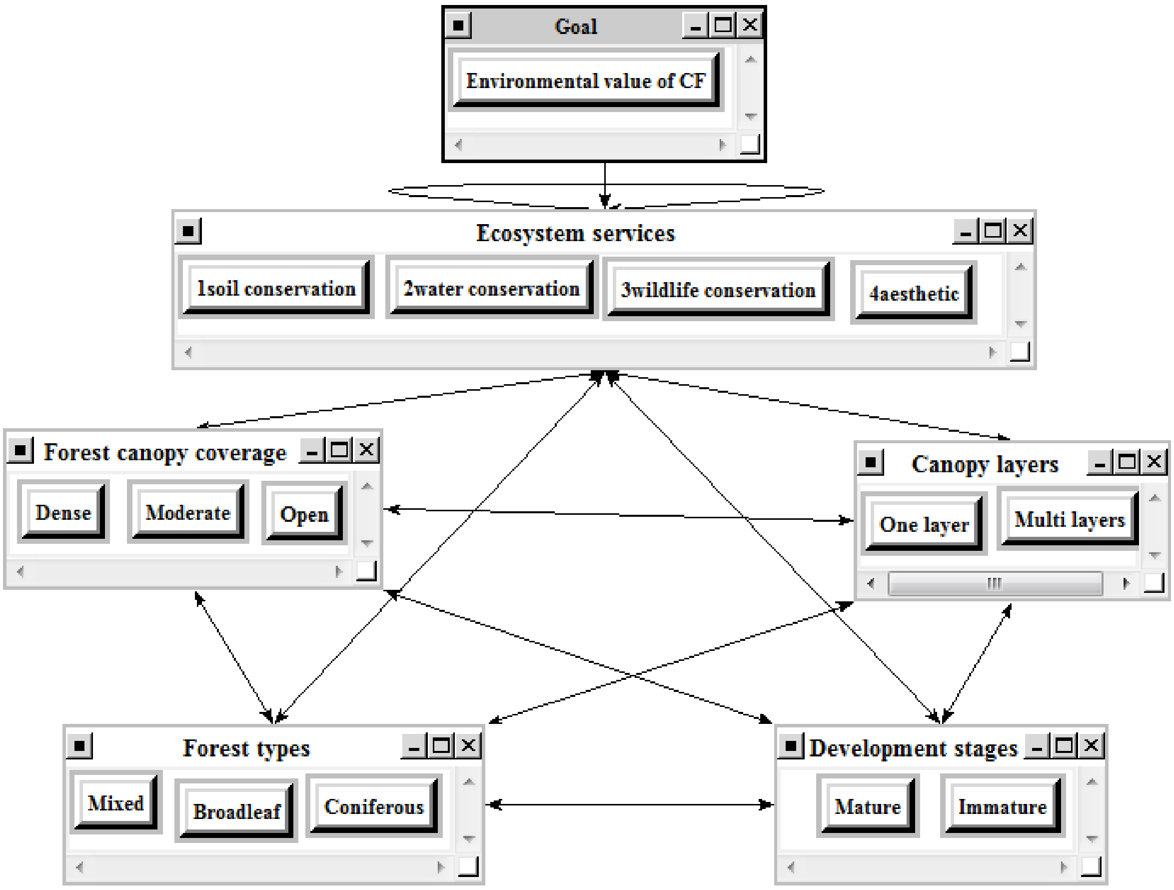



**Figure 5.4 ANP model from ANP Super Decisions Software**

#### 5.6.4.6 *Data collection procedure*

Before asking CFUG members the ANP questions, an A3 size poster of a forest network model was presented to conceptualise the relationships between forest attributes and forest ESs. A forest network model is presented in Figure 5.5.

The upper part of the figure illustrates the link between forest attributes and ESs and the lower part illustrates types of forest attributes. Along with the forest network model, a poster of a nine-point scale was also presented (Table 4.1). Various examples were presented to explain the concept of a pairwise comparison and the application of the scale ranging from 1 (the two choice options are equally preferred) to 9 (one choice option is extremely preferred over the other). One of them was comparing the taste of two varieties of apples and to state the relative taste preference on the nine point scale.

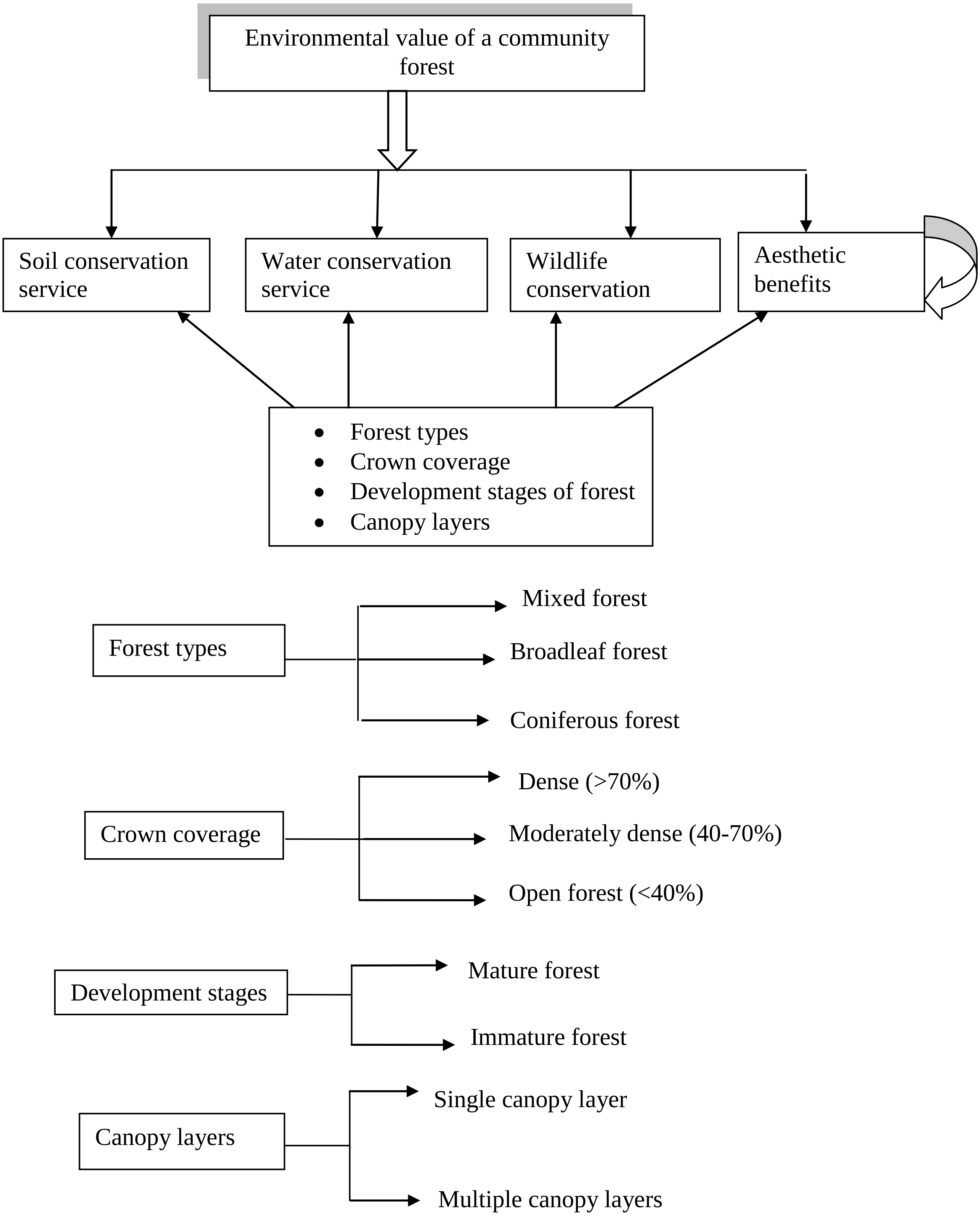



**Figure 5.5 Forest network model used to conceptualise the relationships between forest attributes and ecosystem services**

Once the groups were comfortable with the concept of the network model and the 9-point scale, they were asked the ANP questions such as given in Box 5.2. First, the CFUG members were asked to make pairwise comparisons and then they were asked to state the relative importance of the preferred element based on the 9 point scale. All the information related to the pairwise comparisons was recorded in a questionnaire **(Appendix D)**. First entire sets of questions were handed over to the group members to have a close look at. In order to make the questions more understandable to the groups, questions were also presented on A3 size paper. In addition, various types of visual aids, such as photographs showing different types of forest and the different development stages of forests, were used whenever a group felt unclear about the different forest attributes (Figure 5.6).

Top (left): Immature forest: Top (right): Broadleaf mature forest: Bottom: Coniferous forest

**Figure 5.6 Photographs used to illustrate the type and development stage of a forest**

If large numbers of pairwise comparisons have to be made, the pairwise comparisons and the respective degree of importance scores, may not be consistent throughout (see Section 4.4.2.1

for detail). To this end, if a very unacceptable[5] level of inconsistency was encountered in pairwise comparisons, the groups were informed about the inconsistency. Most groups acknowledged the inconsistencies and revised their judgements accordingly. Various authors have suggested repeating pairwise comparisons if unacceptable level of inconsistencies are observed (Kangas, 1993; Ramanathan, 2001). Despite these efforts to reduce inconsistencies, it was not possible to eliminate inconsistency. An acceptable level of inconsistency was obtained upon aggregating comparison matrices. Duke & Aull-Hyde (2002) also observed an acceptable level of inconsistency by aggregating comparison matrices even though the majority of the 129 individual comparison matrices, were not of an acceptable level of consistency.

Each pairwise comparison and the associated degree of importance were decided on the basis of consensus, but in some cases group members stated their individual judgment. The individual judgements were recorded and later aggregated using the geometric mean (Khan & Faisal, 2008), which is less affected by extreme values than other aggregation methods, such as the arithmetic mean (Aull-Hyde et al., 2006). In some CFUG, a tendency for executive committee and higher caste members to answer most of the questions was observed. This tendency was mitigated by the interviewer directing questions to other members.

## 5.7 Data description and analysis

### 5.7.1 Direct forest product benefits

Benefits from CFs for forest users were assessed by valuing the commodities collected from forests. Despite the fact that there are many potential forest products, mainly information on timber, fuelwood, fodder, litter and grasses were collected. Timber and fuelwood were collected only during the dry season of the year which ranges from December to June. Fodder, litter and grass were collected year around. CFUGs have regulated the harvesting of timber and fuelwood and they harvest only the quantities stipulated in the forest management plan. In contrast, many forest user groups allow unrestricted collection of fodder, litter and grasses. In most of the cases, CFUG members did not have to pay for fuelwood, fodder, litter and grass which were collected freely by individual households. However, since timber harvesting involves large labour costs, the executive committee organises the collection of timber and distributes the timber among users according to demand. Generally timber and fuelwood were

[5]Pairwise comparisons were considered very unacceptable when CFUG members expressed contradictory views. For example, first they preferred broadleaf forest over pine forest, and then preferred mixed forest over pine forest, but at the next instance, if they preferred mixed forest over broadleaf forest, then it was called unacceptable inconsistency.

sold in the markets, if the quantity of these products was more than that required by the community.

Forest products such as fuelwood (in some cases), fodder and litter were not exchanged in formal markets, hence prices for these products were unknown. Therefore, a non-market approach, contingent valuation, was used to approximate the value of these forest products. CFUG members were asked to state their willingness to pay for one head load[6] of fodder, fuelwood, grass and litter. However, the gate price was gathered for timber. The willingness to pay value was based on group discussion. A value rendered from group discussion minimises the variation due to attributes of individual respondents. The group allows individuals to amend their pre-existing value of goods. It has been argued that groups of people can provide the value of public goods in terms of their own utility as well as in terms of widely accepted social values (Sagoff, 1998; Wilson & Howarth, 2002). Many other studies have also applied group willingness to pay to estimate the value of non market forest products (Appanah & Baral, 2009; Karky & Skutsch, 2009; Neupane et al., 2002).

### 5.7.2 Environmental value of CF using ANP

The ANP method was used to calculate preference weights for forest attributes based on their contribution to different forest services. Various types of software packages are used to implement ANP, however the most often used are Expert Choice™ (Ananda & Herath, 2003; Matta et al., 2007; Mau-Crimmins et al., 2005) and Super Decisions (Aragonés-Beltrán et al., 2008; Gencer & Gürpinar, 2007). This study used Super Decisions software, which can handle dependence and feedback relationships among decision elements (Aktar Demirtas & Ustun, 2009). Moreover, the software is free for academic purposes (http://www.superdecisions.com). Expert Choice™ is mostly used for business purposes, and it is only available commercially.

Each forest has different forest attributes, hence aggregation of preference weights of forest attributes does not reflect the relative environmental value of forest compared to another CF. Therefore, based on the preference weights of forest attributes, the normalised environmental value of each CF was calculated, which varies between 0 and 1. A normalised value of 1 indicates the forest provides maximum environmental value and a value of 0 indicates least environmental value. The normalised environmental value ($EV_{normalised}$) of a CF is calculated using the following equation:

$$EV_{normalised} = (EV_{raw} - EV_{\min}) / (EV_{\max} - EV_{\min}) \quad (5.1)$$

[6] One head load; fuelwood= 40kg, fodder =25kg, litter=20kg, grass= 20kg.

$EV_{raw}$ represents the total raw environmental value score of a forest, which was obtained by summing up the preference weights of its attributes. $EV_{min}$ represents a possible minimum environmental value of a forest, and was calculated by adding up the preference weights of forest attributes which carry minimum values or were least prioritised. $EV_{max}$ represents the maximum possible environmental value of a forest. $EV_{max}$ was calculated by summing up the preference weights of forest attributes which carry maximum values or were highly prioritised. A number of other MCDA studies have also used Equation (5.1) to calculate the normalised value score of an entity based on preference weights of its attributes (Chung et al., 2005; Hajkowicz, 2008; Neaupane & Piantanakulchai, 2006). Normalised environmental value score allows comparison between CFUGs.

### 5.7.3 Socio-economic data

Socioeconomic data includes information related to both factors of production and determinants of production efficiency. Rudimentary data from the socioeconomic questionnaire survey were entered into Excel, which was used for data cleaning, and data coding. Variables such as forest type, longevity of the CF, and distance to the government office were directly recorded from the questionnaire. The values of variables such as group heterogeneity, forest dependency and social capital were calculated from their proxies or numbers.

#### *5.7.3.1 Input variables for stochastic production frontier*

The expected sign, unit of measurement and short description of the theoretical input variables used for the stochastic production frontier model, are given in the middle section of Table 5.4. The upper section of Table 5.4 describes the two outputs which have been explained in Section 5.7.1 and 5.7.2. The input variables are described in detail in the following section.

***Link to the market***

Link to the market was measured by whether a CF sells forest products in the market or not. It was expected that links with the market would enhance the economic activities inside a community, increasing production in the CF (Kant & Lee, 2004; Misra, 2004). Links to the market was measured in a dichotomous form, a link to the market represented by 1, otherwise 0.

**Table 5.4 Description of the variables**

| Variables | Expected sign | Description | Unit of measurement |
|---|---|---|---|
| *Outputs* | | | |
| Direct forest products benefits | NA | Sum of economic value of different forest products. | Nepalese Rupees (NRs)/ha |
| Environmental value index | - | Aggregated environmental value of forest based on CF attributes. | 0 to 1 |
| *Factors of production* | | | |
| Link to the market | + | If forest products are sold in the market = 1, 0 otherwise. | 0 or 1 |
| Distance to the government forest office | - | Distance to government forest office. | Km |
| Area of CF | - | Area of forest managed by community. | Hectares (ha) |
| Group heterogeneity;<br>• Social<br>• Economic<br>• Spatial | - | Average of three types of heterogeneities. | 0 to 0.67 |
| Forest product dependency | + | CFUG dependence on forest products. | 0 to 1 |
| Number of households | + | Number of households using the CF resources. | Number |
| *Determinants of production efficiency* | | | |
| CF longevity | + | The time elapsed since a CF was handed over to community | Years |
| Social capital ;<br>• Trust and solidarity<br>• Collective action<br>• Stability<br>• Social cohesion & inclusion | + | Mean of four components of social capital. | 5 point Likert scale |
| Growing stock of CF | + | Density of forest product in forest. | $m^3$/ha |
| Support from government staff | + | CFUG receives support =1, 0 otherwise. | 0 and 1 |
| Caste heterogeneity in Executive committee | - | Executive members in different caste classes. | 0 to 1 |

*Note;* NA= Not applicable.

### *Distance to the government forest office*

The government's District Forest Office and its range posts are responsible for managing public forests in the district. Distance to the government office was considered to affect production positively, because several studies related to community based management, have indicated that proximity to the government office creates favourable conditions for collective management (For example, Agrawal & Chhatre, 2006; Edmonds, 2002). A map used to estimate the distance to these government offices, but measurement from a map only indicates aerial distance. Distance to the range post from each CF was estimated using questionnaire, because community members calculate the distance to the government office considering total surface distance.

### *Area of community forest*

Area of CF measures the size of forest which was handed over to the community. Forest laws and by-laws have no restriction over the individual size of CFs handed over. However, the number of households relying on a forest, the management capacity of forest users and the distance between the forest and the village, typically determines the size of a CF. Various earlier studies have reported that large forest size often produced less output per unit (Carter, 1984; Misra & Kant, 2004). Therefore, it was expected that there would be a negative relationship between production and the forest size in CFs. Area is measured in hectares.

### *Group heterogeneity*

Following Adhikari & Lovett (2006) and Poteete & Ostrom (2004) there are three sources of heterogeneity; spatial, economic and social, and were used in this study. Each CFUG's heterogeneity index was calculated by aggregating three types of heterogeneities. For spatial heterogeneity all the households were divided into three location classes (< 0.5 km, 0.5-1 km and > 1 km from the CF) based on the distance of each CFUG member's house from the CF. Economic heterogeneity was calculated based on the grouping of households into three economic classes (poor, medium and rich). The District Forest Office and the CFUGs have set the criteria for economic classification. According to criteria, households having more than 0.75 ha of land, being almost food self sufficient, having permanent monthly income sources were considered 'rich'. Households with 0.25-0.75 ha of land, have more than 6 months food self sufficiency and households with off farm income sources are considered 'medium'. Households with less than 0.25 ha of land, have less than 6 months food self sufficiency and who are labourers employed by other households are classified as 'poor'. Caste composition was used as an indicator of social heterogeneity. It was calculated by grouping households into three caste categories (*Brahman/Chhetri, Janjati and Dalit*) (Varughese & Ostrom, 2001). *Brahman/Chhetri* are generally considered a privileged caste group, compared to *Janjati and Dalit*. All three heterogeneities were calculated individually using Equation (5.2) (Todaro & Smith, 2006)

$$A_k = 1 - \sum (P_{ik})^2 \qquad i=1,\ 2,\ 3 \tag{5.2}$$

$A_k$ represents the heterogeneity index $k$ and $P_{ik}$ represents the proportion of CFUG members in each class $i$ for index $k$. In essence, $A_k$ measures the probability that any two individuals from a CFUG will not be from the same group (Gautam, 2007). To derive the overall heterogeneity index all $A_k$'s were averaged;

$$\text{Overall heterogeneity} = \frac{1}{3}\sum_k A_k \tag{5.3}$$

Theoretically, the value of heterogeneity varies between 0 and 1. Zero indicates that a community is homogeneous. That is, all community members have the same status in terms of social, economic and spatial diversity. On the other hand, a value of 1 indicates the extreme heterogeneity. However, a value of 1 is possible only if there are infinite categories with equal representation of each category. As the number of categories increases, the maximum value of the index score also increases. This study used three categories in each type of heterogeneity; hence the maximum value of heterogeneity is 0.67. Following Ostrom (1990), it is assumed that social, economic and spatial heterogeneities affect the interaction among community members, resulting in higher transaction costs and consequently affecting production in a negative way.

***Forest products dependency***

Dependence of the CFUG on the CF was measured in terms of the fraction of the total requirement for each product, that is being met from the CF. Dependence varies between 0 and 1. Zero indicates that the community does not receive any forest products from the CF, and 1 indicates that the community receives its entire forest product requirement from the CF. CFUG forest dependence is the arithmetic mean dependency for individual forest products. It was expected that higher dependency of forest users on CFs may result in the higher withdrawal of forest products from forests (refer to Section 2.5.3).

***Number of households***

The number of households is the number of families who use the forest resources and take part in CF management activities. The number of households involved was recorded, which is a good proxy for labour inputs (Misra & Kant, 2004). Much literature has highlighted the idea that group size improves collective action in community managed resources, (refer to Section 2.5.1), and therefore it was expected that the value of forest products would increase as the number of households increases.

#### *5.7.3.2 Model and variables for explaining production efficiency*

This study was not only aimed at ranking CFs according to efficiency, but also aimed at identifying factors causing differences in efficiency. Choice of factors explaining the differences in efficiency is contested. Viitala & Hanninen (1998) argued that performance of an organisation is determined by internal and environmental factors. Therefore, these factors should be regressed with efficiency variation to identify their influence. The internal factors include employee characteristics (knowledge and skills), motivational factors and organisational factors, and the environmental factors are socio economic features of client, geographical position of organisation and climatic conditions. According to Binam et al. (2004), the factors, which are under the control of a firm should be regressed with efficiency difference. They claimed that a firm should be able to manipulate the factors; only then firm can achieve improvement in the efficiency scores. Murillo-Zamorano (2004) have claimed that the factors must be able to introduce heterogeneity in the analysis and should not be highly related with the factors used in frontier estimation procedure. According to Worthington & Dollery (2000) inputs, which are under management's control such as labour, capital and equipment are included in computing the efficiency score. The factors not under management's control are regressed with the efficiency score in the second stage. Carter & Siry (2003), taking a case of forest management, argued that efficiency difference is generally caused by the factors such as 'geographical location, demographic and social condition, ownership, market structure, uncertainty, regulatory policies, managerial experience, training and environmental condition'. Coelli et al. (2005) have stated that efficiency is influenced by the environment in which the production takes place, and they categorised environment variables into stochastic variables (for example, type of firm ownership and age of the labour force) and non-stochastic variables (for example, weather condition). These arguments show that there is no consistent criteria regarding factors to be included in computing efficiency differences.

However, embracing the arguments suggested by Coelli et al. (2005) and Carter & Siry (2003), this study recognised that time of CF establishment, social capital of CFUG, growing stock, support from government staff and caste heterogeneity in executive committee may be potential factors influencing efficiency difference in CF. The expected sign, the unit of measurement and a short description of the theoretical variables for production efficiency in an explaining model, are given in the lower section of Table 5.4. The variables are described in detail in the following section.

***Community forest longevity***

CF longevity is measured by the number of years CFM has been practiced. CF longevity is related to forest management knowledge and skills. Previous studies have documented that knowledge and skills help to improve resource use (Carter & Siry, 2003; Lindara et al., 2006). Hence, it was hypothesised that CF longevity affects the production efficiency positively.

***Social capital***

Grootaert et al. (2002) and Van Ha et al. (2006) identified four components of social capital. They are trust and solidarity, collective action, stability and social cohesion and inclusion. These components were used to calculate the social capital index of CFUGs. The social capital index was calculated by averaging indices of social capital components.

The index for each component of social capital was measured in terms of variables included in it. Categorical responses were used to measure the variables, which were later converted to number scale. Based on the number scale index value for each component was calculated. In the next step, the value of each component was scaled to a range from 0 to 100 and then the arithmetic mean was divided by 20 to produce an index with a maximum value of 5 (Grootaert & Narayan, 2004; Grootaert et al., 2002).

Box 5.3 Questions related to the social capital

1. **Stability and social cohesion of CFUGs**

    1.1. How frequently do the rules changed?
    a. Very frequently b. Occasionally c. Changed only if needed

    1.2. How frequently are executive committee meetings held?
    a. Once in a month c. Occasionally b. Whenever required

    1.3. How are the decisions made by the executive committee?
    a. By consensus b. By voting c. Unilaterally

    1.4. How frequently does the general assembly meeting takes place?
    a. Once in a year b. Twice a year c. As and when required

Box 5.3 illustrates the stability component of social capital and variables under it. Four variables were used to measure the stability component. Each variable of the stability component were measured in terms of three categorical responses. These responses were changed into a three point scale. If the value of the stability component is 2.6 then its scaled value would be 86.7. Dividing this component value by 20 would give an index value of 4.3 for stability and social cohesion component. It was essential to avoid highly correlated (r>0.9) and uncorrelated (r=0) variables. Therefore, factor analysis was carried out to identify the most important variables, and to avoid highly correlated and uncorrelated variables (Onyx & Bullen, 2000). The social capital index was measured in 5-point Likert type scales. It was believed that social capital affects positively, CF production efficiency (refer to Section 2.5.2).

***Growing stock volume***

Growing stock measures the above ground standing volume of a forest. It was measured in $m^3$/ha. Higher growing stock volume is related to the condition of forest. A higher growing stock volume in a forest indicates that the forest has the potential to supply more forest products such as timber, fuel wood and fodder. Therefore a higher growing stock is expected to have a positive association with production efficiency (Carter & Siry, 2003).

***Support from government staff***

Government staff provide support to all CFUGs whilst developing their constitution and forest operation plan. However, only a few CFUGs receive support after hand over, mainly because of a CFUG seeks support or their forest requires specialist measurement or because the CFUG has personal links to government staff (Thoms, 2008). The main supports were; measuring forest products, providing training to the CFUG members and making links to the markets. The support was measured in a dichotomous form. That is, if government staff provide support then the variable has a value of 1, otherwise 0. Earlier studies have reported that government support helps to reduce transaction costs thereby increasing production efficiency (Lindara et al., 2006; Rehman & Romero, 1993); therefore it was hypothesised that support from government staff enhances CF production efficiency.

***Caste heterogeneity in the executive committee***

An executive committee (EC) is the main decision making body in the CFs. This study believes that caste heterogeneity in ECs influences production. Caste heterogeneity in the ECs was calculated in the form of an index whose value varies between 0 and 1. A value of 0 represents a committee with all its members being the same caste, and 1 indicates that different castes are represented in the EC. Since this study has used three groups of castes the maximum possible value of the index is 0.67. Many authors have argued that heterogeneity induces differences in interests and as a result reduces cooperation among the members, thereby hindering collective action (Naidu, 2005; Thoms, 2007; Varughese & Ostrom, 2001). Hence, it was believed that heterogeneity in ECs will have a negative impact on CF production efficiency.

### 5.7.4 Production analysis

Of the many models available for production analysis, the SFM was judged to be appropriate for this study for two main reasons. First, SFM allows separation of inefficiency components from overall error components to be estimated. Second, since this model applies statistical theory to estimate production efficiency, further validity testing regarding the parameters of SFM is possible (Chen, 2007). A Cobb-Douglas production function represented by the Equation (3.25) was used to estimate production. The CD functional form is widely used in agricultural production analyses in both developing and developed countries (Kompas, 2004; Lindara et al., 2006; Tadesse & Krishnamoorthy, 1997). In addition, some work suggests that the choice of functional form might not have a significant impact on the measured efficiency level (Ahmad & Bravo-Ureta, 1996).

### 5.7.5 Production efficiency ranking

Monte Carlo simulation was used to identify the efficiency ranking of individual CFUGs. According to the simulation procedure, if an individual CF should be the best in terms of the efficiency rank, its efficiency value must be better than all others (Jensen, 2000). In the Monte Carlo experiment, efficiency of CFUGs, was compared in pairs and probability estimated, such that a randomly drawn efficiency score of a particular CFUG exceeded the randomly drawn efficiency of other CFUGs in 10,000 draws. A particular CFUG is said to be more efficient than another, the probability of that particular CFUG exceeding the efficiency of another CFUG is greater than 95%. For example, there are two CFUGs A and B. If the probability of a randomly drawn efficiency score of A exceeding the randomly drawn efficiency score of B is more than 95% in 10,000 draws, then A is considered more efficient than B. An example of a Monte Carlo simulation experiment used in this study is in **Appendix E**.

### 5.7.6 Model explaining efficiency ranking variation

The ordered logit model was used to identify the factors of (in)efficiency because CFs were grouped based on their efficiencies (Lu, 1999). Following Greene (2002), an ordered logit model of the following form was used;

$$y^* = x'\beta + \varepsilon$$

and $y = \begin{cases} 2 \text{ if the CF is a member of the most efficient group} \\ 1 \text{ if the CF is a member of the moderately efficient group, and} \\ 0 \text{ if the CF is a member of the least efficient group,} \end{cases}$

where $y^*$ is the unobserved or latent dependent variable, $x'$ is a vector of independent variables, $\beta$ is a vector of regression coefficients and $\varepsilon$ an error term.

## 5.8 Limitations

There are several limitations in this study. First, there was limited time and budget. A larger sample would have been better. However, the large size of the sample unit (the community as a whole), the sparse distribution of communities and the difficult terrain have constrained the number of communities surveyed.

Second, in production efficiency analysis, a panel data set is usually preferred to either a time series or cross-sectional data set (Coelli, 1995; Kalirajan & Shand, 1999). Panel data minimise sampling error and allow identification of reasons behind variations in production (Kalirajan & Shand, 1999). However, due to poor data recording systems in CFUGs, panel data or time series were not available. Therefore, cross sectional data, with one set of observations for each community, were collected.

Third, some communities may have reported incorrect information. For example, Iversen et al. (2006) observed that some CFUGs were reluctant to disclose their economic transactions because of 'rent seeking behaviour'. To improve reliability, information was verified from district forest office records.

ANP required a relatively large set of questions. It is generally acknowledged that ANP questions are often difficult to understand, particularly questions related to interaction effects (Dyer, 1990; Oeltjenbruns et al., 1995; Wolfslehner et al., 2005). Therefore, visual aids such as posters and photographs were used to make the questions more clear. Misunderstanding of the questions may have led to invalid inferences. In addition, to my knowledge, this was possibly the first attempt to use ANP among rural people; most previous ANP studies have been applied among experts, and this may have caused some error in the preference weights of forest attributes.

## 5.9 Summary

This chapter has discussed the methodology of the study. Since production efficiency entails interactions of various kinds of variables associated with forests and communities, a quantitative approach to inquiry was used. Information was collected using questionnaire surveys about communities and field surveys for forest attributes.

The *Kavrepalanchwok* and *Makawanpur* districts were selected as study sites because the districts have a long history of CF management and they represent the majority of CFs in Nepal. The ANP method using Super Decision software was used to calculate the environmental value of CFs. A SFM was used to investigate the production efficiency of CFs using the LIMDEP 9.0 Econometric software. A Monte Carlo simulation was used to identify the efficiency ranking of individual CFUGs. An ordered logit model was employed in order to find the determinants of efficiency ranking. The next chapter will report on outcomes of data gathering and data analysis.

# Chapter 6
# Results

## 6.1 Introduction

Chapter five identified the methodologies used to empirically investigate the research problems. This chapter reports the outcomes of the study. The information is analysed in relation to the research questions of this thesis.

The first section of this chapter presents results on outputs and socio economic information. The second section describes estimation of stochastic production frontier for direct forest product benefits. The last section presents the production efficiency of CFUGs and factors determining production efficiency rankings.

Out of the initial sample of 60 CFs, only 57 were analysed. Three CFs were omitted from the data set as two of them produced extremely high values of direct forest benefits, casting doubt on the data, and the data for the third one was incomplete. The following paragraphs describe the results of socio-economic and environmental-related data analysis.

## 6.2 Outputs of the community forests production process

Two types of aggregate outputs were considered in this study. One is the direct benefits obtained from consumption of forest products and the other is the indirect benefits provided by forest ESs.

### 6.2.1 Direct forest product benefits

Direct forest benefits include products such as fuelwood, timber and fodder that are collected directly from CFs. Table 6.1 shows the quantity of different direct forest products collected in each CFUG in one year. Huge variation in yield was recorded for litter, fodder and grass. For example, the highest recorded collection for litter was by Bhotekhola CFUG, which collected 1429 bhari of litter per hectare. The next highest reported yield was 655 bhari per hectare by Betkholsi CFUG. CFUGs did not regulate litter collection, and CFUG members were allowed to collect as they required. The quantity of these forest products collected largely depends on the number of livestock in a community, and forest type. Fodder and litter from broadleaf forest are more useful than from coniferous forest. All CFUGs collected timber except Mahila Srijana CF, because the forest had not matured to a stage where it could yield timber.

## Table 6.1 Yield (per hectare) of different direct forest products from CFs

| SN | CF | Area (ha) | Timber | Firewood | Fodder | Grass | Litter |
|---|---|---|---|---|---|---|---|
| 1 | Bageshari | 221.0 | 3.0 | 27 | 90 | 23 | 32 |
| 2 | Bajrabarhi | 45.6 | 4.6 | 131 | 0 | 0 | 244 |
| 3 | Balkumari | 9.0 | 163.5 | 42 | 0 | 0 | 333 |
| 4 | Baluwabharreng | 106.0 | 11.5 | 109 | 257 | 150 | 231 |
| 5 | Banaskhandi | 93.3 | 5.9 | 41 | 78 | 0.0 | 96 |
| 6 | Bansgopal | 204.5 | 4.0 | 29 | 35 | 0.0 | 0.0 |
| 7 | Basuki | 17.4 | 31.6 | 10 | 0 | 301 | 313 |
| 8 | Betkholsi | 37.5 | 9.5 | 29 | 0 | 0.0 | 655 |
| 9 | Bhagawan thumki | 28.7 | 4.5 | 17 | 0 | 139 | 522 |
| 10 | Bhairabkali | 216.0 | 0.5 | 31 | 0 | 62 | 259 |
| 11 | Bhotekhola | 32.2 | 12.7 | 6 | 0 | 0.0 | 1429 |
| 12 | Bhutan devi | 16.7 | 20.3 | 60 | 0 | 0.0 | 0 |
| 13 | Bungdal | 63.1 | 12.6 | 38 | 8 | 43 | 137 |
| 14 | Chakradevi | 160.8 | 10.9 | 32 | 19 | 15 | 6.2 |
| 15 | Chhanauta | 316.9 | 8.7 | 36 | 49 | 4 | 46 |
| 16 | Chhilli bans | 18.2 | 5.4 | 142 | 0.0 | 210 | 293 |
| 17 | Chhitrepani | 143.3 | 9.4 | 45 | 75 | 502 | 188 |
| 18 | Chuchekhola | 238.0 | 13.2 | 25 | 80 | 0.0 | 945 |
| 19 | Chulipran | 110.5 | 1.1 | 45 | 0 | 187 | 104 |
| 20 | Chunnidevi | 21.7 | 6.9 | 0 | 0 | 0.0 | 505 |
| 21 | Churekalilek | 425.0 | 5.8 | 37 | 100 | 51 | 49 |
| 22 | Dangdunage | 194.4 | 5.1 | 104 | 111 | 111 | 162 |
| 23 | Dhaneshwar | 42.2 | 5.9 | 33 | 0 | 71 | 99 |
| 24 | Dipat | 148.0 | 15.8 | 169 | 135 | 0 | 0 |
| 25 | Dovan khola | 64.0 | 14.0 | 62 | 0 | 0 | 312 |
| 26 | Ektare | 58.6 | 2.5 | 61 | 26 | 8.5 | 17 |
| 27 | Gosaikunda | 46.2 | 3.7 | 27 | 0 | 0.0 | 14 |
| 28 | Hariyali | 463.0 | 13.3 | 58 | 65 | 65 | 0 |
| 29 | Jarungshakti | 203.0 | 9.4 | 74 | 148 | 74 | 69 |
| 30 | Jyoti | 295.9 | 6.2 | 12 | 115 | 34 | 117 |
| 31 | Kalabanzar | 322.0 | 0.2 | 38 | 6 | 5 | 5 |
| 32 | Kalika | 12.6 | 7.9 | 8 | 0 | 143 | 0 |
| 33 | Kalika chandika | 896.7 | 1.0 | 22 | 17 | 11 | 12 |
| 34 | Kalika hariyali | 315.5 | 9.2 | 89 | 49 | 95 | 33 |
| 35 | Kalilek | 435.7 | 5.7 | 6 | 5 | 0.7 | 48 |
| 36 | Kotthumki | 125.0 | 1.9 | 14 | 0 | 0.0 | 136 |
| 37 | Laljhadi | 155.0 | 2.8 | 7 | 21 | 19 | 39 |
| 38 | Lother | 67.3 | 6.9 | 87 | 94 | 42 | 30 |
| 39 | Mahila srijana | 44.0 | 0.0 | 11 | 238 | 310 | 170 |
| 40 | Manakamana(Mana | 220.2 | 9.4 | 118 | 41 | 31 | 82 |
| 41 | Mangleshar | 198.0 | 2.1 | 25 | 0 | 0.0 | 50 |
| 42 | Mankamana(Gadi) | 133.7 | 13.0 | 246 | 246 | 246 | 295 |
| 43 | Namuna | 74.0 | 11.3 | 77 | 348 | 348 | 348 |
| 44 | Navalpur sarswati | 234.2 | 14.9 | 35 | 38 | 26 | 19 |
| 45 | Newreni chisapani | 72.2 | 10.7 | 44 | 170 | 41 | 41 |
| 46 | Parbati mahila | 85.6 | 10.3 | 46 | 43 | 69 | 0 |
| 47 | Patleshar | 47.0 | 1.1 | 12 | 0 | 0.0 | 145 |
| 48 | Rani | 151.9 | 13.1 | 42 | 92 | 39 | 165 |
| 49 | Resheswar | 468.0 | 3.2 | 64 | 0 | 107 | 418 |
| 50 | Saradidevei | 44.5 | 2.8 | 67 | 0 | 0.0 | 76 |
| 51 | Shikaribas | 66.0 | 17.9 | 164 | 251 | 251 | 251 |
| 52 | Siddhakali | 87.3 | 3.8 | 1 | 0 | 0.5 | 174 |
| 53 | Simpani devkot | 358.4 | 11.2 | 41 | 28 | 0.0 | 59 |
| 54 | Soltu | 79.7 | 0.3 | 60 | 0 | 0.0 | 120 |
| 55 | Subhlaxmi | 184.5 | 7.0 | 117 | 255 | 200 | 68 |
| 56 | Sundar | 109.5 | 12.8 | 18 | 19 | 18 | 196 |
| 57 | Thakaldanda | 49.4 | 12.2 | 101 | 0 | 315 | 630 |

*Note.* Timber is measured in cubic feet per hectare and all other forest products are measured in Bhari/ha. Quantity of timber includes both Sal timber and others.

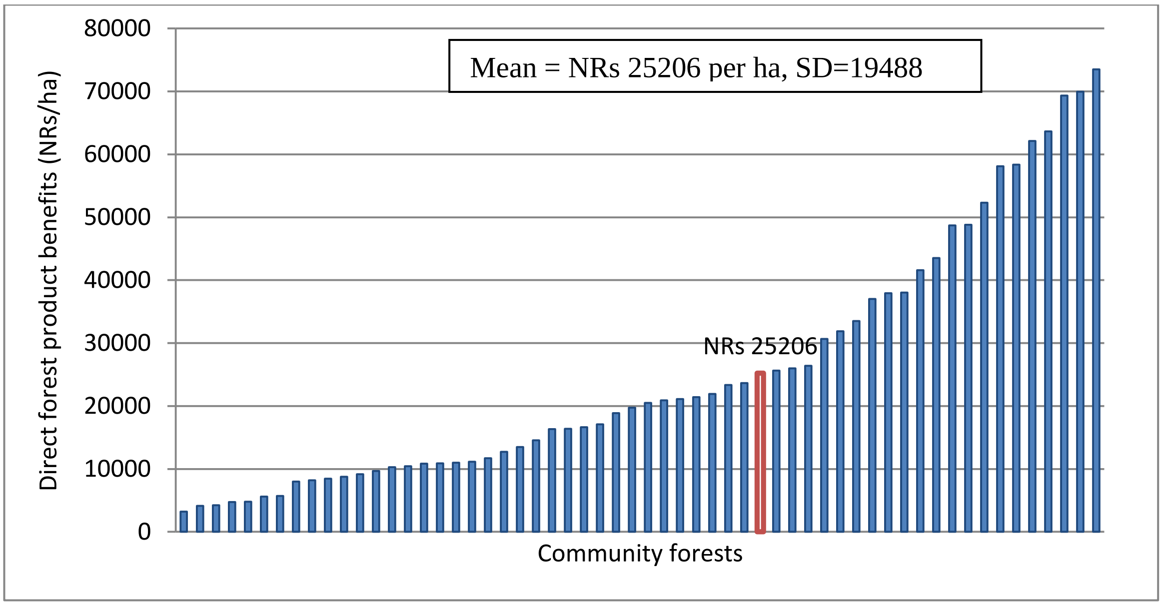
The prices and quantities of the direct forest products are measurable, hence direct benefits are derived from product prices and quantities. CFUGs have different prices for different forest products. Table 6.2 shows simple average prices for different forest products as stated by CFUGs. Identical simple average prices for direct forest products were applied uniformly across all CFs.

**Table 6.2 Average product prices for forest outputs**

| Forest products | Unit of measurement | Price (in NRs per unit) | Min | Max |
|---|---|---|---|---|
| Timber | Cubic feet (cft) | 263.20 ( for Sal timber) | 256 | 290 |
| | | 63.10 (for other timber) | 60 | 68.5 |
| Fuelwood | Bhari[7] | 83.80 | 40 | 180 |
| Fodder | Bhari | 59.50 | 30 | 150 |
| Litter | Bhari | 50.50 | 20 | 120 |
| Grasses | Bhari | 63.90 | 25 | 150 |

*Note*. 1 US $ =76.00 Nepalese Rupees (NRs) [August 2009, source: http://www.ekantipur.com/np/)

Using the prices for forest products, the value of direct forest product benefits was calculated for individual CFUGs. The direct forest product benefits for individual CFUG are shown in Figure 6.1. The value of direct forest product benefits in the sampled CFs shows wide variations. Benefits from direct forest products range from NRs 3,210 to NRs 73,523 per hectare.




Note. NRs= Nepalese rupees, SD= Standard deviation.

**Figure 6.1 Direct forest products benefits for individual CFUGs**

[7] Bhari resembles head load, 1 bhari fuel wood= 40kg, 1 bhari fodder= 25 kg, 1 bhari litter= 20 kg and 1bhari grass= 20 kg.

The average value of forest product benefits in Table 6.3 was calculated based on the prices shown in Table 6.2 and quantities shown in Table 6.1. Litter/grass contributed the highest value, followed by fuelwood, and other forest products such as fodder and timber (Table 6.3).

**Table 6.3 Average contribution of different forest products to total benefits**

| Forest products | Timber | Fuelwood | Fodder | Litter/grass | Total |
|---|---|---|---|---|---|
| Average income (NRs/ ha/year) | 2688 | 4555 | 3498 | 14464 | 25206 |
| Percentage contribution to total income | 11 | 18 | 14 | 57 | 100.00 |

*Note.*1US$= 76.00 Nepalese rupees [August 2009, source: http://www.ekantipur.com/np/)

Fuelwood, fodder and litter/grass contribute substantially to the wealth of the communities. Previous studies had singled out timber as the main contributor to CFUGs' incomes (Gebremedhin et al., 2003).

### 6.2.2 Environmental benefits value

Along with direct forest products, CFs produce various ecosystem services. Like forest products, these services also contribute to the livelihood of forest users. The value of forest products which are directly consumed was estimated using their respective prices. However, the environmental value of a CF is not straightforward as many ESs are produced together and they are not exchanged in the market. This study used the ANP technique to estimate the environmental benefits of CFs (see Section 5.7.2 for detail). ANP involves the estimation of environmental values of CFs based on the preference weights of ESs and forest attributes.

#### *6.2.2.1 Preference weights of forest ecosystem services and forest attributes*

Environmental values of CFs were calculated based on the communities' preference weights over different ESs and forest attributes. Table 6.4 elucidates the communities' relative preferences over ESs and forest attributes. These relative preference weights were derived by averaging individual CFUG's preference weights for forest attributes and ESs. Individual CFUG weights are presented in **Appendix F**. Communities assigned the highest priority to soil conservation service, followed by water conservation and wildlife conservation. The aesthetic service was least valued.

**Table 6.4 Average preference weights for forest services and forest attributes (N=57)**

| Variables | | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| *Ecosystem services* | | | | | |
| Soil conservation | | 0.40 | 0.05 | 0.29 | 0.47 |
| Water conservation | | 0.35 | 0.05 | 0.23 | 0.48 |
| Wildlife conservation | | 0.13 | 0.04 | 0.06 | 0.32 |
| Aesthetic value | | 0.12 | 0.04 | 0.06 | 0.21 |
| *Forest attributes* | | | | | |
| Canopy layers | Multi layers | 0.20 | 0.01 | 0.16 | 0.22 |
| | One layer | 0.05 | 0.01 | 0.03 | 0.08 |
| Development stage | Immature | 0.15 | 0.02 | 0.09 | 0.19 |
| | Mature | 0.09 | 0.02 | 0.06 | 0.15 |
| Crown coverage | Dense | 0.15 | 0.01 | 0.12 | 0.17 |
| | Moderate | 0.09 | 0.01 | 0.06 | 0.09 |
| | Open | 0.02 | 0.00 | 0.02 | 0.04 |
| Forest types | Broadleaf | 0.13 | 0.02 | 0.07 | 0.17 |
| | Coniferous | 0.04 | 0.00 | 0.02 | 0.03 |
| | Mixed | 0.09 | 0.02 | 0.06 | 0.15 |

Regarding the preference ranking for forest attributes which influence ESs, the study identified that forest crown cover was considered by the respondents to be the most important forest attribute (0.26), followed by canopy layers (0.25). However, forest types (0.24) and development stages (0.24) of forest were equally important. Within these attributes, multiple layers and dense crown cover were among the most important attributes for producing ESs. Conifer forest, open crown coverage and single layer forest produce fewer ESs. Average preference weights for forest attributes as indicated in Table 6.4 were used to calculate the environmental benefits value of an individual CF.

#### 6.2.2.2 Environmental benefits of community forests

As was discussed in Section 5.7.2, based on the average preference weights for forest attributes, the environmental value index was calculated for individual CFs. These are presented in Table 6.5. The results show that a broadleaved, dense, immature and multiple layered CF produced the highest environmental benefits ($EV_{normal}$ =1). On the other hand, one layered mature coniferous forest with moderate crown density generated the fewest environmental benefits ($EV_{nomal}$= 0.12). Only a few CFs performed well in terms of the production of environmental benefits.

**Table 6.5 Environmental value index for individual CFs**

| CF | Forest attributes related to CF | | | | Total raw environmental value score ( $E_{raw}$) | EV (normalised) ( $E_{norma}$= $(E_{raw} – E_{min})/(E_{max}* – E_{min}**)$ |
|---|---|---|---|---|---|---|
| | Forest type | Forest density | Canopy layers | Development stage | | |
| 5 | BL | D | ML | IM | 0.62 | 1.00 |
| 6 | BL | D | ML | IM | 0.62 | 1.00 |
| 11 | BL | D | ML | IM | 0.62 | 1.00 |
| 13 | BL | D | ML | IM | 0.62 | 1.00 |
| 18 | BL | D | ML | IM | 0.62 | 1.00 |
| 22 | BL | D | ML | IM | 0.62 | 1.00 |
| 26 | BL | D | ML | IM | 0.62 | 1.00 |
| 31 | BL | D | ML | IM | 0.62 | 1.00 |
| 35 | BL | D | ML | IM | 0.62 | 1.00 |
| 44 | BL | D | ML | IM | 0.62 | 1.00 |
| 48 | BL | D | ML | IM | 0.62 | 1.00 |
| 57 | BL | D | ML | IM | 0.62 | 1.00 |
| 47 | MF | D | ML | IM | 0.58 | 0.91 |
| 49 | MF | D | ML | IM | 0.58 | 0.91 |
| 14 | BL | D | ML | M | 0.57 | 0.88 |
| 16 | BL | MD | ML | IM | 0.54 | 0.82 |
| 33 | BL | MD | ML | IM | 0.54 | 0.82 |
| 38 | BL | MD | ML | IM | 0.54 | 0.82 |
| 39 | BL | MD | ML | IM | 0.54 | 0.82 |
| 42 | BL | MD | ML | IM | 0.54 | 0.82 |
| 43 | BL | MD | ML | IM | 0.54 | 0.82 |
| 1 | MF | MD | ML | IM | 0.50 | 0.72 |
| 20 | MF | MD | ML | IM | 0.50 | 0.72 |
| 25 | MF | MD | ML | IM | 0.50 | 0.72 |
| 29 | MF | MD | ML | IM | 0.50 | 0.72 |
| 52 | MF | MD | ML | IM | 0.50 | 0.72 |
| 4 | BL | MD | ML | M | 0.49 | 0.70 |
| 21 | BL | MD | ML | M | 0.49 | 0.70 |
| 24 | BL | MD | ML | M | 0.49 | 0.70 |
| 30 | BL | MD | ML | M | 0.49 | 0.70 |
| 37 | BL | MD | ML | M | 0.49 | 0.70 |
| 51 | BL | MD | ML | M | 0.49 | 0.70 |
| 53 | BL | MD | ML | M | 0.49 | 0.70 |
| 8 | BL | D | OL | IM | 0.47 | 0.65 |
| 45 | BL | D | OL | IM | 0.47 | 0.65 |
| 50 | BL | D | OL | IM | 0.47 | 0.65 |
| 56 | BL | D | OL | IM | 0.47 | 0.65 |
| 7 | C | MD | ML | IM | 0.44 | 0.58 |
| 10 | C | MD | ML | IM | 0.44 | 0.58 |
| 28 | BL | O | ML | M | 0.45 | 0.58 |
| 2 | MF | D | OL | IM | 0.43 | 0.56 |
| 9 | MF | D | OL | IM | 0.43 | 0.56 |
| 23 | MF | D | OL | IM | 0.43 | 0.56 |
| 12 | BL | MD | OL | IM | 0.40 | 0.47 |
| 46 | BL | MD | OL | IM | 0.40 | 0.47 |
| 19 | C | D | OL | IM | 0.37 | 0.42 |
| 17 | MF | MD | OL | IM | 0.36 | 0.37 |
| 15 | BL | MD | OL | M | 0.35 | 0.35 |
| 40 | BL | MD | OL | M | 0.35 | 0.35 |
| 55 | BL | MD | OL | M | 0.35 | 0.35 |
| 54 | MF | O | OL | IM | 0.31 | 0.26 |
| 3 | C | MD | OL | IM | 0.30 | 0.23 |
| 27 | C | MD | OL | IM | 0.30 | 0.23 |
| 32 | C | MD | OL | IM | 0.30 | 0.23 |
| 36 | C | MD | OL | IM | 0.30 | 0.23 |
| 41 | C | MD | OL | IM | 0.30 | 0.23 |
| 34 | C | MD | OL | M | 0.25 | 0.12 |

*Possible maximum environmental value ($E_{max}$) = 0.6207; **Possible minimum environmental value ($E_{min}$) = 0.1991
Coniferous forest= C, Broadleaf forest= BL, Mixed forest=MF; One layer =OL, Multiple layers=ML; Immature= IM, Mature= M

## 6.3 Factors influencing the production of direct forest products and environmental benefits

There are large numbers of factors which affect the production of direct forest products and environmental benefits in CFs. If the entire range of factors are included in the production analysis, the majority of CFs might exhibit an identical performance (Wagner & Shimshak, 2007). Considering this fact, this study has included only those factors which were relevant to policy decisions and were identified in common property resource management discourse. In addition, variables are included which are either fully or partially controlled by CFUGs. Prominent factors involved in the production of direct forest product benefits and environmental benefits of CFs, include socio-economic characteristics such as distance to the government forest office, CF size, links to the market, heterogeneity of the CFUG and forest products dependency of users. The following sections present a description of the factors considered in the production of direct forest product benefits and environmental benefits. A summary of the statistics of the factors are presented in Table 6.6.

**Table 6.6 Descriptive statistics of factors influencing production of direct forest product benefits and environmental benefits in CF (N=57)**

| Variables | Unit | Mean | SD | Min. | Max. |
|---|---|---|---|---|---|
| Distance to the government forest office | Km | 5.95 | 4.75 | 0.00 | 20.00 |
| Area of CF | Hectares | 159.28 | 157.89 | 9.00 | 896.75 |
| Link to the market | 0 or 1 | 0.30 | 0.46 | 0.00 | 1.00 |
| Heterogeneity of CFUG | 0 to 1 | 0.43 | 0.14 | 0.15 | 0.66 |
| Forest product dependency | 0 to 1 | 0.49 | 0.26 | 0.06 | 0.99 |
| Number of households | - | 250.79 | 178.57 | 31.00 | 890.0 |

Note. SD= standard deviation, Km = Kilometres, NRs= Nepalese rupees.

### 6.3.1 Distance to the government forest office

A physical distance from the government forest office was measured. The District Forest Office (DFO) is responsible for the management of most of the public forest lands. At the village level, Range Posts (RPs) have been established under the DFO. CFs are located at varying distances from the RPs. In this sample, the distances range from 0 to 20 km from RPs with a mean distance of approximately 6 km. Distance to the government office affects the flow of forest management related information. CFUGs located near the RPs receive the information more easily than CFUGs located far away. This is because the CFUGs located nearby do not have to travel far to get information. Close proximity to the RPs produce opportunities for the CFUG members to discuss informally, management related issues with government forest staff.

### 6.3.2 Area of community forest

Since the existing forest laws and by-laws have no restrictions over the individual CF size, it varies across CFUGs. Some CFUGs studied were relatively large and others were smaller. The largest CF was 896.75 hectares whereas the smallest was nine hectares. The majority of CFs were less than 200 hectares in size (Figure 6.2).

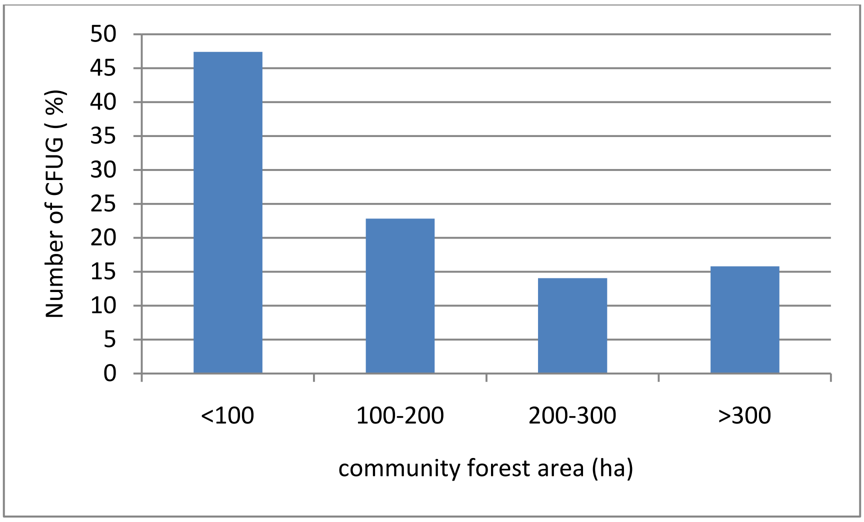



**Figure 6.2 Size of community forests**

### 6.3.3 Links to the market

Links to the market were measured depending on whether a CFUG sells forest products to the market or not. Only 30 % of CFs studied had links to the market, indicating a great proportion of CFUGs were far from the market. The production of direct forest product benefits was higher in the CFUGs which were linked to the market compared to the CFUGs which were not linked (Table 6.7).

**Table 6.7 Proportion of CFUGs linked to the market**

| Community forests | Number of CFs | % | Mean direct forest product benefits (NRs/ha) |
|---|---|---|---|
| Linked with market | 17 | 30 | 32968 |
| Not linked with market | 40 | 70 | 21908 |

Note. NRs= Nepalese rupees.

### 6.3.4 Heterogeneity of CFUG

An overall heterogeneity index was calculated by taking the average of social, economic and spatial categories. This heterogeneity index provides the maximum value of 0.67. The minimum and maximum values of CFs ranged from 0.15 to 0.66. This result shows that CFUGs were neither totally homogeneous nor heterogeneous. The distribution shows that the majority of CFUGs are relatively heterogeneous (coefficient of skewness =0.16) (Table 6.8).

**Table 6.8 Group heterogeneity index of CFUGs**

| Group heterogeneity index | Number of CFUG | % CFUG |
|---|---|---|
| 0.15-0.30 | 13 | 23 |
| 0.30-0.45 | 19 | 33 |
| 0.45-0.60 | 16 | 28 |
| >0.60 | 9 | 16 |

### 6.3.5 Forest product dependency

Forest product dependency was measured by the proportion of total forest product requirements forest users extract from their CFs. The result shows that the dependency varies from 0.06 to 0.99, indicating that some CFUGs were heavily dependent on their CF and others were not (Table 6.6). A higher value of dependency of CFUG members indicated that they have either fewer other sources for forest products such as trees on their own land or less capacity for substitutes such as buying cooking gas instead of fuelwood.

### 6.3.6 Number of households

The number of households involved in each CF was recorded. The Forest Act 1993 does not dictate the number of households that should be in any one CFUG. However, the government staff and local community members decide on the number of families to be included in a CFUG. The number of households in sampled CFs varied from 31 to 890 households. An analysis shows that CFUGs which had lower than 100 and higher than 300 households, generated higher direct forest product benefits (Table 6.9).

**Table 6.9 Household Numbers and Direct Forest Product Benifits**

| Number of households | Number of CFUGs | Mean direct forest product benefits ( NRs/ha) |
|---|---|---|
| 0-100 | 9 | 28659 |
| 100-200 | 19 | 21491 |
| 200-300 | 10 | 21854 |
| >300 | 19 | 29818 |

Note. NRs= Nepalese rupees.

## 6.4 Production frontier estimation

From the results above it can be summarised that CFUGs produce mainly two outputs; direct forest product benefits and environment benefits. It is expected that socio-economic factors such as the distance of CFs to the government office, the forest size, the links to the market, the heterogeneity of the CFUG, the forest product dependency and the group size, affect the production of the benefits. When multiple inputs are used to produce multiple outputs the stochastic output distance function is appropriate. However, the stochastic output distance function approach has complications in estimating production function (section 3.9.3.3). The transformation function, with one output on the left hand side and other outputs and inputs on the right hand side, avoids some complications associated with the stochastic output distance function (Felthoven & Catherine, 2004). The data envelopment analysis method also has many disadvantages in estimating production frontier (section 3.9.2). Hence in the next step, the stochastic production frontier model was used to estimate the effect of factors on the production of the benefits. Direct forest product benefits and environmental benefits were treated as outputs, and socio-economic factors were considered as inputs, or factors of production.

The SFM allows the estimation of relationships between direct forest product benefits and socio-economic factors, and considering environmental benefits as an input factor. In addition, the SFM permits an estimation of the production efficiency of CFUGs. However, SFM model estimation considers that composed error terms in the stochastic frontier production model are asymmetrically distributed (see Section 3.9.3.2). Therefore, in order to estimate SFM normality of composed error terms was tested.

### 6.4.1 Normality test

A stochastic production frontier model assumes that deviation in observed production from the best performance frontier, is comprised of statistical error and inefficiency components. Statistical error and inefficiency components are assumed to have normal and asymmetric distributions, respectively (see Section 3.9.3.2 for details). Because of different distributions for the two components, the residual terms have to be asymmetric.

The Jarque-Bera (JB) test was used to test normality (Gujarati, 2005; Misra, 2004). For this purpose, OLS residuals were estimated, considering direct forest products as outputs and socioeconomic factors as explained in Section 6.3 including environmental benefits, as inputs. The JB test statistic is zero if the residuals are normally distributed (Gujarati, 2005). Under the null hypothesis that residuals are normally distributed, the JB statistic, which is a chisquare distribution with 2 degrees of freedom, is 30.55 ($p < 0.005$) leading to the rejection of the normality assumption. In addition to the JB test, the Kernel density estimator was used to estimate the distribution of least square residuals (Greene, 2007). Figure 6.3 shows an asymmetrical distribution of the least square residuals. Because its positive tail is truncated, it implies the presence of technical inefficiency in the data (Kumbhakar & Lovell, 2000).

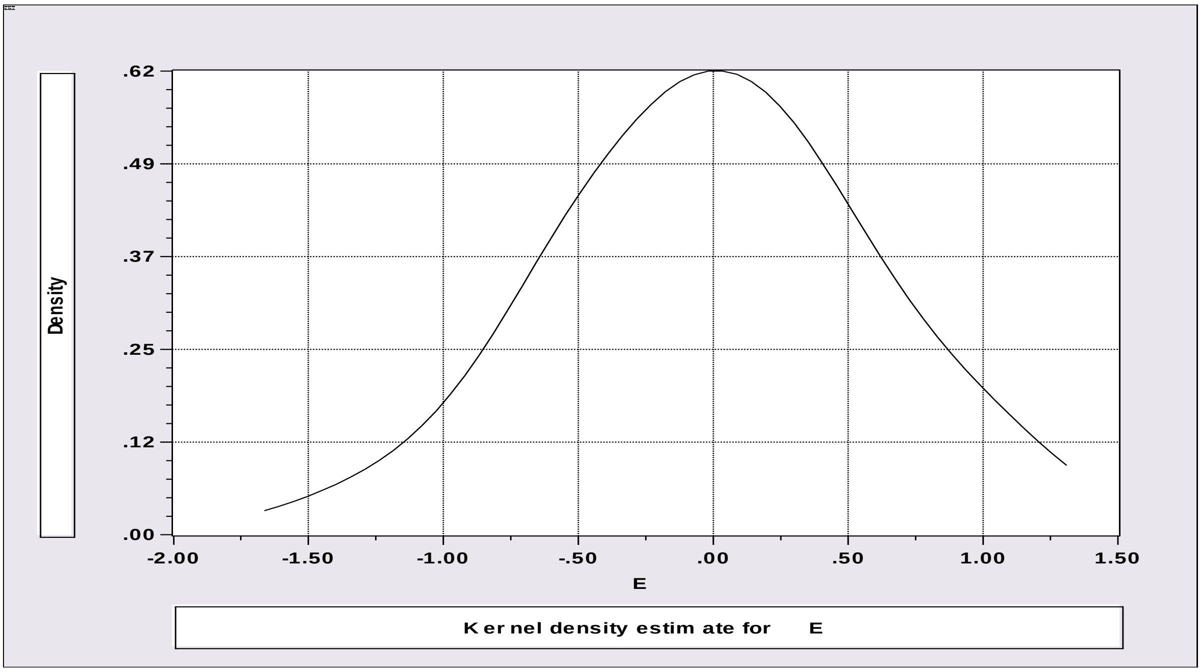



**Figure 6.3 Kernel density for least square residuals**

### 6.4.2 Functional form

Asymmetric distribution of the residuals indicated that the inefficiency component outweighs the error component, and thus it justifies the use of the stochastic frontier model for this data set. The next challenge was to specify an appropriate functional form to estimate a stochastic production frontier. An attempt to estimate the more flexible TL functional form failed. To test for multi-collinearity, correlation coefficient pairs for input variables were calculated (Hill et al., 1997). Only four input variables were free from strong linear association. The TL function which included these four variables did not identify a significant association between direct forest product and environmental benefits. A possible reason for multicollinearity is the relatively small sample size. Inclusion of second order and cross-terms restricts the degrees of freedom (Estache & Rossi, 2002). An alternative to TL, the CD functional form was found to fit better and was used to explain the production of direct forest product benefits. Other researchers, for example Siry & Newman (2001), also opted for the CD for the same reason.

Estimation of a stochastic frontier production function for cross sectional data requires explicit specification of the distribution of statistical noise and the inefficiency term. For the inefficiency term, several distributions have been considered in the literature. However, widely used distributions are half normal, truncated normal and exponential (see section 3.9.3.2). The estimated coefficients of parameters related to half normal, truncated normal and exponential inefficiency distributions for the Cobb Douglas model are reported in Table 6.10. Most coefficients are not significant for the truncated normal and exponential distributions, so these models are unable to estimate production efficiency. For instance, the value of θ in the exponential model is insignificant, indicating that inefficiency cannot be isolated from the random error term using this model. The extremely high value of λ in the truncated normal distribution model indicates that all the deviation from the best practice frontier is attributed to the inefficiency terms, and variation due to random error is very small. In this case, the model turns to a deterministic form (Kumbhakar & Lovell, 2000).

**Table 6.10 Comparison among parameters of stochastic production frontier model with three different distributional assumptions for the inefficiency term**

| Selection criteria | Half normal | Truncated normal | Exponential |
|---|---|---|---|
| $\lambda = \sigma_u / \sigma_v$ | 1.4651***<br>(0.5167) | 406.562<br>(23951.93) | NA |
| $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$ | 0.7497***<br>(0.0110) | 0.7389***<br>(0.2003) | 0.5379***<br>(0.1306) |
| θ | NA | NA | 14.0783<br>(69.7453) |
| μ | NA | 0.6091<br>(0.4156) | NA |
| $\sigma_u$ (=1/$\theta$ for exponential) | 0.6192<br>(NA ) | 0.7389<br>( NA) | 0.0710<br>(NA) |
| $\sigma_v$ | 0.4226<br>(NA) | 0.0018<br>(NA ) | 0.5560***<br>( 0.1088) |

*Note:* The notation ***, ** and * denote statistical significance at the 0.01, 0.05 and 0.10 levels respectively. Standard errors are in parentheses. NA stands for not applicable.

Lamda (λ) in the half normal specification is significantly greater than 1, indicating that inefficiency plays an important role in the residual, and suggests the application of the stochastic frontier approach to estimate the production efficiency of the CFUGs. A significant coefficient for $\lambda$ implies that there is some degree of inefficiency in production. In other words, on average, CFs are not using their resources efficiently. Hence, a half normal case has been found appropriate. Other academics such as Greeny (2002) also chose the half normal form because it performs well with the CD model. Cummins & Zi (1998) reported that efficiency rankings are consistent, regardless of the assumption for the inefficiency term. In addition, the principle of parsimony supports the use of the simpler half normal distribution (Kumbhakar & Lovell, 2000; Murillo-Zamorano, 2004).

### 6.4.3 Estimation of stochastic production frontier

As was discussed in Section 3.9.3.2 the stochastic production frontier model assumes an asymmetrical distribution for the composed error term. Asymmetrical distribution for the composed error term is desirable to estimate the production efficiency of an individual producer. ML might be preferred to OLS to estimate the production frontier model, because OLS produces only an 'average production function' (Bravo-Ureta & Pinheiro, 1997). To ensure the estimation of the production function is stochastic, ML estimation of the production function is compared with the OLS estimation. If the slope parameters estimated by ML and OLS are not equal then it confirms the underlying estimation of production function is stochastic and therefore allows estimating the production efficiency of an individual producer.

Following the above process, ordinary least squares (OLS) parameters were estimated for the CD model (Table 6.11). The model used direct forest product benefits (NRs/ha) as a dependent variable and socioeconomic, forest related factors and an environmental value index as independent variables. The model explains 52.98% of the variation in forest products benefits.

**Table 6.11 Ordinary least square estimate of the stochastic production function (Cobb-Douglas)**

| Variable | Coefficient | Standard error | t-ratio |
|---|---|---|---|
| Constant | 8.2583*** | 0.9754 | 8.4662 |
| Ln Distance to government office | -0.0688 | 0.0465 | -1.4796 |
| Ln CF area (ha) | -0.4909*** | 0.1237 | -3.9678 |
| Link to the market | 0.3600* | 0.1875 | 1.9205 |
| Ln Heterogeneity of CFUG | -1.1556*** | 0.2898 | -3.9870 |
| Ln Forest products dependency | 0.3860** | 0.1686 | 2.2893 |
| Ln Number of households | 0.6370*** | 0.1635 | 3.8956 |
| Ln Environmental value index | 0.4681*** | 0.1746 | 2.6807 |
| R-squared | 0.5298 | | |
| Adjusted R-squared | 0.4627 | | |

Note: ***, ** and * denote statistical significance at the 0.01, 0.05 and 0.10 levels respectively.

The maximum likelihood (ML) estimate of the stochastic production frontier considering direct forest products benefits as a dependent variable, is presented in Table 6.12. Under the normality assumption for composed error terms, the OLS and ML coefficients of the variables are equal (Gujarati, 2005). However, in this study the coefficients of variables estimated by OLS (Table 6.11) and ML (Table 6.12) are unequal, implying residuals are asymmetric and hence the stochastic production frontier will allow estimating of the production efficiency of CFUGs. Authors such as Tadesse & Krishnamoorthy (1997), Bravo-Ureta & Evenson (1994) and Siry & Newman (2001) have also used OLS function to test the normality of residuals.

**Table 6.12 Maximum likelihood estimate of stochastic production frontier (Cobb-Douglas)**

| Variable | Coefficient | Standard error | t-ratio |
|---|---|---|---|
| Constant | 8.7706*** | 0.9110 | 9.6272 |
| Ln Distance to government office | -0.0733* | 0.0429 | -1.7070 |
| Ln CF area (ha) | -0.5253*** | 0.1172 | -4.4840 |
| Link to the market | 0.4120** | 0.1776 | 2.3196 |
| Ln Heterogeneity of CFUG | -1.1041*** | 0.2674 | -4.1293 |
| Ln Forest products dependency | 0.4084** | 0.1598 | 2.5552 |
| Ln Number of households | 0.6713*** | 0.1535 | 4.3743 |
| Ln Environmental value index | 0.4361*** | 0.1650 | 2.6428 |
| Variance parameters for compound error | | | |
| λ | 1.4651*** | 0.5167 | 2.8354 |
| σ | 0.7497*** | 0.0110 | 68.1973 |

Note: ***, ** and * denote statistical significance at the 0.01, 0.05 and 0.10 levels, respectively.

The significant value of λ for the half normal distribution for inefficiency term for CD functional form suggests its appropriateness to estimating the production frontier for direct forest product benefits in CFs.

The stochastic production frontier in Table 6.12 demonstrates that socio-economic factors, as well as traditional input factors such as land, labour and capital have contributed significantly to CF production. CF size, heterogeneity and distance to the government forest office have negative effects on production. Links to the market, forest product dependency, and the number of households in the community are all significantly different from zero, and have the expected positive sign. A negative sign was expected for the environmental value index. One possible reason for the positive relationship is the congruence between forest attributes related to higher ESs and forest product production. This means that the forest attribute that forest users find to be suitable for higher ESs, is also found to be conducive for the production of forest products.

## 6.5 Production efficiency of community forest user groups

An estimate of the stochastic production frontier explained the functional specification for the production of direct forest products and the important factors. However, the stochastic production function alone does not provide much information regarding the performance of an individual CFUG. An estimation of production efficiency allows the comparison of individual CFUG efficiency, to the best practicing CFUG. Analysis of production efficiency has two components; one is to estimate the production efficiency of each CFUG and the other is to identify the factors which contribute to variation in production efficiency.

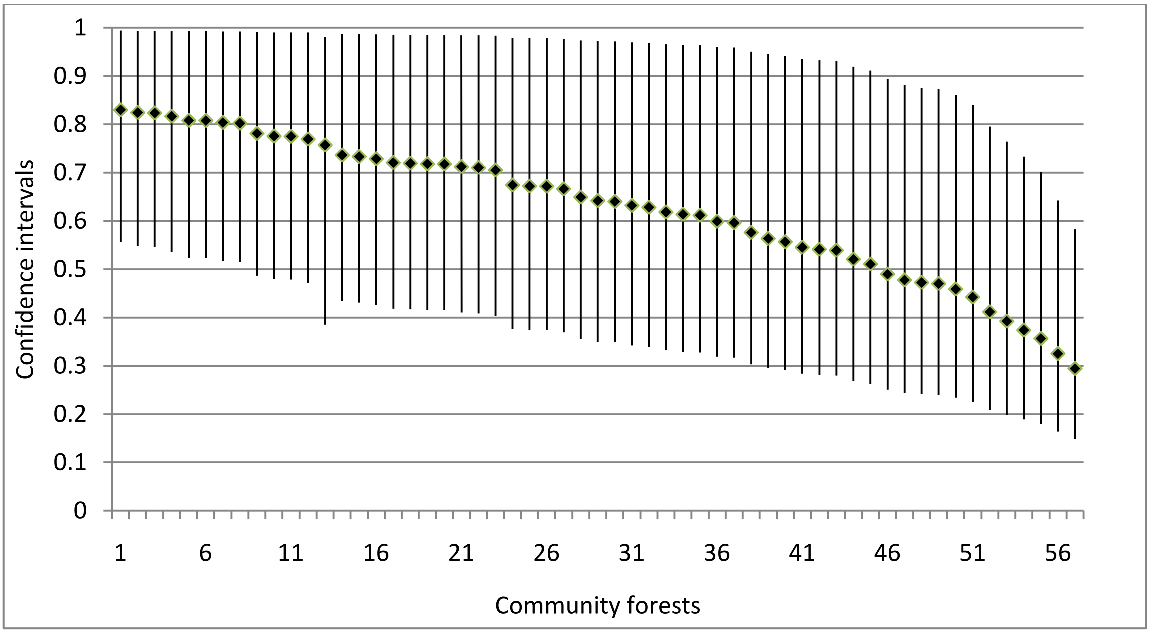
Following the formula devised by Jondrow et al. (1982, Equation 3.30), the production efficiency $\left[E(u_i \mid \varepsilon_i)\right]$ of an individual CFUG was estimated (**Appendix G**)**.** The distribution of CFUG production efficiency measures from **Appendix G** is presented in Table 6.13. The distribution of technical efficiency estimates is quite dispersed. Production efficiency ranges from 0.2942 to 0.8298, with an average efficiency of 0.6281. The modal decile for production efficiency was 0.70 to 0.80 (26% of CFUGs), followed by 0.60 to 0.70 (21%). Only 14% of CFUGs have a production efficiency greater than 0.80, so only a small proportion of CFUGs were operating close to the efficiency frontier.

**Table 6.13 Frequencies of CF production efficiencies**

| Efficiency | Number of CF | Percent |
|---|---|---|
| >0.80 | 8 | 14 |
| 0.80-0.70 | 15 | 26 |
| 0.70-0.60 | 12 | 21 |
| 0.60-0.50 | 10 | 18 |
| 0.50-0.40 | 7 | 12 |
| 0.40-0.30 | 5 | 9 |
| Mean efficiency | 0.6281 | |
| Minimum | 0.2942 | |
| Maximum | 0.8298 | |

Since the current study deals with output-oriented efficiency, efficiency estimation is interpreted in terms of direct forest product benefits. The results indicate that a 20.17% increment in benefit is feasible for the average CFUG (62.81%) with respect to the best performing CFUG (82.98%). On average the potential annual increase in benefit is estimated to be 830 NRs/ha.

It is commonly acknowledged that various sources of uncertainty, such as sampling error and different assumptions made in order to estimate the frontier, make point estimates of efficiency uncertain (Brummer, 2001; Horrace & Schmidt, 1996; Ogundari et al., 2010). Making inferences solely based on point estimates is likely to be misleading. Following Bera & Sharma (1999) and Kim & Schmidt (2000), confidence intervals (CIs) for production efficiency scores were estimated [Equations (3.32) and (3.33)]. **Appendix H** shows the estimated 95 % CI bounds, which are wide and overlapping. A plotting of these CIs are shown in Figure 6.4. Vertical lines represent CIs. Dots on the line represent point estimates.




*Note.* 1 is the most efficient and 57 is the least efficient CFUG

**Figure 6.4 95% confidence intervals for production efficiency**

The CI bounds for the CFUG with the highest point estimate of efficiency are 0.5567 and 0.9941, with a width of 0.4374. The CI bounds for the CFUG with the lowest point estimate of efficiency are 0.1485 and 0.5826, with width of CI of 0.4341. Thus even CFUGs at the top and bottom of efficiency, have overlapping CIs.

Because of the wide and overlapping nature of CIs, individual efficiency rankings based on point estimates are thus unreliable. An alternative technique was needed to rank the production efficiency of CFUGs. A Monte Carlo simulation was carried out to test differences in efficiency between each pair of CFUGs. The simulation revealed that the efficiency of the top six CFUGs was significantly different from the bottom eight CFUGs. Thus the entire sample of CFUGs was classified into three groups (for details refer to Section 5.7.5). Six top CFUGs form the most efficient group, and eight bottom CFUGs are the least efficient CFUGs. The remaining CFUGs are indeterminate, forming an intermediate group. Table 6.14 shows the CFUG efficiency ranking according to point estimate, and the last column shows the number of CFUGs, that each CFUG is significantly different from.

**Table 6.14 Ranking of CFs using Monte Carlo simulation**

| Name of CF | PE | Rank | Number of CF different from | Significantly different from rank number |
|---|---|---|---|---|
| Chuchekhola | 0.8298 | 1 | 31 | CF27-CF57 |
| Subhlaxmi | 0.8241 | 2 | 24 | CF34-CF57 |
| Jyoti | 0.8233 | 3 | 16 | CF41-CF44, CF46-CF57 |
| Thakaldanda | 0.8165 | 4 | 12 | CF46-CF57 |
| Betkholsi | 0.8079 | 5 | 12 | CF46-CF57 |
| Chulipran | 0.8076 | 6 | 8 | CF50-CF57 |
| Shikaribas | 0.8036 | 7 | | |
| Bhotekhola | 0.8021 | 8 | | |
| Kotthumki | 0.7810 | 9 | | |
| Mankamana( Gadi) | 0.7755 | 10 | | |
| Bhairabkali | 0.7749 | 11 | | |
| Basuki | 0.7693 | 12 | | |
| Bageshari | 0.7569 | 13 | | |
| Chhilli bans | 0.7362 | 14 | | |
| Chhitrepani | 0.7330 | 15 | | |
| Chunnidevi | 0.7285 | 16 | | |
| Resheswar | 0.7205 | 17 | | |
| Hariyali | 0.7190 | 18 | | |
| Churekalilek | 0.7180 | 19 | | |
| Bhagawan thumki | 0.7174 | 20 | | |
| Jarungshakti | 0.7121 | 21 | | |
| Mahila srijana | 0.7102 | 22 | | |
| Namuna | 0.7050 | 23 | | |
| Dangdunage | 0.6741 | 24 | | |
| Kalika chandika | 0.6718 | 25 | | |
| Rani | 0.6715 | 26 | | |
| Balkumari | 0.6662 | 27 | | |
| Bajrabarhi | 0.6491 | 28 | | |
| Kalika | 0.6418 | 29 | | |
| Baluwabharreng | 0.6400 | 30 | | |
| Kalika hariyali | 0.6319 | 31 | | |
| Mangleshar | 0.6281 | 32 | | |
| Parbati mahila | 0.6182 | 33 | | |
| Siddhakali | 0.6135 | 34 | | |
| Kalabanzar | 0.6116 | 35 | | |
| Lother | 0.5990 | 36 | | |
| Newreni chisapani | 0.5961 | 37 | | |
| Sundar | 0.5759 | 38 | | |
| Laljhadi | 0.5634 | 39 | | |
| Soltu | 0.5566 | 40 | | |
| Dovan khola | 0.5451 | 41 | | |
| Dipat | 0.5409 | 42 | | |
| Bansgopal | 0.5388 | 43 | | |
| Patleshar | 0.5203 | 44 | | |
| Bungdal | 0.5103 | 45 | | |
| Banaskhandi | 0.4896 | 46 | | |
| Navalpur sarswati | 0.4775 | 47 | | |
| Chhanauta | 0.4723 | 48 | | |
| Chakradevi | 0.4700 | 49 | | |
| Kalilek | 0.4587 | 50 | | |
| Saradidevei | 0.4421 | 51 | | |
| Simpani devkot | 0.4115 | 52 | | |
| Bhutan devi | 0.3923 | 53 | | |
| Ektare | 0.3739 | 54 | | |
| Manakamana(Manahari) | 0.3564 | 55 | | |
| Dhaneshwar | 0.3250 | 56 | | |
| Gosaikunda | 0.2942 | 57 | | |

*Note:* PE= Production efficiency

## 6.6 Factors explaining production efficiency

The production function of an individual CFUG only indicates its ability to produce forest products with given inputs. Identification of exogenous factors that have contributed to production efficiency may provide information on where potential sources of inefficiency originate, and suggest policies that can be implemented or changed to increase the overall efficiency level (Reinhard et al., 2002). As was discussed in Section 5.7.3.2, five factors were expected to affect production efficiency of CFUGs. Summary statistics for exogenous factors used in this analysis are presented in Table 6.15 and explained in detail in the following section.

**Table 6.15 Summary statistics for factors explaining production efficiency**

| Factors | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| Social capital index | 4.12 | 0.25 | 3.57 | 4.75 |
| CF longevity (years) | 11 | 3.88 | 3.00 | 19.00 |
| Growing stock ($m^3$/ha) | 190 | 67.12 | 84 | 346 |
| Support from government staff (1=yes, 0= no) | 0.35 | 0.48 | 0 | 1 |
| Caste heterogeneity in EC | 0.33 | 0.21 | 0 | 0.64 |

*Note*. SD= standard deviation.

### 6.6.1 Social capital

As was discussed in Section 5.7.3.2, social capital of a CFUG was expected to influence production efficiency. Social capital was measured using a 5 point Likert scale. Variability in terms of a social capital index was recorded among CFUGs. An analysis shows that the majority (60%) of CFUGs have a social capital index of 4.0 - 4.5 (Table 6.16). Thirty two percent of CFUGs have a relatively lower value social capital, indicating room for improvement in social capital.

**Table 6.16 Distribution of CFUG according to social capital index**

| Social capital index | Number of CFUGs | % of CFUG |
|---|---|---|
| 3.5 - 4.0 | 18 | 32 |
| 4.0 - 4.5 | 34 | 60 |
| 4.5 - 5.0 | 5 | 8 |

### 6.6.2 CF longevity

CF longevity varies greatly, ranging from 3 to 19 years. CF longevity is related to the knowledge and skill that a CFUG gains from practicing forest management. An analysis of CFUG longevity shows that most of them had been practicing forest management for 10-15 years. Only 12 % of CFUGs have been practicing forest management for more than 15 years. A considerable number of CFUGs were young, with less than 10 years of forest management experience. This implies that CFUGs lack forest management knowledge and skills. There is opportunity for improving CFUGs' forest management knowledge and skills using multiple strategies such as training, exposure visits and workshops if necessary.

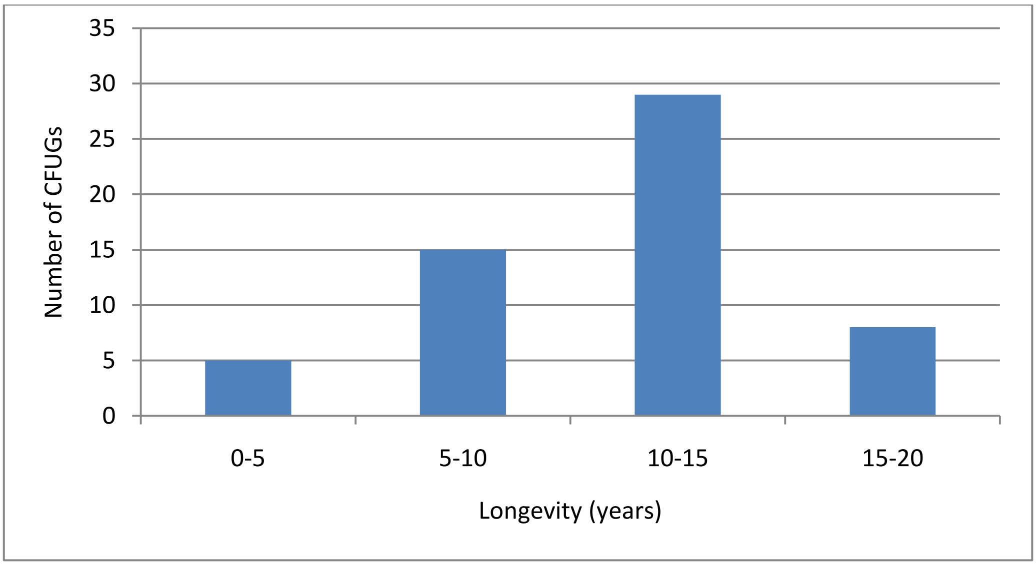



**Figure 6.5 CFUG's longevity**

### 6.6.3 Growing stock

The growing stock volume of CFs in this sample set shows wide variation with a minimum growing stock of 84 $m^3$/ha and a maximum of 346 $m^3$/ha. Growing stock indicates the potential capacity of a forest to supply forest products.

### 6.6.4 Government support

Government support was measured in dichotomous form (see Section 5.7.3.2). The result shows that the majority of the CFUGs were not receiving support from government staff. Only 35% of CFUGs were getting support from government staff. The main support included forest inventory, the measurement of forest products and establishing links with the timber market.

### 6.6.5 Heterogeneity in the executive committee

As was discussed in Section 5.7.3.2, caste heterogeneity varies from between 0 and 0.67, with three castes. The maximum value of caste heterogeneity was 0.64, which is highly heterogeneous, and the minimum was zero, indicating complete homogeneity. A distribution of CFUGs in terms of the EC heterogeneity index indicates that the majority of the ECs in CFUGs are heterogeneous (heterogeneity index >0.33) (Figure 6.6).

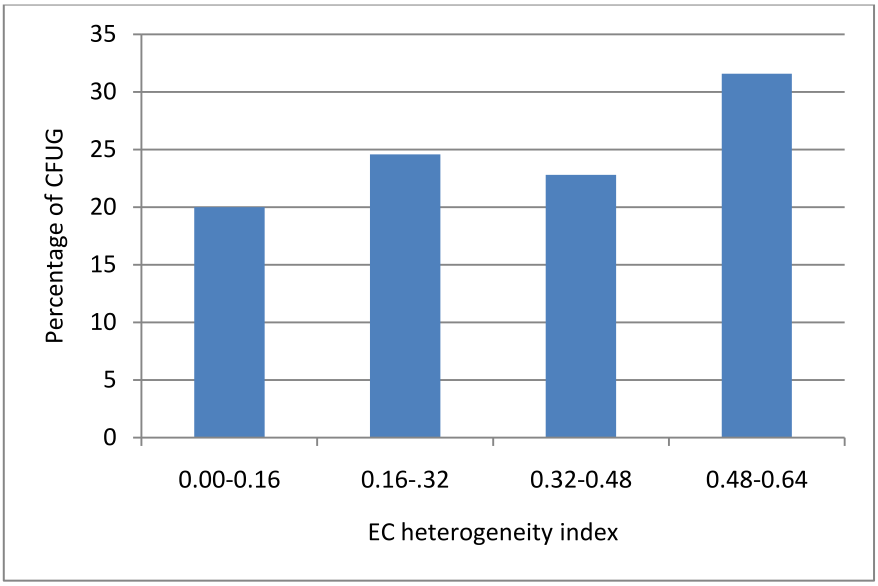



**Figure 6.6 Distribution of CFUGs in terms of heterogeneity index in EC**

## 6.7 Model explaining production efficiency

The section above described expected factors that may influence production efficiency. This section studies the effect of these factors on production efficiency using an ordered logit model.

As discussed in Section 6.6 using a Monte Carlo simulation, three groups of CFUGs were identified; the most efficient, moderately efficient and the least efficient. This designation for a CFUG used as a dependent variable in an ordered logit model. The dependent variable carried a value of 0, 1 or 2 corresponding to least efficient, moderately efficient and most efficient. Factors such as the longevity of the CF, social capital, growing stock of the forest, support from government staff and caste heterogeneity in the EC were used as independent variables. The maximum likelihood method was used to estimate the parameters of the ordered logit model, and the results are presented in Table 6.17.

**Table 6.17 Factors explaining production efficiencies**

| Variable | Coefficient | Standard Error | t-ratio |
|---|---|---|---|
| Constant | -5.3842** | 2.7194 | -1.98 |
| CF longevity (years) | 0.1193** | 0.0549 | 2.1708 |
| Social capital index | 1.1317* | 0.6433 | 1.7593 |
| Growing stock ($m^3$/ha) | 0.0069** | 0.0031 | 2.2411 |
| Support from government staff (yes=1, else 0) | 1.57*** | 0.5069 | 3.097 |
| Caste heterogeneity in EC | -2.0297** | 0.9278 | -2.1875 |
| Mu( 1) | 3.1949*** | 0.4997 | 6.3941 |
| Log -likelihood (lnL) | -31.26 | - | - |
| McFadden's Pseudo $R^2$ | 0.27 | - | - |
| Adjusted pseudo $R^2$ | 0.35 | - | - |
| Count $R^2$ | 0.72 | | |
| N | 57 | - | - |

*Note:*

1. ***, ** and * denote statistical significance at the 0.01, 0.05 and 0.10 levels respectively.
2. Count $R^2$ is the proportion of actual outcomes accurately predicted by the model. Pseudo $R^2$ is the associated likelihood ratio index, $1-[\ln L/\ln L_0]$, where L is the unrestricted log-likelihood; $L_0$ is the log likelihood without regressors. An adjusted pseudo $R^2 = 1 - \frac{\ln L - k/2}{\ln L_0}$, where k is the number of parameters in the model. LIMDEP 9 was used to obtain the above results.

The model provided a good fit, with a pseudo $R^2$ score of 0.27 and adjusted pseudo $R^2$ of 0.35. For interpreting the goodness of the fit for the model, there is no direct equivalent to $R^2$ as used in linear regression (Gujarati, 2005; Verbeek, 2005). However, a number of pseudo $R^2$ have been developed and one of the commonly used is McFadden's $R^2$. However this measure cannot detect the increase in the number of variables in a model, and therefore its application is limited (Cook et al., 2002). Instead adjusted pseudo $R^2$ is generally used and it accounts for the number of parameters in the model. A good fit is indicated when McFadden's $R^2$ is above 0.2, and the value approaching to 0.4 for an adjusted $R^2$is considered an extremely good fit (Hensher & Johnson, 1981).

CF longevity, social capital index, growing stock, support from government staff, and caste heterogeneity in the EC, had significant effects on a CFUG's efficiency ranking, although social capital is significant only at the 10% level. Most of the factors have positive effects on production efficiency, except caste heterogeneity in the EC, which has a negative effect. A positive effect implies that the likelihood of improvement in the production efficiency ranking increases with an increase in the social capital of the CFUG, the growing stock of the forest, CF longevity and government support. These results are similar to the other results (refer Section 5.7.3.2).

## 6.8 Summary

CFUGs have been producing both direct forest products and ES benefits. Timber and other forest products, such as fuelwood, fodder and litter, contribute significantly to the income of the CFUGs. CFUG members were concerned with various ESs that CFs generate. Soil conservation was their highest priority followed by water conservation, wildlife and aesthetic services.

Forest crown cover was the most important forest attribute influencing the generation of ESs. Comparatively, forest canopy layers, types and different development stages have lesser significance in producing ESs. Based on the preference for these forest attributes, environmental performance of a broadleaved, immature and dense forest with multiple layers produced the greatest ESs whereas one layered, mature coniferous forest with moderate crown density produced the lowest ESs.

Using a Cobb-Douglas functional form to describe the CF production process, stochastic frontier analysis revealed that the proximity to the government office, CF size and heterogeneity in the CFUGs negatively influence the production of forest products. However, a CFUG's links to the market, forest product dependency and the number of households in the community have a positive effect on the forest product production. Contrary to expectation, environmental performance and forest product benefits appear to be complementary products in CFs.

Efficiency scores yielded by the stochastic frontier model showed that the average production efficiency was 62.81%, suggesting the potential for improvement in the CFUGs' production performance. Variation in the efficiency ranking indicated that some of the CFUGs were performing better than others. Factors such as time since the CFUG's establishment, social capital of the community, growing stock, government staff support and caste heterogeneity in the executive committee were found to influence the production efficiency ranking of the CFUG. Except for caste heterogeneity in the EC, the factors are positively related to production efficiency scores.

# Chapter 7
# Discussion

## 7.1 Introduction

Chapter Five identified the methodologies that were selected to empirically investigate the research problems. Chapter Six reported the description of information collected from the research sites and findings based on the analysis of the information gathered. The findings were related to the production function, and production efficiency and its determinants. Stochastic frontier analysis was carried out to estimate the production function and production efficiency of community forests. An ordered logit model was applied to identify the determinants of production efficiency. This chapter discusses the significance of the findings in Chapter Six. First, this Chapter discusses the production function in the CFs. In addition, consideration of the findings in the light of existing research and their implications are identified. It then explains the determinants which were found to be significant in production efficiency. The explanation includes how the factors associated with CFs affect the production efficiency, and implications for enhancing efficiency.

## 7.2 Preference for ecosystem services

CFUGs were asked to prioritise four types of ESs and to rate each of these ESs based on the four types of forest attributes. The highest priority was given for soil conservation service, followed by water conservation, and wildlife conservation services and aesthetic benefits were least valued (Table 6.4).

The highest priority for the soil conservation service could be because of the great impact of soil conservation on the forest user's livelihood. Various studies have also indicated that stakeholder attached values for ESs depends upon the impact of the service on their livelihood (Bishop, 1999; Hein et al., 2006; Sandhu et al., 2007). CFUGs depend on farming and several empirical studies have indicated that agriculture productivity declined, due to continuous soil nutrient loss in Nepal (Awasthi et al., 2002; Shrestha et al., 2004). The second largest preference weight was for water conservation, which suggests that water sources have a considerable impact on CFUGs' livelihoods. Many studies in Nepal have indicated the importance of water conservation for communities (Acharya, 2004; Gilmour et al., 2004a; Guthman, 1997). Studying the socio-economic impact of community forest in two districts in Nepal, Upreti (2000) noted that water supply in a community was a major concern.

Chaudhary (2000) claimed that soil and water are the main resources affecting the livelihood of the Nepalese people.

The wildlife conservation service had a lower priority relative to soil and water conservation services, possibly because communities have not realised much benefit from it. CFs are discrete patches and are surrounded by human habitation. Therefore they are not suitable for much wildlife, particularly those which prefer large habitat range.

Aesthetic values also had low importance for these communities. This may be because aesthetic values have not contributed to the livelihoods of CFUGs. Low preference for aesthetic values is not surprising considering the economic status of CFUG members. Most of the CFUG members' livelihoods either depend on direct forest product benefits, or to some extent on ESs such as soil conservation and water conservation. They seem to have little interest on ESs which do not contribute to their economic well-being. Silvano et al. (2005) have documented that farmer's perceptions about the importance of ESs were apparently influenced by the direct uses and the opportunity costs of the ESs.

## 7.3 Priority for forest attributes

The forest attributes that produce the largest environmental benefits suggest that a dense, broadleaved, immature and multiple canopy layered forest was the most important. On the other hand, an open coniferous forest, which is mature and has a single canopy layer was the least favoured for producing environmental benefits. A number of empirical studies show why this would be the case. For example, Schmidt et al. (1993) found that soil under broadleaf forest is less prone to erosion than under a coniferous forest. This was because a broadleaf forest contains more humus, and humus reduces soil erosion by intercepting and dissipating rain drops. A study in China  (Zhao et al., 2009) found that mature forest conserves soil better from erosion than immature or young forest. David et al. (1966) and Pathak et al. (1984) reported that dense crown cover reduces the surface runoff, and as a result water is conserved. It is worth noting that the similarity of the ranking of forest attributes by local forest users with the results from other studies, demonstrates that ANP is an appropriate method for studying the importance of forest attributes.

## 7.4 Production of forest products in a community forest

### 7.4.1 Stochastic production function

The present study aimed to estimate a production function for direct benefits (e.g., timber, fuel wood and fodder) and environmental benefits. In order to estimate a production function with two outputs (direct benefits from forest products in NRs/ha and environmental benefits in the form of an index), an attempt was made to fit a stochastic output distance function. However, the complementary nature of the two outputs did not permit the estimation of the output distance function. This led to the use of a single output stochastic production frontier based on direct benefits, with environmental benefits as an input.

An attempt to estimate the stochastic production function using the translog model was not successful. Possibly, this failure is attributable to the small sample size in the present study, which brings the risk of multicollinearity in second order terms (Bigsby, 1994; Siry & Newman, 2001). The Cobb-Douglas (CD) functional form was used to explain CF production instead. Several studies related to agriculture and forest production have demonstrated the appropriateness of the CD model (Bravo-Ureta & Pinheiro, 1997; Kompas, 2004; Lindara et al., 2006; Siry & Newman, 2001).

### 7.4.2 Factors determining production of direct forest product benefits

The CD production frontier indicated that socio-economic factors associated with the community, and forest associated characteristics, have significant impacts on production. Socio economic factors include the distance of the CF from the government office, the number of households involved, whether forest products are sold in a market or not, the heterogeneity of the CFUG, and forest product dependency (Table 6.12). Forest characteristics include the area and the environmental performance index. The role of factors other than land, labour and capital (Table 6.12) in the production function, supports an argument put forward by institutional economists, such as North (1990) and Coase (1937), that transformation and transaction factors both contribute to the production process. Misra & Kant (2005) have also demonstrated the role of transformation and transaction factors in the production process. Thus, consideration of socio-economic factors related to the production agency, along with land, labour and capital in the production process, is essential to enhance the productivity of resources. The following section explains each factor of production in detail.

#### *7.4.2.1 Distance to the government forest office*

The coefficient for distance to the government forest office is negative, but significant (Table 6.12). The negative sign indicates that the close proximity of the CF to a government office increases CF benefits. There are three possible reasons for this. First, the closely located forest users group can get access to the government office more easily than the users located at some distance (Edmonds, 2002; Schweik, 2000). This makes closer CFUGs better informed in terms of forest management practices, forest-related rules and regulations (Agrawal & Gupta, 2005). CFUGs also have to get approval from the government forest office before implementing any activities such as harvesting and the distribution of forest products. Easy access to government staff may reduce the time and costs for acquiring these approvals. Delegating more forest- related authorities to CFUGs, such as the decision-making for selling forest products in the market and the amount of forest products extracted every year may reduce their dependency on the government office and, thus, the cost for approvals (Agrawal & Gupta, 2005). Even though CFUGs are allowed to sell forest products as indicated in the forest operational plan, they have to receive approval from the DFO every year.

The second reason is that forests which are located close to the government forest office, usually receive priority for handing over to communities. Government staff have the propensity to form CFUGs first, in closely located communities, rather than relatively distant communities. This is because less effort is required to hand-over a closely located forest (Edmonds, 2002). Earlier formed CFUGs began protecting and harvesting forest products earlier than the recent CFUGs. Longer protection of a forest might lead to greater abundance of forest products and hence, increased forest extraction.

Some scholars however, do not agree that the government's presence is conducive to increased output under community forest management. For example, Agrawal & Chhatre (2006) argued that the presence of a government office would be a 'disincentive' for the collection of forest products. This claim may be true when institutional arrangements are either absent or are not effective for controlling access to forest resources. Sethi & Somanathan (1996) claimed that increased government interference would destroy local management systems and consequently may result in overharvesting of resources in community forests. However, the findings of this study did not explore whether or not the communities near to the government forest office were harvesting beyond the allowable cut limit.

The relationship between proximity to the government office and benefits from CFs cannot be interpreted as evidence that establishment of more government offices would necessarily increase benefits. The result could also indicate the possibility of delegating more authority to CFUGs, to enable them to make decisions on their own rather than establishing more offices. Agrawal & Gupta (2005) suggested this option for increasing benefits in community managed forest.

#### *7.4.2.2 Community forest area*

The relationship between the forest area and outputs of benefits is the subject of debate (Misra & Kant, 2005; Siry & Newman, 2001). This study found that forest area has a significant negative impact on CFUG outputs. This might reflect more intensive management of small forests (Cornia, 1985). CFUGs with smaller forest areas carry out silvicultural activities such as thinning and pruning more actively. Silvicultural activities ameliorate growth-limiting factors and thereby enhance the availability of desired forest products (Fox, 2000). The data in this study revealed that nearly 72% of the CFUGs with a smaller forest area[8] were involved in silvicultural activities as opposed to only 24% of CFUGs with a larger forest area.

The Forest Act 1993 does not dictate the size of forests to be handed over to communities. However, it has specified certain criteria for handing over forests under community management, particularly that the management capacity of the community is taken into consideration (see Section 2.6.3). However, in the absence of a thorough examination of the criteria, anomalies in forest size abound in CFUGs (Kanel & Kandel, 2004). For example, a community with a large number of households may have a small CF and vice-versa. A CFUG largely uses voluntary labour in forest protection and management (Kanel, 2004). When a large forest area is handed over to smaller community, the forest users may not be able to manage the forest using different silvicultural activities, due to a shortage of labour.

The results here are consistent with other findings, such as Misra & Kant (2004) who have also reported a negative association between forest area and productivity in joint forest management in India. A negative relationship between farm size and productivity has been also documented in the agricultural sector (Bardhan, 1973; Carter, 1984; Cornia, 1985). They found that small farms used more labour per hectare compared to larger farms, and hence, produced more per unit area.

On the other hand, Lien et al. (2007) and Siry & Newman (2001) found a positive relationship between forest area and timber production across private forest owners in Norway and state forests in Poland respectively. Differences in the results between these studies and the current study could stem from methods used to measure production. They have used the total amount of timber as a forest output, whereas the current study employed the amount per unit area of forest products, as an output. Another possible explanation is the economies of scale; these forests are more capital intensive and use more machinery for production. Therefore, with increasing area of forest, benefits from the forest also increases.

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[8] For this study forests are classified into two groups, a forest is considered large if it is larger than 107 ha (median value) and a forest is considered small if it is smaller than 107 hectares.

The inverse relationship between forest product benefits per hectare and CF area shows that a smaller forest generated higher benefits. This is believed to be largely because of silvicutlural activities. Silvicultural activities will be carried out if there is enough voluntary labour available to CFUGs. This suggests that the government should handover forest areas which are manageable given the size of a community.

#### *7.4.2.3 Link to the market*

CFUG links to the market contribute positively to the level of forest production (Table 6.12). This finding was expected and is consistent with the findings of other authors, such as Agrawal & Chhatre (2006), Gebremedhin et al. (2003) and Masozera & Alavalapati (2004) (see Section 2.5.1). There are at least two possible explanations for the positive contribution of the market. The first is that the market price for forest products is higher relative to the price within the community. The field survey showed that the average market price for timber was NRs 163.20 per cubic foot, but CFUG members were paying only NRs 53.49. This price difference might have increased benefits to those CFUGs which are selling timber in the market. The second reason is that the market link can also increase demand for forest products (Lawrence et al., 2007).

Several other authors have claimed that links to the market adversely affect forest resources. Market access and higher prices for forest products may lead to overharvesting of forest resources (Lawrence et al., 2007; Robinson et al., 2002; Young, 1994). Godoy & Bawa (1993) showed that a market link is a causal agent in the degradation of forests. However, there is evidence to show that market access can increase the harvest of forest products without exceeding the limits of sustainable harvest. The presence of local institutional arrangements and the transferring of property rights over resources to a community, can prevent the adverse impact of market linkages. In Honduras, Southern and Thucker (2001) observed an increase in forest cover due to enforcement of local rules that controlled overharvesting. Agrawal & Yadama (1997) observed that local institutions were effective in preventing excessive harvesting of forest products in Kumaon Himalaya in India. Likewise, Edmonds (2002) made similar observations in the community forestry of the Middle Hills of Nepal.

The positive relationship of production in CFs with links to the market may have practical implications for augmenting the livelihoods of CFUG members by generating higher benefits. In this regard, government and non-governmental agencies can facilitate a link between CFUGs and markets (Dev et al., 2003). CFUGs are lacking the organizational capacity to negotiate with forest product traders independently. In that situation, a CFUGs network can enhance its negotiating capacity for its higher value for forest products (Springate-Baginski et al., 2003).

#### 7.4.2.4 Group Heterogeneity

The role of heterogeneity in the use of common property resources (CPR) has been well documented but is ambiguous (Gautam, 2007; Naidu, 2005; Varughese & Ostrom, 2001). This study shows that the heterogeneity of CFUGs has a highly significant negative effect on CF production (Table 6.12). This negative relationship is possibly because of the individual effects of all three forms of heterogeneities (see Section 2.5.3). In CFs, wealthier households have greater use of forest products compared to poorer households (Adhikari et al., 2004), which generates different incentives for forest use and forest management (Kant, 2000; Varughese & Ostrom, 2001). According to Adhikari & Lovett (2006) wealthier households prefer forest products which support the agriculture system such as timber, fuelwood and fodder, whereas poorer households want forest products which generate cash and support their livelihoods. This difference in preferences may impede the decision making process resulting in a lower collection of forest products (Adhikari & Lovett, 2006).

Locational heterogeneity among CFUG members has created different incentives (Varughese & Ostrom, 2001). CFUG members who live closer to the forest might have a more accessible supply of forest products (Gunatilake, 1998). Distant users, on the other hand, have harder access and therefore have to bear higher costs in order to receive benefits from the CF (Adhikari & Lovett, 2006). Thus, this disparity in benefits and costs between closer and distant users generates conflicts, as it may either delay or defer decisions regarding the collection or production of forest products (Poteete & Ostrom, 2004).

Caste heterogeneity has increased the social distances between individual households and resulted in differences in resource management activities (Thoms, 2008). Generally, higher caste households are educated, relatively rich and hold greater political opportunities. Lower caste households have less access to forest resources compared to higher castes (Cooke, 2000). Differences in access lead to heterogeneous forest product preferences (Thoms, 2007). Thus, decisions regarding forest product collection and use may be delayed due to differences in forest product preferences in heterogeneous communities.

Similar results have been resported in various previous studies (Bardhan, 2001; Dayton-Johnson, 2000; Dayton-Johnson & Bardhan, 2002, discussed in Section 2.5.3). While a large number of studies have established relationships between different forms of heterogeneity and collective outcomes, some studies (such as, Adhikari & Lovett, 2006; Varughese & Ostrom,

2001) found no strong evidence of a relationship between group heterogeneity and levels of collective outcomes. They argued that groups generally design a set of local rules and regulations to nullify the potential effects that emerge due to different forms of heterogeneities. Differences in the results could stem from the methods of data analysis. These findings are based on a small number of observations and lack statistical validity. For instance, Adhikari & Lovett's (2006) study is based on only eight CFUGs, and Varughese & Ostrom (2001) have studied only 18 CFUGs.

The result of this current study underscores the effect of group heterogeneity in CF production. Alleviation of heterogeneity is not possible within a short period of time and so is its effect. Even though some studies suggest that the crafting of rules and regulations can overcome the adverse effects of heterogeneity, the evidence is not so strong. Thus, there are no simple recipes for overcoming the heterogeneity effect.

#### *7.4.2.5 Forest products dependency*

The other factor which influenced forest product benefits was the dependency of the user group on the forest. CFUGs' forest product dependencies were positively related with CF production (Table 6.12), as hypothesised. When community members realise that the forests are more useful for their subsistence and their livelihoods, they make greater efforts to protect and harvest forest products (Misra & Kant, 2004).

Several other studies have reported similar results. Adhikari et al. (2004) found that households with a higher dependency on forest products, received higher benefits than the less dependent in Nepal. Agrawal & Chhatre (2006) found that forest product dependency was positively associated with the condition of the forest. Though the study is not directly related to forest product benefits, the improvement in the forest condition is essential to ensure the supply of forest products (Jefferson, 1993; Yadav et al., 2003). In Southern Malawi, a higher dependency on forest products induced more forest product collection at the household level (Fisher, 2004). Based on the study involving three states of India, Lise (2000) has demonstrated that a higher level of forest dependency promoted greater participation in forest management. People are generally keen to participate in forest management activities only if they receive benefits from forest resources.

In contrast, Misra & Kant (2004) have noted that the dependency of CFUGs has no significant connection to the supply of direct forest products in India. This result may have arisen because of differences in the roles of CFs in Nepal and joint forest management in India; there is more government control in decision making in India (Kumar, 2002). Government control over harvesting may prevent forest users from collecting forest products according to their preferences. In addition, Misra and Kant (2004) have measured dependency based on a wide range of forest values including psychological, spiritual and heritage, in addition to direct forest product dependency, and there is no clear link between spiritual, psychological and heritage values with the amount of forest products harvested (Kant, 2000).

Misra (2004) argued that greater forest dependency of users may promote the withdrawal of produce, depleting forest condition. Therefore, before drawing any conclusion about the relationship between CF production and forest dependency, a study of relationships between a forest's biophysical condition (it may be in terms of canopy cover or environmental value of a forest) and forest dependency of users is essential.

#### *7.4.2.6 Number of households*

The result showed a significant positive association of group size to the benefits per ha in CFs (Table 6.12). The outcome seems reasonable, because of the nature of the forest products which were collected by the forest users. Other than timber and fuelwood, the extraction of forest products such as fodder, grasses and litter were generally less restricted in many CFUGs and CFUG members were allowed to collect as much as they required for their household use. Thus, fodder, litter and grass were relatively non-excludable and relatively non-rival within the community (Adhikari et al., 2004). At the same time, these products occupy a large proportion of the total benefits accrued from CFs (Section 6.2). When the collective good is public in nature – non-excludable as well as non-rival – the larger group size is able to produce more collective goods (Oliver & Marwell, 1988; Poteete & Ostrom, 2004).

Several empirical and theoretical studies have examined the group size relationships and many of them have found that group size is positively related to the collective action. For example, research on community forest governance in the Indian Himalaya by Agrawal & Chhatre (2006) found that larger group size is necessary to improve forest conditions. They argue that a large number of people is conducive to forest conservation, as long as the benefit from effort outweighs its cost. The likelihood of a labour contribution is more from a larger group than from a smaller group. In a theoretical study, Chamberlin (1974) showed that as group size increased, the total contribution of labour in absolute terms increased. Misra & Kant (2004) claimed that in community based forest management, each household can be considered as a labour input, so they contribute to the production process. However, Misra and Kant (2004) have pointed out that the role of group size in forest production depends on the nature of the group. Groups highly concerned about environmental conservation may reduce the production of forest products. On the other hand, a medium level or low level of interest about environmental conservation may contribute to higher forest production.

Arguments in favour of the effectiveness of small groups in collective action are equally widespread. For example, Esteban & Ray (2001) argued that when group size is larger, it is more likely to have incentives for individuals to defect from cooperation, for two main reasons. First, the larger the group, the smaller is the perceived effect, if someone is absent in cooperative work. Second, if the produced benefit is rival in nature, then the possibility of receiving a higher benefit for each individual is less likely in a larger group.

Likewise, Olson (1965) affirmed the inverse relationship between collective action and group size, but this claim was based on the assumption that the collective good was relatively private in nature. Baland & Platteau (1999) reiterated Olson and claimed that the smaller the group the stronger its ability to perform collectively. However, these findings are valid only if the collective good is excludable and rival. In that situation, the cost of collective action increases as group size increases, and as a result individual incentive to contribute vanishes. Group members prefer to defect from collective action for their individual benefit and this would result in the degradation of the resource condition (Esteban & Ray, 2001; Poteete & Ostrom, 2004).

The result of this and other empirical studies, thus, implies that the benefit from forests is related to group size, as long as the collective good is relatively public in nature and the benefit of the good outweighs the costs. From this finding, it appears that the formation of larger groups by merging smaller CFUGs is likely to increase the performance of CFs in terms of benefit generation, but the effects of other factors need to be considered carefully.

#### *7.4.2.7 Environmental performance*

The relationship between environmental value and direct benefits in a forest ecosystem has direct relevance to public policy. This relationship has been the subject of considerable interest over the past decades (Cameron, 2002; Lichtenstein & Montgomery, 2003). It has been the central concern of policy makers and ecologists (Lehtonen et al., 2003; Wossink & Swinton, 2007; Xu et al., 2003). However, the direction and underlying mechanism of this relationship is highly debated.

The relationship between environmental conservation and forest product benefits has been widely studied elsewhere, but has not been studied in CFs. The stochastic frontier analysis revealed a positive association between environmental value and direct forest products benefit in CFs in Nepal (Table 6.12). The positive sign indicates environmental benefit supply was complementary with forest product supply. This result was a contrast to the results identified by other researchers (Lichtenstein & Montgomery, 2003; Pattanayak et al., 2003; Rohweder et al., 2000; Xu et al., 2003; Zhou & Gong, 2005).

Using a production possibility frontier, Lichtenstein & Montgomery (2003) demonstrated that biodiversity conservation, measured by vertebrate species diversity and timber production, are inversely related. They found that within a certain range of biodiversity, vertebrate biodiversity could be increased with little loss of timber production. However, beyond that range, as biodiversity increases the opportunity cost of conservation also shoots up. Likewise, in an analysis of the joint production of timber and amenity value, Pattanayak et al. (2003) found a negative association between timber production and amenity value. The amenity value index is comprised of a measure of tree diversity, scenic beauty and deer and bird habitat. Similar findings have been reported by Zhou & Gong (2005). They reported a trade off between different uses of forests such as timber production, biodiversity preservation, reindeer grazing and recreation in three communes in northern Sweden. One possible explanation for these negative relationships is the choice of proxies for the environmental value measure (Costanza et al., 2007). For example, Lichtenstein & Montgomery (2003) chose vertebrate species as a proxy for environmental value. Conservation of vertebrate species required modifications in timber management practices such as shifting the periods and the scales of timber harvesting, thus, reducing the amount of timber harvested.

Numerous studies have also shown the positive association between the environmental value component and forest product benefits. For example, Misra & Kant (2004) found that forest production increases with an increase in biological output in joint forest management in India. Canopy cover of a forest was taken as a measure of biological output. Nalle et al. (2004) have examined the relationships between three outputs; timber value, porcupine population and great horned owl population, and have demonstrated both complementary and competing relationships between them. They further claimed that because porcupines prefer younger forests, timber production and porcupine population are complementary. On the other hand, great horned owl populations and timber production were competing uses, because great horned owls prefer mature forest for nesting. These studies have also shown that the nature of the relationship (complementary or competing) between marketed commodities and non marketed ESs very much depends on the nature of the commodity.

There are two possible explanations for the positive relationship between environmental benefits and forest product benefits in CFs. First is the selection of the measure of environmental benefits. The environmental benefit of a CF was computed from preference weights for forest attributes based on their contribution to ESs. CFUG members have expressed different preferences for forest attributes (Table 6.4), and this makes for a diverse environmental value index for forests (Table 6.5). The forest which has higher environmental benefit also produces more forest products. For example, broadleaved forest produces more variety of forest products than pine. Pine forest suppresses ground flora vegetation and makes the site unfavourable for grass. Further, pine trees are useless for fodder and litter (Adhikari, 2005; Chhabra et al., 2002; Mohns et al., 1988; Richards et al., 2003). Dense forest contains higher growing stock volume than moderately dense forest and therefore has the potential to supply more forest products (Chhabra et al., 2002). A multi-layer forest often provides a variety of forest products because it harbours trees of different sizes and trees of different species (Gautam & Devoe, 2006; Straede et al., 2002). This association between forest product availability and forest attributes, validates the positive relationship between the environmental benefits of a CF and the forest product benefits of this study.

The second reason for the positive relationship is that communities prefer forest products such as fuel wood, fodder, and litter, and these products constitute a large contribution to the total benefit of these communities. Most of the previous studies which have identified a negative relationship between economic and biological outcomes of a forest have considered only timber as an economic outcome (Lichtenstein & Montgomery, 2003; Rohweder et al., 2000). Forests managed specially for timber production are more regulated and entail silviculture treatments such as pruning, thinning and singling at regular intervals. Thus, a forest stand solely managed for timber can reduce the production of non-timber products, and hence, a competitive relationship is observed (Lichtenstein & Montgomery, 2003; Nalle et al., 2004; Rohweder et al., 2000). On the other hand, forest stands which are managed for multiple forest products, such as CFs in Nepal, are not so intensively managed. To obtain multiple forest products, diversity in terms of species, canopy layers, development stage and crown coverage is necessary and this diversity also favours maintaining ESs. This interdependency between forest product supply and ESs is consistent with their positive relationship in CFs. This finding is not generalisable to other forests. It may be an outcome of the purposive sampling process, and may not be true in leasehold and government managed forests. Further research could clarify this matter.

Understanding how a community can supplement the public supply of ESs is of great interest to policy makers. To this end, the positive association indicates that there is a possibility for augmenting forest product supply along with environmental performance in CFs. However, manipulation of forest attributes will be essential to maximise both environmental and direct forest product benefits (Gilmour et al., 1990). For example, to augment forest product benefits and environmental benefits, pine forests will have to be gradually converted into broadleaf forest and one layered forests into multiple layered forests.

## 7.5 Production efficiency of community forests

The stochastic production function identified the factors influencing the production process in CFs. Identification of influencing factors alone does not explain much about how the resources have been used to produce forest products, that is, whether the communities are utilizing the input resources in a proper way or not. To this end, the production efficiency of individual CFs was computed following a formula devised by Jondrow et al. (1982).

Production efficiency estimates for individual CFs ranges from 29.42 % to 82.98%, with an average efficiency of 62.81%. This implies that if the average CF in the sample was to achieve full production efficiency, then they would achieve approximately 20.17% more forest product benefits from the same inputs, including environmental conditions. The least efficient CF could improve production by 53.56%. This result suggests that CFUGs fail to generate as many benefits as input factors could allowed. Thus there is considerable scope for expanding production and raising efficiency, by improving CFUGs' technical management abilities.

Besides, there is a wide variation in production efficiency among CFUGs. This variation is not surprising as various previous empirical studies have had similar results. For example, Siry & Newman (2001) employed stochastic frontier production function in Polish State Forests and reported production efficiency estimates of between 25% and 88%, with average efficiency equal to 49%. In a stochastic production frontier analysis of agroforestry in Sri Lanka, Lindara et al. (2006) estimated technical efficiency ranging from 30.53 to 97.35%. In a more recent study, using the output distance function technique, Misra and Kant (2005) found efficiency ranging from 51% to 99%, in joint management forest in India.

It is widely recognised that point estimates of production efficiency are influenced by several sources of uncertainty such as; sampling error, and uncertainty arising from the estimation of the frontier (Horrace & Schmidt, 1996; Street, 2003). Due to these uncertainties, it is not possible to pin point which CF has been using its input resources most efficiently. Following Horrace & Schmidt (1996) CIs were estimated and confidence bounds for individual CFs are shown in **Appendix H**. All CFs' CIs were wide and overlapping (Figure 6.4). Several other related studies have also observed the wide and overlapping problem in confidence interval estimation (Bera & Sharma, 1999; Brummer, 2001; Fraser & Horrace, 2003; Jensen, 2000;

Latruffe et al., 2004, 2005; Ogundari et al., 2010). Horrace & Schmidt (1996) claimed that statistical noise is the main reason for the wide and overlapping CIs. Consistent with Horrace & Schmidt, Fraser & Horrace (2003) attributed wide CIs to sampling error. Along a similar line, Brummer (2001) posited that the stochastic frontier CI formulation [Equations (3.32) and (3.33)] only considers the uncertainty induced by the distribution of the non negative error term, and does not take into account uncertainty embedded into the production frontier parameters. As a result the equations only give a minimal width of CI for production efficiency.

It is interesting to note that CIs were relatively smaller for the most efficient and inefficient CFs (refer to Figure 6.4). The *Chuchekhola* CF, which was the most efficient point estimate, has the smallest CI (0.5567, 0.9941). On the other hand, the least efficient, the *Gosaikunda* CF, did not have the largest confidence interval (0.1485, 0.5826). The *Dipat* CF which has a forty second point estimate ranking has the largest CI width (0.2812, 0.9330). This result was consistent with what Bera & Sharma (1999) found in the production efficiency analysis of the electric utility industry. They postulated that production uncertainties are smaller for the most efficient and the least efficient, production units. According to Bera & Sharma (1999), when a production unit operates at its most efficient level, there is less likely to be variation in production. Likewise, when a production unit is least efficient, the production is at such a low level that there is little variation in production. On the other hand, a production unit which produces in between the least and most efficient, can have greater variation in its production (Bera & Sharma, 1999).

Overlapping CIs for production efficiency are not surprising given the nature of the data and the technique used for frontier estimation (see Section 5.8 for detail). The data were cross sectional and were collected for a single year only. If instead panel data were used, efficiency estimates would then be computed by comparing different observations from different years for individual CFs (Street, 2003). Greater numbers of observations for individual units, reduce the likelihood of sampling errors (Horrace & Schmidt, 1996). The collection of time series data for this study was not possible owing to the poor quality of record keeping in many CFUGs. Availability of time series data could improve the reliability of efficiency estimation (Thiam et al., 2001).

## 7.6 Efficiency ranking of community forests

The distribution of forest product benefits across three groups of CFs based on the efficiency ranking, shows that CFs with higher production of forest products per hectare were the most efficient. The most efficient group of CFUGs, annually earned an average of NRs 52,971 per hectare. The moderately and least efficient groups of CFs have generated NRs 22,293 and NRs 10,954 per hectare respectively. This phenomenon of CFUG with higher efficiency and generating higher benefits indicates that CFUGs with lower production of forest products were not necessarily utilising their inputs (factors of production) in the most effective ways. Thus, there appears to be a case for concurrently increasing production and the production efficiency of these CFs, so that for the same amount of inputs, the production of forest products could be increased. Alternatively, inputs could be reduced while producing the same level of forest products. A similar pattern of distribution was also observed by Lien at el. (2007) in their study on technical efficiency of timber production in private forest land in Norway. They found that the high efficiency group had a significantly higher timber harvest. However, contrary to this finding, Misra and Kant (2005) have reported that forest production was lower in the village communities where there was higher efficiency. One possible explanation for their result is that a higher marginal cost may have been involved, in harvesting forest products at a higher end of output in joint forest management. The second explanation may be the types of outputs; they have used the supply of forest products, forest canopy cover and social empowerment as outputs. Canopy cover was positively associated with the supply of forest products and social empowerment. On the other hand, social empowerment and supply of forest products were rival products (Misra & Kant, 2004).

It is interesting to note that CFs such as *Rani* and *Nureni Chisapani*, which were recognised as active and well managed CFs and received the national award for forest management, had efficiency scores of only 67.15% and 59.61% respectively, and were categorised as moderately efficient. A reason for this apparent inconsistency is the criteria for CF management evaluation. The government evaluated criteria such as the state of the forest before it was handed over to the community, expenditure on the community, forest development, administrative activities, participation by women, and the forest product distribution system to evaluate CF management (Pokharel & Larsen, 2007). The awards therefore address criteria somewhat different from efficiency.

## 7.7 Factors explaining production efficiency

Once performance in terms of production efficiency is measured, identifying the sources of performance difference is essential in order to develop management and policy prescriptions for improving performance (Bravo-Ureta & Pinheiro, 1997; Lien et al., 2007; Parikh et al., 1995). The model for production efficiency effects provides some helpful clues to improve the performance of the CF. Various factors related to the community were hypothesized to influence production efficiency.

Since CFs were grouped based on their efficiencies, and ordinal ranking was allotted to the CFs, an ordered logit model was used to identify the factors of inefficiency (see Section 5.7.6). The results showed that factors such CF longevity, the growing stock of the forests and support from government staff, positively contribute to production efficiency. Caste heterogeneity within CFUGs' ECs has been found to have a negative association with production efficiency.

### 7.7.1 CF longevity

The time since the establishment of the CF has an effect on efficiency, which was significantly positive and substantial, indicating that forests which have been managed for a long time were more efficient. This may be due to managerial skills and knowledge, which CFUG members have learnt over time (Carter & Siry, 2003). To my knowledge, no studies have examined the relationship between longevity and production efficiency. Instead, many other forms of knowledge or skill acquiring sources, such as age, education, experience and the training of producers, have been widely studied, and have documented both negative and positive relationships between efficiency and various sources of skills and knowledge. Only a few studies related to forestry have considered the relationship of efficiency with skills and knowledge (For example, Carter & Siry, 2003; Lien et al., 2007; 1998). Carter & Siry (2003) demonstrated that production efficiency is positively associated with the age and experience of pulpwood producers in Southern US pulpwood industries. However, on the contrary, Lien et al. (2007) noted that highly educated forest owners were less technically efficient in timber production than the lower educated ones. In the same study, highly experienced owners were less efficient. A possible explanation for this negative relation of education and experience with efficiency is that the more educated and experienced farmers had less time for the supervision of their forestry farms, because of their participation in other social activities such as politics (Ojo, 2003). The association of efficiency with skills and knowledge has been extensively studied in agriculture and the studies have reported positive relationships of production efficiency with age, experience and education (Binam et al., 2004; Bravo-Ureta & Pinheiro, 1997; Lindara et al., 2006; Parikh et al., 1995; Rehman & Romero, 1993).

The positive relationship between CF longevity and production efficiency has implications for improving the production efficiency of newly formed CFUGs. Instead of waiting for the skills and knowledge, which CFUGs do learn in the course of time, the government authorities can enhance skills and knowledge by training, workshops and exposure visits (Dev et al., 2003). A further study may be needed to find out what sort of managerial skills CFUG members need in order to enhance production efficiency.

### 7.7.2 Social capital

The role of social capital in economic development has been widely recognised (Grootaert & Narayan, 2004; Narayan & Pritchett, 1999; Nepal et al., 2007). Like other studies, this study also found a positive role of social capital in CF production efficiency (Table 6.12). The relationship was as expected. It is possible that social capital reduces transaction costs among CFUG members, and hence helps to enhance efficiency (Pretty, 2003; Pretty & Ward, 2001). According to Grootaert & Narayan (2004) and Binam et al. (2004), social capital induces a sharing of information, thereby reducing opportunistic behaviour, which consequently facilitates collective decision making. Narayan & Pritchett (1999) similarly claimed that greater social capital potentially leads to better outcomes, by improving cooperation among group members, because it builds trust among group members (Narayan & Pritchett, 1999). Various empirical research corroborates the positive relationship between social capital and production efficiency (Sakurai, 2006; Van Ha et al., 2006, discussed in Section 2.5.2).

This study considered an aggregate of four components of social capital – trust and solidarity, stability, collective action and cooperation, and social cohesion and inclusion, but the relationship of individual component with production efficiency was not examined. The contribution of different components of social capital to production efficiency may vary (Van Ha et al., 2004). Therefore, the result of this study alone is not sufficient as a basis for policy recommendations. Results from other empirical studies (Narayan & Pritchett, 1999; Van Ha et al., 2004) and the positive association of social capital with production efficiency in CFs, may offer some insight into improving the economic performance of CFs. Some level of social capital is inherently embedded in CFUGs (Adhikari, 2006; Nepal et al., 2007; Thoms, 2008), therefore activities should be directed towards improving the existing social capital. For example, interactions among forest users and between forest users and government staff would help to build trust among them. Likewise, developing information sharing mechanisms among the agencies concerned with CF management, would help to avoid conflict in CF management.

Since the current study has examined the positive role of social capital on production efficiency, its effect on other infrastructure and development activities in a community cannot be similar (Nepal et al., 2007). These subjects are not topics for production efficiency analysis, but are possible topics for future study.

### 7.7.3 Support from government staff

CFUGs continuously receive support in various forms from forestry staff to perform management activities (Thoms, 2007). With limited numbers of staff and limited capacity, it is not possible to provide thorough support to an ever increasing number of CFs (Kanel & Kandel, 2004; Paudel & Vogel, 2009). Levels of support are not the same for all CFUGs. The support varies from CFUG to CFUG and depends on various factors such as the physical proximity of the CF from the supporting agencies and CFUG members' personal relationships with forestry staff (Edmonds, 2002; Thoms, 2008). This study examined whether the level of support to CFUGs determines their production efficiency.

Forestry staff provide support in various forms, such as assessments of forest products, legal advice and in building links with external markets. It was expected that these supports would help to reduce the cost of forest product production, resulting in CFs which receive support from forestry staff, performing better in terms of production efficiency than those not receiving support. The result showed that government support had a positive and statistically significant impact on production efficiency. Government support contributes to reduce transaction costs between external markets and CFUGs, and between community members (Misra & Kant, 2004). Similarly, local forestry staff visits may reduce the costs of negotiations between district level forest offices and CFUGs (Adhikari, 2006). In the absence of local staff CFUG members have to negotiate directly with district level staff and this involves a longer time to get results.

This finding is consistent with Lindara et al. (2006), who found that farm visits by extension officers increased the production efficiency of Sri Lankan farmers. Examining the profit efficiency of rice farming in Bangladesh, Rahman (2003) found that diffusion of modern rice farming to the farmers through extension played a significant role in enhancing profit efficiency. Likewise, in examining the effect of internal factors on the inefficiency of the Regional Forestry Board in Finland, Viitala & Hanninen (1998) have documented a significant positive influence of government management support, on motivation and production efficiency. Misra & Kant (2004) found that support from non-governmental organisations (NGOs) contributes to increasing the supply of forest products, because NGOs facilitate interaction among the forest users and hence reduce transaction costs.

The significant positive impact of government support on production efficiency can be used to improve the production efficiency of CFs. The support service provided by government staff seems insufficient compared to the increasing demands of CFUGs (Paudel & Vogel, 2009). Therefore, external support seems essential for efficient output. Government agencies could facilitate support from other non governmental agencies related to forestry, to those not receiving support from forestry staff. Various other authors have also realised the need of support from non-governmental organisations (Kanel, 2004; Neupane, 2003).

### 7.7.4 Growing stock

Only a few studies related to forestry have investigated the role of forest capital in production efficiency. This study attempted to identify the role of CF growing stock, which is a form of capital, on production efficiency. The result showed that the coefficient of growing stock was positive and significant, suggesting that a CF with higher growing stock is more efficient than a CF with lower growing stock (Table 6.12). High growing stock indicates more forest products availability per unit area of a forest (Misra & Kant, 2004; Siry & Newman, 2001). As a result CFUG members incurred fewer costs to harvest one unit of forest products. Similar results have been reported in past analyses of productivity in the forest and agriculture sectors. For example, Viitala & Hanninen (1998) found a positive association between forest stock and production efficiency in the Forestry Board of Finland. Siry & Newman (2001) noted that the growing stock of the forest was positively associated with production efficiency in Poland. Kant and Misra (2004) demonstrated a positive association between growing stock and forest product supply in joint forest management in India.

The positive influence of growing stock on production efficiency indicated by this study and other studies suggest that maintaining a higher growing stock is likely to increase efficiency in the production of forest products. However, improving growing stock in forest management is not possible in the short term. There is very little implication for forest capital stock in the short term, because of the nature of forest capital stock.

### 7.7.5 Heterogeneity in Executive committee

The effect of group heterogeneity on common property resource management is a highly contestable issue and has been debated extensively in the literature. Some researchers have argued that heterogeneity produces variability in interest, so cooperative arrangements are difficult to achieve (Ostrom, 2002). On the other hand, authors such as Gautam (2007) and Adhikari and Lovett (2006) were unable to establish any significant relationship between group heterogeneity and collective action in community managed forests. Olson (1965) hypothesised that higher heterogeneity may favour collective action if those with the most economic interests and power, initiate collective action.

This study investigated the effects of caste heterogeneity in executive committees (ECs), on production efficiency. ECs are the main decision making bodies in CFs and they make decisions regarding the distribution of forest products and forest management activities. ECs are either formed by election or nominated by consensus. Many CFUGs attempt to make ECs more representative, appointing representatives from different castes and economic classes. In these circumstances, this study hypothesised that caste variability in ECs is an impediment to production efficiency.

The ordered logit model showed that the coefficient for caste heterogeneity in ECs is negative and significant (Table 6.17), which implies that CFs which have relatively homogenous ECs were more efficient than CFs which have heterogeneous ECs. One possible reason for the negative sign is that heterogeneity affects interactions among EC members, incurring higher transaction costs (Varughese & Ostrom, 2001). Due to the variability in castes, EC members hold different values, therefore involving higher transaction costs to make a decision (Adhikari & Lovett, 2006). Similarly, authors such Thoms (2007) and Lawrence et al. (2007) observed that EC members tend to make decisions that favour their own interests and those of others who belong to their group. For example, low caste members of CFUGs usually prefer fuelwood, fodder and medicinal plants, and therefore low caste EC members emphasise the production of these products. On the other hand, higher caste EC members may prioritise timber production because they use more timber (Lawrence et al., 2007; Thoms, 2008).

Similar results have also been reported by other empirical studies. For example, Naidu (2005) has found that a certain level of caste heterogeneity was negatively associated with collective action, in forest communities in the North-western Himalayas in India. However, Naidu noticed that the probability of cooperation became higher when two households belonging to the same caste exceeded 30 percent. Similarly, Banerjee et al. (2005) have demonstrated that caste heterogeneity is correlated with a low level of public good provision, across 391 Indian districts.

There is no straight-forward way to mitigate the diversity in values among the members, which arise because of caste differences. If however, exclusion and discrimination are minimal, a high level of cooperation may be achieved, even in caste heterogeneous communities. Therefore, government agencies implement policies which help to minimise discrimination and exclusion. Naidu (2005) however, has argued that a high level of cooperation is likely to occur if equal numbers of members from each caste are included in the ECs. In that situation, the possibility of domination by one caste group is low. Government forest staff can minimise the effects of caste heterogeneity by engaging in a negotiator's role (Thoms, 2007).

## 7.8 Summary

A dense, broadleaved, immature and multiple canopy layered forest, produced the highest environmental benefits, whereas an open coniferous forest, which is mature and has a single canopy layer, produced the least. Soil conservation was the most important service for CFUGs, followed by water conservation, wildlife conservation, and aesthetic value. This preference ranking suggests that community members attach value to ESs depending upon the current or likelihood of impact of the services on their livelihoods.

The CF stochastic production frontier estimation clearly shows the influence of various socio-economic and environmental factors including the environmental condition, on forest productivity and production efficiency. The existence of a market link, higher forest product dependency and larger group size enhances production, whereas distance to the government office, CF area and group heterogeneity reduces production in a CFUG. In contrast to other studies, this study found a complementary relationship between environmental performance and forest product production, implying that improvement in the ESs may be possible along with an increase in forest product benefits.

The production efficiency analysis suggested a substantial potential for improving efficiency in CFUGs. A Monte Carlo simulation technique categorised CFs into three groups: efficient, moderately efficient and inefficient. The ordered logit model indicated that; CF longevity, social capital, growing stock, support from government staff and caste heterogeneity in the executive committee affect the production efficiency. This implies that the production efficiency of individual CFUG might be able to be improved by management of these factors. Based on these findings and their interpretations, the next Chapter draws conclusions, and provides recommendations and suggestions for future research.

# Chapter 8
# Summary, Recommendations and Conclusions

This chapter summarises findings and draws conclusions based on the discussion. Important findings, challenges and possible future research directions are discussed.

## 8.1 Research objectives and research design

The community forest management programme is the main thrust of Nepalese government forest policy, and it has received the highest priority compared to other types of forest management. In addition, government forest policy statements have emphasised the effective role of community forests in poverty reduction through their impact on local level economies and environmental conservation. In order to reduce poverty, efficiency in production, equity in distribution of forest products and ecosystem sustainability are essential. Efficiency in production contributes to poverty reduction by 'making the overall cake bigger' (Adhikari, 2005; Binam et al., 2004). Ecosystem sustainability contributes to a continuous supply of forest goods and services (Chakraborty, 2001). Equity requires that benefits are distributed according to the contribution of individual members. Existing studies in community forestry are either focused on production aspects of individual products or on the distribution of forest products. Studies focused on the production of single products have revealed that the biophysical condition of forests has improved since they became CFs (Chakraborty, 2001; Gautam et al., 2002), but the studies were unable to provide evidence of forest product benefits and effects on community welfare. Similarly, from the distributional perspective, studies have shown that poorer households have less access to forest products and income than the richer households (Adhikari, 2005), but provided limited information on changes in environmental conditions due to the extraction of forest product benefits. The relationship between community welfare from the consumption of forest products, and the condition of the natural environment in CFs, has not been addressed. Identification of factors which affect the outputs of forest products in CFs has also not received much research attention. The evaluation of production efficiency of CFs in terms of direct forest product benefits and its determining factors, also has not been well studied. Identification of the factors affecting direct forest product benefits and production efficiency, is essential for recognizing opportunities for *Pareto improvement*. Therefore, this study investigated:

- Factors that determine direct forest products benefits in community forests.
- The relationship between CF environmental and direct forest product benefits.

- Whether community forest user groups (CFUGs) produce direct forest product benefits efficiently.
- Factors that explain the production efficiency of CFUGs.

To address these research questions, two Middle Hills districts - *Makawanpur* and *Kavrepalanchok* - were selected for the study. Structured questionnaires were employed to collect information regarding socioeconomic conditions of communities. Group discussions were used to collect information regarding environmental condition of forests. The Analytic Hierarchy Process was used to the estimate environmental benefits of forests. Forest related information was collected by establishing sample plots in CFs. A sample set of fifty seven communities were used for this study. A stochastic production frontier model was employed to identify the relationship between direct forest product benefits and environmental benefits.

The stochastic production frontier analysis shows that various socioeconomic factors influence CF production of direct forest product benefits. Factors such as distance to the government office, CF size and group heterogeneity negatively affect CF products benefits. On the other hand, links to the market, forest products dependency, and the number of households in the community augment benefits from CFs. These factors go beyond the conventional factors of - land, labour and capital (Misra & Kant, 2004). The relationship between CF production and various socioeconomic factors indicates possibilities for benefit enhancement. For example, establishing a link to the market would allow communities to sell their products for higher prices, resulting in increased benefits to communities. Likewise, support from non-governmental organizations could lessen the negative effect of the government forest office being too far from the CFUGs. Contrary to expectation, the study found that environmental benefits and forest product benefits are not competing objectives. This positive association implies the possibility for concurrently augmenting forest product supply along with environmental benefits from CFs.

Production efficiency estimates provide evidence that individual CFs were not producing efficiently. Based on cross sectional data for the year 2009, the average production efficiency was 62.81%, indicating opportunities for improvement in production efficiency. CFUGs which have been generating higher direct forest product benefits were generally found more efficient than the CFUGs generating lower benefits. This indicated that CFUGs with a lower production of forest products were not utilising their inputs in the most effective ways. Thus the production of direct forest product benefits in less efficient CFUGs could be increased by reallocating the inputs which have already been used.

The identification of determinants of production efficiency, provided helpful information to improve the performance of CF management in Nepal. Factors such as the longevity of CFs, social capital, growing stock and support from government staff, induced high CF production efficiency. Heterogeneity in executive committees decreased production efficiency.

## 8.2 Practical implications

Policy makers and CFUGs should pay due consideration to these factors that affect the production. In particular, the positive association of environmental benefits with the benefits from direct forest product benefits, explored the possibility for the improvement of ecosystem services together with forest product benefits. This is an important outcome for policy makers and forest users should be given due consideration in community forestry programme implementation.

It is generally accepted that point estimation of production efficiency involves uncertainty; as a result it is difficult to make a distinction between efficient and inefficient production units (Jensen, 2000). In this connection, this study used the Monte Carlo simulation experiment to distinguish community forests into three different categories based on their efficiency. Thus, this study showed a possible application of the Monte Carlo simulation experiment for production efficiency analysis study, in the future.

Policy makers and forest users should make an effort to increase the levels of factors that improve production efficiency. Although enhancement of the growing stock of a forest and differences in the values due to caste heterogeneity may not be possible to change in a short period of time, the effects of other factors such as social capital and the longevity of the CF can be enhanced through indirect means such as training, exposure visit and workshops.

## 8.3 Contributions

This study has contributed to the literature in three main aspects. First, this study explored the sources of benefits in CFUGs. The benefits from direct forest products are typically emphasised, and environmental benefits are usually ignored in community forest management discourse. The government emphasises the production of direct forest products as a source of income in CF management. However, this study has identified that besides the contribution of timber, litter, fuelwood, fodder and grasses, environmental benefits are important to communities and are greatly contributing to the income of CFUGs. In addition, the study found that, for the forests studied here, direct forest product benefits and environmental benefits are complementary goods.

The second major contribution is the modelling of environmental benefits. This study uses ANP for an environmental benefit evaluation. ANP enabled the complex problem of the environmental value of forest ecosystems to be broken into a systematic network of ecosystem services and related forest attributes. Based on the priority weights for ecosystem services and forest attributes, this study was able to estimate the environmental benefits of a CF. The advantage of ANP was that it allowed the ranking of different forests based on their contribution to ecosystem services, without measuring the willingness to pay in terms of monetary value.

The third major contribution is the application of stochastic production frontier analysis to study community based forest management. Deterministic and non-parametric production analyses have been used in many instances to study CF. To my knowledge, this is the first study which has used stochastic production frontier analysis to analyse forest product benefits in CF management. The use of stochastic production frontier analysis allowed assessment the factors of production in the first stage and production efficiency in the second stage. This study opens up an avenue for use of stochastic frontier analysis in other aspect of community forest management, such as performance in terms of governance (Adkins et al., 2002; Méon & Weill, 2005).

## 8.4 Strengths, weaknesses and avenues for future research

The main strength of this research lies in conceptualising the production process in CFs, developing methodology, collecting data related to forestry and community, and modelling the joint production of environmental benefits and direct forest product benefits. Particularly, the study explored the application of ANP for the estimation of the environmental benefits of forest ecosystems. The research described the structure of production, and estimated production efficiency for individual communities. The study provided many policy relevant outcomes, which have already been discussed. Because of the pioneering nature of this study, some limitations are apparent, which should be addressed through future research.

First, since this study was carried out in the Middle Hills of Nepal, results cannot be generalised to other parts of the country. However, use of the same approach in other parts of the country would be useful for the better understanding of CF production possibilities. The study suffers from the lack of time series production data. Availability of time series data would improve the reliability of the CF production analysis (Coelli, 1995; Hallam & Machado, 2001; Siry & Newman, 2001). Therefore, government staff, researchers and even forest users should make efforts to establish a system of annual data recording in each CF.

Such data resources are essential for complete production analysis. However, policy decisions should not be deferred in the absence of time series data. The outcomes of this study can be used to improve CF production efficiency in the Middle Hills of Nepal.

Second, owing to budget and time constraints, this study sampled only 57 CFs, which was relatively small for the detailed analysis of the CF production process. Application of the Cobb-Douglas functional form in this study has provided only the direct effects of production factors. With a larger sample, application of the more flexible translog functional form could possibly provide more information, especially related to the interaction effects of different factors of production (Adkins et al., 2002; Cubbin & Zamani, 1996; Siry & Newman, 2001). Therefore, this study suggests further investigation with the use of a larger sample for CF production analysis.

Third, this study is the first attempt to use the ANP technique to estimate the environmental benefits in CFs. Execution of ANP at the community level had some issues. The prevalent issues were handling large numbers of questions and participant difficulty in understanding ANP questions, especially questions related to the interaction effects of ecosystem services and forest attributes. Therefore, future effort should be directed at simplifying the ANP model and the ANP questions.

## 8.5 Conclusions

This study has made a number of significant contributions to the understanding of CFs in Nepal, and to the production efficiency literature, by: (i) developing a production model in community based management of forest resources, (ii) identifying the role of socioeconomic factors in community based production processes, and finally, (iii) designing and applying a Monte Carlo simulation experiment to identify the ranking of production units in terms of production efficiency, when point efficiency estimates were highly uncertain. The design and application of the ANP model to evaluate the environmental benefits of forest resources from a community perspective, constitutes an innovative step. Finally, work developed in this study and methods employed, may have relevance to audiences concerned with production modelling, in cases other than the community managed forest case explored here.

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# Appendix A

## Mathematical derivation of efficiency

This appendix explains the derivation of efficiency, when inefficiency ($u_i$) is assumed to following a half normal distribution.

Assume that the stochastic production frontier follows the Cobb-Douglas functional model;

$$\ln Y_i = \beta_0 + \sum \beta_n \ln X_{ni} + (v_i - u_i)$$

and

(i) $v_i$ is identically independently distributed with N(0, $\sigma_v^2$ )

(ii) $u_i$ follows a half normal distribution i.e $u_i \sim N^+(0, \sigma_u^2)$

(iii) $v_i$ , $u_i$ and $X_{ni}$ are mutually independent

Then the probability density function of $u_i$ >0 is by (subscript *i* is removed for convenience);

$$f(u) = \frac{2}{\sqrt{2\Pi}\sigma_u} \cdot \exp\left\{-\frac{u^2}{2\sigma_u^2}\right\} \qquad (A.1)$$

Similarly, the probability density function of $v_i$ is:

$$f(v) = \frac{1}{\sqrt{2\Pi}\sigma_v} \cdot \exp\left\{-\frac{v^2}{2\sigma_v^2}\right\} \qquad (A.2)$$

Since *u* and *v* are independent of each other, the joint probability density function of *u* and *v* is the product of their individual probability density functions and is;

$$f(u,v) = f(u).f(v) = \frac{2}{2\Pi\sigma_u\sigma_v} \cdot \exp\left\{-\frac{u^2}{2\sigma_u^2} - \frac{v^2}{2\sigma_v^2}\right\} \qquad (A.3)$$

Since $\varepsilon = v - u$, $v = \varepsilon + u$ and therefore $v^2 = (\varepsilon + u)^2$. Substituting the value of $v^2$ in Equation (A.3), the joint probability density for *u* and *ε* is:

$$f(u,\varepsilon) = \frac{2}{2\Pi\sigma_u\sigma_v} \cdot \exp\left\{-\frac{u^2}{2\sigma_u^2} - \frac{(\varepsilon+u)^2}{2\sigma_v^2}\right\} \qquad (A.4)$$

The marginal density function of *ε* is obtained by integrating *u* out of *f* (*u, ε*) which is;

$$f(\varepsilon) = \int_0^\infty f(u,\varepsilon)dx$$

$$= \frac{2}{\sqrt{2\Pi}\sigma} \cdot \left[1 - \Phi\left(\frac{\varepsilon\lambda}{\sigma}\right)\right] \cdot \exp\left\{-\frac{\varepsilon^2}{2\sigma^2}\right\}$$

$$= \frac{2}{\sigma} \cdot \phi\left(\frac{\varepsilon}{\sigma}\right) . \Phi\left(-\frac{\varepsilon\lambda}{\sigma}\right) \qquad (A.5)$$

Where $\sigma = (\sigma_u^2 + \sigma_v^2)^{1/2}, \lambda = \sigma_u / \sigma_v$ and $\phi(.)$ and $\Phi(.)$ are, respectively, the probability density function and the cumulative distribution function of the standard normal distribution.

Therefore, conditional density of u given ε is the ratio of Equation (A.4) to Equation (A.5), which is given by;

$$f(u \mid \varepsilon) = \frac{f(u,\varepsilon)}{f(\varepsilon)} = \frac{1}{\sqrt{2\Pi}\sigma_*}.\exp\left\{\frac{u-\mu_*}{2\sigma_*^2}\right\} / \left[1-\Phi\left(-\frac{\mu_*}{\sigma_*}\right)\right] \qquad \text{(A.6)}$$

where $\mu_* = -\varepsilon\sigma_u^2/\sigma^2$ and $\sigma_*^2 = \sigma_u^2\sigma_v^2/\sigma^2$.

Since $f(u \mid \varepsilon)$ is distributed as $N^+(\mu_*, \sigma_*^2)$ either mean or mode of this distribution can serve as a point estimator for $u_i$;

$$E(u_i \mid \varepsilon_i) = \mu_{*i} + \sigma_*\left[\frac{\phi(-\mu_{*i}/\sigma_*)}{1-\Phi(-\mu_{*i}/\sigma_*)}\right]$$

and

$$M(u_i \mid \varepsilon_i) = -\varepsilon_i\left(\frac{\sigma_u^2}{\sigma^2}\right) \text{ if } \varepsilon_i \leq \mathbf{0}$$

$$= 0 \text{ otherwise.}$$

# Appendix B

## Socio-economic Questionnaire

**1. General information of CFUG**

Name of CF: Area of forest (ha):
Number of households: Type of forest:
Handed over date: VDC /Ward:

**2. What is the approximate distance of CF from market (the market place where forest products are sold) (in Km)?**

**3. What is the approximate distance of CF from nearest government forest office (in Km)?**

**4. Socio-economic condition of CFUG**

4.1 Number of households in different economic classes

| Economic classes | No of HHs |
|---|---|
| *Rich* | |
| *Medium wealth* | |
| *Poor* | |

4.2 Number of households in different caste groups

| Social groups | No of HHs |
|---|---|
| *Brahmin & Chhetri* | |
| *Janajati* | |
| *Dalit* | |

4.3 Number of households head in different education groups

| Education | No of HHs |
|---|---|
| Illiterate | |
| Literate | |
| Highly literate | |

4.4 Number of households living at different distances from community forest.

| Distance | No of HHs |
|---|---|
| < 0.5 Km | |
| 0.5 – 1 Km | |
| > 1 km | |

4.5 Number of households in different profession

| Profession | No of HHs |
|---|---|
| Agriculture and livestock farming | |
| Business | |
| Job holders | |
| Others | |

**5. Socio-economic condition of community forest's executive committee.**

5.1 Number of executive committee members in different economic classes.

| Economic class | Number of executive committee members |
|---|---|
| Rich | |
| Medium | |
| Poor | |

5.2 Number of executive committee members in different caste classes.

| Social groups | No of households |
|---|---|
| Brahmin & Chhetri | |
| Janajati | |
| Dalit | |

**6. Block division of CF and their description**

| Block description | Objectives of management ( on the priority basis) | Changed in forest condition since its hand over | |
|---|---|---|---|
| Block no:<br>Area (ha):<br>Forest type: | 1. Timber ☐<br>2. Fuel wood/fodder ☐<br>3. Medicinal plant ☐<br>4. Others ☐ | Forest density<br>Forest area | Increased ☐ decreased ☐ Same ☐<br>Increased ☐ decreased ☐ Same ☐ |
| Block no:<br>Area (ha) :<br>Forest type: | 1. Timber ☐<br>2. Fuel wood/fodder ☐<br>3. Medicinal plant ☐<br>4. Others ☐ | Forest density<br>Forest area | Increased ☐ decreased ☐ Same ☐<br>Increased ☐ decreased ☐ Same ☐ |
| Block no:<br>Area (ha) :<br>Forest type: | 1. Timber ☐<br>2. Fuel wood/fodder ☐<br>3. Medicinal plant ☐<br>4. Others ☐ | Forest density<br>Forest area | Increased ☐ decreased ☐ Same ☐<br>Increased ☐ decreased ☐ Same ☐ |
| Block no:<br>Area (ha):<br>Forest type: | 1. Timber ☐<br>2. Fuel wood/fodder ☐<br>3. Medicinal plant ☐<br>4. Others ☐ | Forest density<br>Forest area | Increased ☐ decreased ☐ Same ☐<br>Increased ☐ decreased ☐ Same ☐ |
| Block no:<br>Area (ha) :<br>Forest type: | 1. Timber ☐<br>2. Fuel wood/fodder ☐<br>3. Medicinal plant ☐<br>4. Others ☐ | Forest density<br>Forest area | Increased ☐ decreased ☐ Same ☐<br>Increased ☐ decreased ☐ Same ☐ |

| | | | |
|---|---|---|---|
| Block no:<br>Area (ha):<br>Forest type: | 1. Timber ☐<br>2. Fuel wood/fodder ☐<br>3. Medicinal plant ☐<br>4. Others ☐ | Forest density<br>Forest area | Increased ☐ decreased ☐ Same ☐<br>Increased ☐ decreased ☐ Same ☐ |
| Block no:<br>Area (ha):<br>Forest type: | 1. Timber ☐<br>2. Fuel wood/fodder ☐<br>3. Medicinal plant ☐<br>4. Others ☐ | Forest density<br>Forest area | Increased ☐ decreased ☐ Same ☐<br>Increased ☐ decreased ☐ Same ☐ |

**7. What sort forest products are being extracted from your community forest?**

7.1 Quantities of different forest products being harvested;

| Forest products | Unit | Demand of forest products from CFUG | Quantity of forest products collected | | Forest products consumed | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 2007 | | 2008 | |
| | | | 2007 | 2008 | Within CFUG | Outside CFUG | Within CFUG | Outside CFUG |
| Timber | | | | | | | | |
| Firewood | | | | | | | | |
| Fodder | | | | | | | | |
| Grasses | | | | | | | | |
| Others | | | | | | | | |

7.2 Forest products harvested (block wise);

| Block No | Forest products | unit | Supply from CF (cubic feet) | | Maximum allowable ($m^3$/ha) | Growing stock ($m^3$/ha) |
|---|---|---|---|---|---|---|
| | | | 2007 | 2008 | | |
| 1 | Timber | | | | | |
| | Firewood | | | | | |
| | Fodder | | | | | |
| | Grasses | | | | | |
| | Others | | | | | |
| 2 | Timber | | | | | |
| | Firewood | | | | | |
| | Fodder | | | | | |
| | Grasses | | | | | |
| | Others | | | | | |
| 3 | Timber | | | | | |
| | Firewood | | | | | |
| | Fodder | | | | | |
| | Grasses | | | | | |
| | Others | | | | | |
| 4 | Timber | | | | | |
| | Firewood | | | | | |
| | Fodder | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Grasses | | | | | |
| | Others | | | | | |
| 5 | Timber | | | | | |
| | Firewood | | | | | |
| | Grasses | | | | | |
| | Fodder | | | | | |
| | Others | | | | | |
| 6 | Timber | | | | | |
| | Firewood | | | | | |
| | Grasses | | | | | |
| | Fodder | | | | | |
| | Others | | | | | |

**8. How many days does district forest office allocate for the collection of timber?**

**9. Has any one of your FUG taken training related to the harvesting of forest products?**

**10. Is there any sort of monitoring from district forest office?**

Yes ☐ If yes, how many times in a year? ☐

No ☐

**11. How many times in a year fuel wood is collected?**

**12. How many times in a year fodder is collected?**

**13. How many times in a year litter/ grasses is collected?**

**14. Are there any hindrances or supports from government forest office, in the production of following forest products?**

a. Timber:

Hindrances: Yes ☐ if yes explain: ☐

No ☐

Supports: Yes ☐ if yes explain ☐

No ☐

b. Fire wood:

Hindrances: Yes ☐ if yes explain: ☐

No ☐

Supports: Yes ☐ if yes explain: ☐

No ☐

c. Fodder

Hindrances: Yes ☐ if yes explain: ☐

No ☐

Supports: Yes ☐ if yes, explain: ☐

No ☐

d. Grass

Hindrances: Yes ☐ if yes, explain: ☐

No ☐

Supports: Yes ☐ if yes explain ☐

No ☐

e. Litter

Hindrances: Yes ☐ if yes explain ☐

No ☐

Supports: Yes ☐ if yes explain ☐

No ☐

**15. Do your CF has road access to the market to sell forest products?**

Yes ☐ No ☐

**16. Do you have information about market price of the following forest products?**

| SN | Forest products | No (Pls tick the box) | Yes (Pls tick the box) | If yes, how much is the price? ( In NRs) |
|---|---|---|---|---|
| 1 | Timber | ☐ | ☐ | |
| 2 | Fire wood | ☐ | ☐ | |
| 3 | Fodder | ☐ | ☐ | |
| 4 | Other forest products | ☐ | ☐ | |

**17. Are you receiving any technical assistance regarding forest management from government forest offices or any other agencies? If yes, explain**

Yes ☐ If yes explain ☐

No ☐

**18. What sort of assistance do you get from government forest office to sell forest products?**

**19. What kind of assistance do you expect from government regarding production of different forest products?**

**20. Direct Benefits from a CF;**

20.1 Willingness to pay for different forest products which are not sold in market directly;

| SN | Forest products | Willingness to pay for per unit ( in term of NRs) |
|---|---|---|
| 1 | Fodder | |
| 2 | Fire wood | |
| 3 | Grasses | |
| 4 | Litter | |

20.2 Benefits from forest products;

| S. N. | Forest products | Unit | Quantity consumed within CFUGs | Price/ unit for users | Quantity sold outside CFUGs | Price (NRs)/unit for outsiders |
|---|---|---|---|---|---|---|
| 1 | Timber | | | | | |
| 2 | Firewood | | | | | |
| 3 | Fodder | | | | | |
| 4 | Grasses | | | | | |
| 5 | Litter | | | | | |

**21. Benefits from forest services of CF**

21.1 Are you doing any activities for the following forest services?

a. Soil conservation: Yes ☐ No ☐ If yes, explain ☐

b. Water conservation: Yes ☐ No ☐ If yes, explain ☐

c. Aesthetic value: Yes ☐ No ☐ If yes, explain ☐

d. Wildlife habitat: Yes ☐ No ☐ If yes, explain ☐

**22. Is your CFUG getting any incentive or assistance from GO or NGOs governmental organisations for producing forest services mentioned in the question 21?**

22.1 What kind of benefit?

Cash ☐ Technical assistance ☐ Training ☐ Any other ☐

Explain: _____________

22.2 Have you got any directives or suggestion from the government regarding production of environmental services?

Yes ☐ No ☐

If yes please explain:

**23. Costs of producing different forest products**

23.1 Cost of harvesting forest products

| S.N | Forest products | Unit | Labour days/ Time spent ( hours)/ cash | | Remarks |
|---|---|---|---|---|---|
| | | | 2007 | 2008 | |
| 1 | Timber | | | | |
| 2 | Firewood | | | | |
| 3 | Fodder | | | | |
| 4 | Grasses | | | | |
| 5 | Others | | | | |

23.2 Cost of equipments;

| S.N | Types of equipments | Price of equipments | Economic life of equipments | Remarks |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |

23.3 Costs of management activities;

| S.N | Management activities | Labour days | | Rate of payment ( NRs) | Remarks |
|---|---|---|---|---|---|
| | | 2007 | 2008 | | |
| 1 | Thinning | | | | |
| 2 | Pruning | | | | |
| 3 | Plantation | | | | |
| 4 | Weeding | | | | |
| 5 | Others | | | | |

23.4 Time spent for indirect management activities;

| S.N | Related activities | Sub activities | Time spent | | Unit | Remarks |
|---|---|---|---|---|---|---|
| | | | 2007 | 2008 | | |
| 1 | Monitoring | Harvesting activities | | | | |
| | | Distribution activities Others | | | | |
| 2 | Forest protection | Forest watcher | | | | |
| 3 | Information collection and negotiation | Visit to district forest office | | | | |
| | | visit to market | | | | |
| | | Networking | | | | |
| | | Others | | | | |
| 4 | Decision making | Executive committee meeting | | | | |
| | | General assembly meeting | | | | |
| | | Others | | | | |

# Appendix C

## Questionnaire for social capital

1. **General information of CFUG**

   Name of CF: Date of handover:

   Area of forest (ha): Number of households:

2. **Stability of FUGs**

   2.1. How frequently the rules are changed?
   a. Very frequently b. Occasionally c. Changed only if needed

   2.2. How frequently executive committee meetings are held?
   a. Once in a month c. Occasionally b. Whenever required

   2.3. How are the decisions made by executive committee?
   a. By consensus. b. By voting c. Unilaterally

   2.4. How frequently the general assembly meeting takes place?
   a. Once in a year b. Twice in years c. As and when required

3. **Trust and solidarity**

   3.1. After the formation of community forest the trust among the members have

   a. Gotten better b. Gotten worse c. Stayed about the same

   3.2. How the forest user group executive committee members are selected?

   a. By an outside person b. Each member chooses their committee c. By decision of all members

   3.3. As compared to 5 years ago, how do members of FUG participate in CF management activity?
   a. Very actively c. Moderately b. Less actively

4. **Collective action and cooperation**

   4.1. How has the cooperation for collective action changed after entrust of the CF?

   a. Increased. b. Decreased. c. Remain the same.

   4.2. How do you evaluate the women's role in community forest management?
   a. Highly satisfactory. b. Satisfactory. c. Not satisfactory.

   4.3. How do you evaluate the participation of lower castes in the decision making process?
   a. Active b. Rarely. c. Never

   4.4. Are there any rules regarding the use of forest products?
   a. Yes b**.** No

   4.5. How do you evaluate, CF has clear rules of harvesting and distribution?

   a. Highly satisfactory b. Satisfactory c. Not satisfactory

   4.6. How do you evaluate the rules for protection and their implementation?

   a. Satisfactory b. Neutral c. Not satisfactory

4.7. How frequently does user group undertake monitoring and sanctioning activities?

a. Never   b. Occasionally   c. Seasonally   d. Year around

4.8. In your opinion how do you evaluate the compliance of members with rules regarding harvesting, protection and monitoring?

a. Highly satisfactory   b. Satisfactory   c. Neutral   d. Not satisfactory

4.9. What are the arrangements for a monitoring mechanism?
a. Self monitored   b. Paid forest watcher   c. Others _______

4.10. What are the arrangements for law enforcement?
a. Fines   b. Nothing   c. Returning collected products   d. Exclusion from group

4.11. How do you evaluate the institutional performance of CF?
a. Highly satisfactory ( )   b. Satisfactory ( )   c. Neutral ( )   d. Not satisfied ( )

**5. Information share and communication**

5.1. How frequently are information pertaining to decisions carried out by CFU committee disseminated

a. Frequently   b. Occasionally   c. Never

**6. Social cohesion and inclusion**

6.1. Is there any type of conflict regarding CF management?

a. Yes   b. No

6.2. How are the conflicts resolved?

a. Mutual understanding   b. Need third party   c. Not resolved

6.3. What is the status of women inclusion on the decision making process?
a. Equally included   b. only in a few occasion   c. Not included

6.4. What is the status of inclusion of *dalit*, *janjati* etc in decision making process?

a. Equally included   b. Only in few occasions   c. Not included

6.5. What is your perception regarding the distribution of benefits in CF?

| Distribution issue | Degree of satisfaction<br>1 2 3 4 5 | Remarks |
|---|---|---|
| Are you satisfied with the existing institutional arrangement? | | |
| Are you satisfied with the benefit distribution rules? | | |
| Do poor people participate in management activities? | | |

6.6. In your estimation, how do you assess the present forest condition?
a. Improving   b. Degrading   c. No change

6.7. Finally, in your opinion has the CF forest brought any social change (negative and positive) in the community besides mentioned earlier? 5 indicates highest change.

| S.N | Social change | Scale of change |
|---|---|---|
| 1 | | 1 2 3 4 5 |
| 2 | | 1 2 3 4 5 |
| 3 | | 1 2 3 4 5 |
| 4 | | 1 2 3 4 5 |

# Appendix D

## Questionnaire for environmental value of community forests

**General information of community forest user group**

Name of community forest: _____________
Address:
VDC: ________
Ward No: _________

In the following questions, I would like to elicit your opinion regarding the comparative importance of different environmental benefits of your community forest. Table 1 outlines how to rate the importance of one benefit or attribute over another benefit or attribute.

Table 1. Explanation of the standard 9- point preference scoring system

| Degree of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two environmental services ( ESs) or forest attributes (FAs) are equally important |
| 2 | Weakly more important | One ES or FA weakly important over the other |
| 3 | Slightly more important | One ES or FA slightly important over the other |
| 4 | Moderately more important | One ES or FA moderately important over the other |
| 5 | Strongly important | One ES or FA strongly important over the other |
| 6 | Strongly more important | One ES or FA strongly more important over the other |
| 7 | Very strongly important | One ES or FA very strongly important over the other |
| 8 | Very very strongly important | One ES or FA very very strongly important over the other |
| 9 | Absolute importance | One ES or FA extremely important over the other |

1. For environmental benefits of community, which of the following forest service is important, and what is the degree of importance?

| Benefits | Tick (√ )one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Soil conservation<br>Wildlife conservation | □<br>□ | □ | □ | □ | □ | □ | □ | □ | □ | □ |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wildlife conservation<br>Aesthetic value | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aesthetic value<br>Soil conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wildlife conservation<br>Water conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Water conservation<br>Soil conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aesthetic value<br>Water conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

2. For the soil conservation benefit of a forest, which of the following crown coverage is more important, and what is the degree of importance?

| Crown coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br>Moderate | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

3. For the soil conservation benefit of a forest, which forest type is more important, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous<br>Broad leaf | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coniferous<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

4. For the soil conservation benefit of a forest, which of the following forest development stages is more important, and what is the degree of importance?

| Development stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br>Immature forest | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

5. For the soil conservation benefit of a forest, what canopy layer of a forest is more important, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

6. For the water conservation benefit of a forest, which crown coverage is more important, and what is the degree of importance?

| Crown coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br>Moderate | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

7. For the water conservation benefit of a forest, what canopy layer of a forest is more important, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

8. For the water conservation benefit of a forest, which forest type is more important, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous<br>Broad leaf | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coniferous<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

9. For the water conservation benefit of a forest, which of the following forest development stages is more important, and what is the degree of importance?

| Development stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mature forest<br><br>Immature forest | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

10. For the aesthetic value of a forest, which crown coverage, is more important, and what is the degree of importance?

| Crown coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br><br>Moderate | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br><br>Dense | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br><br>Dense | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

11. For aesthetic value of a forest, what canopy layer of a forest is more important, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br><br>Multiple layers | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

12. For the aesthetic value of a forest, which of the following forest types is more important, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous<br><br>Broad leaf | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coniferous<br><br>Mixed | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br><br>Mixed | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

13. For the aesthetic value of a forest, which of the following forest development stages is more important, and what is the degree of importance?

| Development stage | Tick (√ )one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br><br>Immature forest | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

14. For the wildlife conservation benefit of a forest, which crown coverage, is more important, and what is the degree of importance?

| Crown coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br>Moderate | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

15. For the wildlife conservation benefit of a forest, what canopy layer of a forest is more important, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

16. For the wildlife conservation benefit of a forest, which of the following forest types is more important, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous<br>Broad leaf | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coniferous<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

17. For the wildlife conservation benefit of a forest, which of the following forest development stages is more important, and what is the degree of importance?

| Developme nt stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br>Immature forest | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

18. Given that a forest is dense (> 70%), what number of canopy layers is more important for the soil conservation benefit of a forest, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

19. Given that the forest is moderately dense (40-70%), what number of canopy layers is more important for the soil conservation benefit of a forest, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

20. Given that a forest is Open (<40%), what number of canopy layers is more important for the soil conservation benefit of a forest, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

21. Given that a forest has one canopy layer, which of the following crown coverage of a forest is more important for soil conservation, and what is the degree of importance?

| Crown coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br>Moderate | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

22. Given that a forest has multiple canopy layers, which of the following crown coverage of a forest is more important for soil conservation, and what is the degree of importance?

| Crown coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br>Moderate | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

23. Given that a forest is mature, which of the following canopy coverage is more important for the soil conservation benefit, and what is the degree of importance?

| Crown coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br>Moderate | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

24. Given that a forest is immature forest, which of the following crown coverage is more important for the soil conservation benefit, and what is the degree of importance?

| Crown coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br>Moderate | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

25. Given that the forest is dense (>70%), which of the following forest types is more important for water conservation benefit of a forest, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous<br>Broad leaf | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coniferous<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

26. Given that a forest is moderately dense (40-70%), which of the following forest types is more important for water conservation, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous<br>Broad leaf | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Coniferous<br><br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br><br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

27. Given that a forest is open (<40%), which of the following forest types is more important for water conservation benefit, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous<br><br>Broad leaf | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coniferous<br><br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br><br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

28. Given that a forest has one canopy layer, which of the following forest types is more important for water conservation, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous forest<br><br>Broad leaf forest | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coniferous forest<br><br>Mixed forest | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br><br>Mixed forest | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

29. Given that a forest has multiple canopy layers, which of the following forest types is more important for water conservation, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous<br><br>Broad leaf | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coniferous<br><br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br><br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

30. Given that a forest is mature, which of the following forest types is more important for water conservation, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous<br>Broad leaf | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coniferous<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

31. Given that a forest is immature, which of the following forest types is more important for water conservation, and what is the degree of importance?

| Forest type | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Coniferous<br>Broad leaf | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coniferous<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broad leaf<br>Mixed | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

32. Given that a forest is mixed, what number of canopy layers of a forest is more important for the wildlife conservation, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

33. Given that a forest is broadleaf, what number of canopy layers of forest is more important for wildlife conservation, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

34. Given that a forest is coniferous, what number of canopy layers of a forest is more important for wildlife habitat, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| One layer or<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

35. Given that a forest is mature forest, what canopy layers of the forest is more important for wildlife conservation benefit, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

36. Given that a forest is immature forest, what canopy layer of the forest is more important for wildlife conservation benefit, and what is the degree of importance?

| Canopy layer | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| One layer<br>Multiple layers | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

37. Given that a forest is coniferous forest, which of the following crown coverage is more important for wildlife conservation benefit, and what is the degree of importance?

| Crown coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br>Moderate | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

38. Given that a forest is broadleaf forest, which of the following crown coverage is more important for the wildlife conservation benefit, and what is the degree of importance?

| Ground coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br>Moderate | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br>Dense | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

39. Given that a forest is mixed forest, which of the following crown coverage is more important for wildlife conservation, and what is the degree of importance?

| Crown coverage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Open<br><br>Moderate | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open<br><br>Dense | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Moderate<br><br>Dense | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

40. Given that a forest is dense (> 70%), which development stage of forest is more important for aesthetic value benefit, and what is the degree of importance?

| Development stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br><br>Immature forest | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

41. Given that a forest is moderately dense (40-70%), which of the following development stage is more important for the aesthetic value benefit of a forest, and what is the degree of importance?

| Development stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br><br>Immature forest | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

42. Given that a forest is open (< 40%), which development stage of the forest is more important for the aesthetic value benefit, and what is the degree of importance?

| Development stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br><br>Immature forest | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

43. Given that a forest has one canopy layer, which development stage of forest is more important for aesthetic value benefit, and what is the degree of importance?

| Development stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br><br>Immature forest | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

44. Given that a forest has multiple canopy layers, which development stage of forest is more important for aesthetic value benefit, and what is the degree of importance?

| Development stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br><br>Immature forest | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

45. Given that a forest coniferous, which development stage of forest is more important for aesthetic value benefit, and what is the degree of importance?

| Development stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br><br>Immature forest | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

46. Given that a forest broadleaf, which development stage of forest is more important for aesthetic value benefit, and what is the degree of importance?

| Development stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br><br>Immature forest | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

47. Given that a forest mixed, which development stage of forest is more important for aesthetic value benefit, and what is the degree of importance?

| Development stage | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Mature forest<br><br>Immature forest | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

48. Given that water conservation is provided by a broad leaf forest, which of the following benefits is more important for the overall environmental value of a forest, and what is the degree of importance?

| Benefits | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Soil conservation<br><br>Wildlife conservation | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wildlife conservation<br><br>Aesthetic value | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aesthetic value<br><br>Soil conservation | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

49. Given that water conservation is provided by a mixed forest, which of the following benefits is more important for the overall environmental value of a forest, and what is the degree of importance?

| Benefits | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Soil conservation<br><br>Wildlife conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wildlife conservation<br><br>Aesthetic value | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aesthetic value<br><br>Soil conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

50. Given that water conservation is provided by a coniferous forest, which of the following benefits is more important for the overall environmental value of a forest, and what is the degree of importance?

| Benefits | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Soil conservation<br><br>Wildlife conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wildlife conservation<br><br>Aesthetic value | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aesthetic value<br><br>Soil conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

51. Given that wildlife conservation is provided by a multiple layer canopy, which of the following benefits is more important for the overall environmental value of a forest, and what is the degree of importance?

| Benefits | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Soil conservation<br><br>Aesthetic value | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aesthetic value<br><br>Water conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Water conservation<br><br>Soil conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

52. Given that wildlife conservation is provided by one canopy layer, which of the following benefits is more important for overall environmental value of a forest, and what is the degree of importance?

| Benefits | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Soil conservation<br><br>Aesthetic value | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aesthetic value<br><br>Water conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Water conservation<br><br>Soil conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

53. Given that aesthetic value is provided by a mature forest, which of the following benefits is more important for the overall environmental value of a forest, and what is the degree of importance?

| Benefits | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Soil conservation<br><br>wildlife habitat | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| wildlife conservation<br><br>Water conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Water conservation<br><br>Soil conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

54. Given that aesthetic benefit is provided by an immature forest, which of the following benefits is more important for the overall environmental value of a forest, and what is the degree of importance?

| Benefits | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Soil conservation<br><br>Wildlife conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wildlife conservation<br><br>Water conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Water conservation<br><br>Soil conservation | ☐<br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

55. Given that soil conservation benefit is provided by dense forest (>70%), which of the following benefits is more important for the overall environmental value of a forest, and what is the degree of importance?

| Benefits | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Aesthetic value<br><br>Wildlife conservation | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aesthetic value<br><br>Water conservation | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wildlife conservation<br><br>Water conservation | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

56. Given that soil conservation benefit is provided by moderately dense forest (40-70%), which of the following benefits is more important for the overall environmental value of the forest, and what is the degree of importance?

| Benefits | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Aesthetic value<br><br>Wildlife conservation | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aesthetic value<br><br>Ground water yield | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Water conservation<br><br>Wildlife conservation | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

57. Given that soil conservation benefit is provided by open forest (<40%), which of the following benefits is more important for the overall environmental value of a forest, and what is the degree of importance?

| Benefits | Tick (√)one for each pair | Degree of importance (tick one box) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Aesthetic value<br><br>wildlife conservation | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aesthetic value<br><br>Ground water yield | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ground water yield<br><br>Wildlife habitat | ☐<br><br>☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

# Appendix E

## An example of Monte Carlo simulation

| | C | D | E | F | G | H |
|---|---|---|---|---|---|---|
| 1 | | | | A | B | A-B |
| 2 | $\mu^*$ | | | 1.2232 | 1.1231 | 0.100 |
| 3 | σ | | | 0.3490 | 0.3490 | |
| 4 | μ/σ | | | 3.5047 | 3.2179 | |
| 5 | ϕ(μ/σ) | | | 0.9998 | 0.9994 | |
| 6 | Mean | | | 1.225 | 1.121 | 0.104 |
| 7 | Standard Deviation | | | 0.344 | 0.345 | 0.492 |
| 8 | Count>0 | | | | | 5837 |
| 9 | %<0 | | | | | 41.63% |
| 10 | | A | B | A | B | |
| 11 | | Alpha/2 | Alpha/2 | Efficiency | Efficiency | |
| 12 | Draw | Random | Random | Estimate | Estimate | A-B |
| 13 | 1 | 0.24218623 | 0.338704 | 1.46726413 | 1.268457049 | 0.1988071 |
| 14 | 2 | 0.83042488 | 0.918317 | 0.88982295 | 0.63798019 | 0.2518428 |
| 15 | 3 | 0.14514652 | 0.296313 | 1.59226192 | 1.309983473 | 0.2822785 |
| 16 | 9999 | 0.97149729 | 0.183665 | 0.56009444 | 1.437838309 | -0.877744 |
| 17 | 10000 | 0.09048702 | 0.321087 | 1.69007421 | 1.285432656 | 0.4046415 |
| 18 | | | | | | |
| 19 | 95% LCB | | | 0.54044919 | 0.442755838 | |
| 20 | 95% UCB | | | 1.90721255 | 1.807187629 | |
| 21 | 95% Overlap? | YES | | | | |

* simbols refer to equation 3.33.

This worksheet determines the proportion of cases in which the efficiency bounds overlap.

Put data into cells F2:G2 (Make Case A the biggest mu)

Columns D & E are random draws ofpercentiles for each probability distribution.

Efficiency scores for the randomly selected percentiles are calculated in columns F & G

Differences in efficiency scores are derived in Column H.

Cell H8 is the number of times randomly drawn efficiency score A exceeds randomly drawn efficiency score B in 10,000 draws.

Cell H9 is the percentage of times  randomly drawn efficiency score A is less than randomly drawn efficiency score B. H9 is the significance level of the difference between the two

# Appendix F

## Preference weights for ecosystem services and forest attributes

| CFUG | | Bageshari | Bajrabarahi | Baluwabhanjhang | Banaskhandi | Bansgopal | Betkholsi | Bhairabkali | Bhutandevi | Bungdal | Chakradevi | Chanauta | Chillibans | Chitrepani | Chuchekhola | Chulipran | Chunnidevi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ecosystem services | Soil conservation | 0.36 | 0.43 | 0.42 | 0.47 | 0.40 | 0.43 | 0.41 | 0.38 | 0.40 | 0.45 | 0.47 | 0.42 | 0.46 | 0.35 | 0.42 | 0.45 |
| | Water conservation | 0.42 | 0.32 | 0.34 | 0.31 | 0.29 | 0.23 | 0.37 | 0.40 | 0.34 | 0.36 | 0.35 | 0.37 | 0.36 | 0.44 | 0.38 | 0.36 |
| | Wildlife conservation | 0.07 | 0.12 | 0.17 | 0.07 | 0.18 | 0.19 | 0.11 | 0.14 | 0.11 | 0.07 | 0.10 | 0.13 | 0.11 | 0.14 | 0.12 | 0.07 |
| | Aesthetic | 0.15 | 0.12 | 0.07 | 0.15 | 0.12 | 0.16 | 0.11 | 0.08 | 0.14 | 0.11 | 0.08 | 0.08 | 0.06 | 0.07 | 0.08 | 0.11 |
| Forest attributes | Multi layers | 0.19 | 0.20 | 0.20 | 0.21 | 0.18 | 0.21 | 0.20 | 0.17 | 0.19 | 0.21 | 0.22 | 0.16 | 0.17 | 0.21 | 0.20 | 0.21 |
| | One layer | 0.06 | 0.05 | 0.05 | 0.04 | 0.07 | 0.04 | 0.05 | 0.08 | 0.06 | 0.04 | 0.03 | 0.04 | 0.03 | 0.04 | 0.05 | 0.04 |
| | Immature | 0.16 | 0.14 | 0.12 | 0.17 | 0.18 | 0.17 | 0.13 | 0.16 | 0.13 | 0.17 | 0.15 | 0.09 | 0.13 | 0.17 | 0.10 | 0.16 |
| | Mature | 0.09 | 0.11 | 0.13 | 0.08 | 0.07 | 0.08 | 0.12 | 0.09 | 0.12 | 0.08 | 0.10 | 0.11 | 0.07 | 0.08 | 0.15 | 0.09 |
| | Dense | 0.15 | 0.15 | 0.17 | 0.16 | 0.12 | 0.15 | 0.15 | 0.15 | 0.15 | 0.16 | 0.17 | 0.12 | 0.12 | 0.15 | 0.15 | 0.16 |
| | Moderate | 0.08 | 0.08 | 0.06 | 0.07 | 0.09 | 0.08 | 0.07 | 0.08 | 0.08 | 0.07 | 0.06 | 0.06 | 0.06 | 0.07 | 0.08 | 0.07 |
| | Open | 0.02 | 0.02 | 0.03 | 0.02 | 0.04 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 |
| | Broadleaf | 0.15 | 0.15 | 0.15 | 0.10 | 0.09 | 0.09 | 0.14 | 0.14 | 0.15 | 0.14 | 0.17 | 0.11 | 0.09 | 0.08 | 0.14 | 0.14 |
| | Coniferous | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.03 | 0.03 |
| | Mixed | 0.08 | 0.08 | 0.07 | 0.12 | 0.13 | 0.14 | 0.08 | 0.08 | 0.08 | 0.08 | 0.06 | 0.06 | 0.09 | 0.15 | 0.08 | 0.08 |

| CFUG | | Chure kalilek | Dangdunge | Dipat | Dobhankhola | Ektare | Hariyali | Jarungsakti | Jyoti | Kalibanzar | Kalika hariyali | kalikachandika | Kalilek | Kotthumki | Laljhadi | Lother |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ecosystem services | Soil conservation | 0.44 | 0.34 | 0.44 | 0.40 | 0.38 | 0.44 | 0.42 | 0.44 | 0.34 | 0.31 | 0.43 | 0.32 | 0.46 | 0.43 | 0.36 |
| | Water conservation | 0.41 | 0.34 | 0.30 | 0.39 | 0.40 | 0.30 | 0.28 | 0.37 | 0.23 | 0.48 | 0.35 | 0.45 | 0.35 | 0.28 | 0.42 |
| | Wildlife conservation | 0.08 | 0.19 | 0.13 | 0.11 | 0.14 | 0.16 | 0.15 | 0.06 | 0.32 | 0.15 | 0.12 | 0.13 | 0.11 | 0.12 | 0.07 |
| | Aesthetic | 0.07 | 0.15 | 0.13 | 0.09 | 0.08 | 0.09 | 0.15 | 0.12 | 0.11 | 0.07 | 0.10 | 0.10 | 0.08 | 0.17 | 0.15 |
| Forest attributes | Multi layers | 0.21 | 0.19 | 0.21 | 0.20 | 0.20 | 0.20 | 0.20 | 0.21 | 0.20 | 0.21 | 0.20 | 0.21 | 0.19 | 0.18 | 0.19 |
| | One layer | 0.04 | 0.06 | 0.04 | 0.05 | 0.05 | 0.05 | 0.06 | 0.04 | 0.05 | 0.05 | 0.05 | 0.04 | 0.06 | 0.07 | 0.06 |
| | Immature | 0.16 | 0.16 | 0.16 | 0.15 | 0.10 | 0.17 | 0.18 | 0.16 | 0.10 | 0.17 | 0.16 | 0.14 | 0.16 | 0.16 | 0.16 |
| | Mature | 0.09 | 0.09 | 0.09 | 0.10 | 0.15 | 0.08 | 0.08 | 0.09 | 0.15 | 0.08 | 0.09 | 0.11 | 0.09 | 0.09 | 0.09 |
| | Dense | 0.16 | 0.14 | 0.15 | 0.14 | 0.14 | 0.15 | 0.14 | 0.16 | 0.16 | 0.15 | 0.16 | 0.16 | 0.15 | 0.16 | 0.15 |
| | Moderate | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.07 | 0.08 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.08 |
| | Open | 0.02 | 0.04 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 |
| | Broadleaf | 0.10 | 0.08 | 0.15 | 0.14 | 0.14 | 0.12 | 0.09 | 0.10 | 0.14 | 0.14 | 0.15 | 0.15 | 0.15 | 0.13 | 0.15 |
| | Coniferous | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 |
| | Mixed | 0.12 | 0.14 | 0.08 | 0.08 | 0.08 | 0.10 | 0.13 | 0.13 | 0.08 | 0.08 | 0.07 | 0.07 | 0.07 | 0.09 | 0.08 |

| CFUG | | Mahila srijana | Mangleshwar | Mankamana(Gadi) | Mankamana (Manahari) | Namuna | Nawalpur sarswati | Newreni Chisapani | Parvati mahila | Patleshwar | Rani | Risheswar | Shubhalaxmi | Siddakali | Sikaribas | Simpani | Soltu | Sundar | **Mean Priority** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ecosystem services | Soil conservation | 0.41 | 0.39 | 0.39 | 0.32 | 0.43 | 0.44 | 0.45 | 0.40 | 0.41 | 0.39 | 0.37 | 0.36 | 0.38 | 0.35 | 0.29 | 0.38 | 0.43 | **0.40** |
| | Water conservation | 0.30 | 0.37 | 0.37 | 0.34 | 0.36 | 0.23 | 0.30 | 0.32 | 0.37 | 0.34 | 0.35 | 0.42 | 0.31 | 0.40 | 0.36 | 0.41 | 0.31 | **0.35** |
| | Wildlife conservation | 0.13 | 0.14 | 0.14 | 0.20 | 0.11 | 0.16 | 0.08 | 0.14 | 0.12 | 0.12 | 0.13 | 0.08 | 0.13 | 0.13 | 0.14 | 0.12 | 0.09 | **0.13** |
| | Aesthetic | 0.16 | 0.11 | 0.11 | 0.14 | 0.10 | 0.17 | 0.16 | 0.13 | 0.11 | 0.16 | 0.15 | 0.14 | 0.18 | 0.11 | 0.21 | 0.10 | 0.16 | **0.12** |
| Forest attributes | Multi layers | 0.20 | 0.19 | 0.19 | 0.20 | 0.19 | 0.18 | 0.19 | 0.20 | 0.20 | 0.19 | 0.21 | 0.21 | 0.19 | 0.20 | 0.20 | 0.19 | 0.21 | **0.20** |
| | One layer | 0.05 | 0.06 | 0.06 | 0.05 | 0.06 | 0.07 | 0.06 | 0.05 | 0.05 | 0.06 | 0.04 | 0.04 | 0.06 | 0.05 | 0.05 | 0.06 | 0.04 | **0.05** |
| | Immature | 0.16 | 0.15 | 0.15 | 0.16 | 0.15 | 0.13 | 0.16 | 0.15 | 0.11 | 0.19 | 0.14 | 0.16 | 0.17 | 0.13 | 0.17 | 0.13 | 0.18 | **0.15** |
| | Mature | 0.09 | 0.10 | 0.10 | 0.09 | 0.10 | 0.12 | 0.09 | 0.10 | 0.14 | 0.06 | 0.11 | 0.09 | 0.08 | 0.12 | 0.08 | 0.12 | 0.07 | **0.09** |
| | Dense | 0.16 | 0.15 | 0.15 | 0.15 | 0.15 | 0.16 | 0.15 | 0.16 | 0.14 | 0.14 | 0.15 | 0.16 | 0.15 | 0.16 | 0.16 | 0.15 | 0.16 | **0.15** |
| | Moderate | 0.07 | 0.08 | 0.08 | 0.08 | 0.08 | 0.06 | 0.08 | 0.07 | 0.08 | 0.08 | 0.07 | 0.07 | 0.08 | 0.07 | 0.07 | 0.07 | 0.07 | **0.09** |
| | Open | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | **0.02** |
| | Broadleaf | 0.14 | 0.14 | 0.14 | 0.15 | 0.14 | 0.15 | 0.07 | 0.14 | 0.14 | 0.09 | 0.10 | 0.13 | 0.14 | 0.14 | 0.14 | 0.14 | 0.15 | **0.13** |
| | Coniferous | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | **0.04** |
| | Mixed | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.07 | 0.15 | 0.07 | 0.08 | 0.13 | 0.12 | 0.09 | 0.08 | 0.08 | 0.08 | 0.09 | 0.07 | **0.09** |

# Appendix G

## Production efficiency of individual CF

| SN | Name of CF | Production efficiency | Rank |
|---|---|---|---|
| 1 | Bageshari | 0.7569 | 13 |
| 2 | Bajrabarhi | 0.6491 | 28 |
| 3 | Balkumari | 0.6662 | 27 |
| 4 | Baluwabharreng | 0.6400 | 30 |
| 5 | Banaskhandi | 0.4896 | 46 |
| 6 | Bansgopal | 0.5388 | 43 |
| 7 | Basuki | 0.7693 | 12 |
| 8 | Betkholsi | 0.8079 | 5 |
| 9 | Bhagawan thumki | 0.7174 | 20 |
| 10 | Bhairabkali | 0.7749 | 11 |
| 11 | Bhotekhola | 0.8021 | 8 |
| 12 | Bhutan devi | 0.3923 | 53 |
| 13 | Bungdal | 0.5103 | 45 |
| 14 | Chakradevi | 0.4700 | 49 |
| 15 | Chhanauta | 0.4723 | 48 |
| 16 | Chhilli bans | 0.7362 | 14 |
| 17 | Chhitrepani | 0.7330 | 15 |
| 18 | Chuchekhola | 0.8298 | 1 |
| 19 | Chulipran | 0.8076 | 6 |
| 20 | Chunnidevi | 0.7285 | 16 |
| 21 | Churekalilek | 0.7180 | 19 |
| 22 | Dangdunage | 0.6741 | 24 |
| 23 | Dhaneshwar | 0.3250 | 56 |
| 24 | Dipat | 0.5409 | 42 |
| 25 | Dovan khola | 0.5451 | 41 |
| 26 | Ektare | 0.3739 | 54 |
| 27 | Gosaikunda | 0.2942 | 57 |
| 28 | Hariyali | 0.7190 | 18 |
| 29 | Jarungshakti | 0.7121 | 21 |
| 30 | Jyoti | 0.8233 | 3 |
| 31 | Kalabanzar | 0.6116 | 35 |
| 32 | Kalika | 0.6418 | 29 |
| 33 | Kalika chandika | 0.6718 | 25 |
| 34 | Kalika hariyali | 0.6319 | 31 |
| 35 | Kalilek | 0.4587 | 50 |
| 36 | Kotthumki | 0.7810 | 9 |
| 37 | Laljhadi | 0.5634 | 39 |
| 38 | Lother | 0.5990 | 36 |
| 39 | Mahila srijana | 0.7102 | 22 |
| 40 | Manakamana (Manahari) | 0.3564 | 55 |
| 41 | Mangleshar | 0.6281 | 32 |
| 42 | Mankamana( Gadi) | 0.7755 | 10 |
| 43 | Namuna | 0.7050 | 23 |
| 44 | Navalpur sarswati | 0.4775 | 47 |
| 45 | Newreni chisapani | 0.5961 | 37 |
| 46 | Parbati mahila | 0.6182 | 33 |
| 47 | Patleshar | 0.5203 | 44 |
| 48 | Rani | 0.6715 | 26 |
| 49 | Resheswar | 0.7205 | 17 |
| 50 | Saradidevei | 0.4421 | 51 |
| 51 | Shikaribas | 0.8036 | 7 |
| 52 | Siddhakali | 0.6135 | 34 |
| 53 | Simpani devkot | 0.4115 | 52 |
| 54 | Soltu | 0.5566 | 40 |
| 55 | Subhlaxmi | 0.8241 | 2 |
| 56 | Sundar | 0.5759 | 38 |
| 57 | Thakaldanda | 0.8165 | 4 |

# Appendix H

## CF production efficiency and 95 % confidence intervals

| SN | Name of CF | Technical efficiency | Rank | Confidence bound (95%) | | Interval difference (UCB-LCB) |
|---|---|---|---|---|---|---|
| | | | | Lower | Upper | |
| 1 | Bageshari | 0.7569 | 13 | 0.3856 | 0.9806 | 0.5950 |
| 2 | Bajrabarhi | 0.6491 | 28 | 0.3555 | 0.9739 | 0.6183 |
| 3 | Balkumari | 0.6662 | 27 | 0.3693 | 0.9773 | 0.6080 |
| 4 | Baluwabharreng | 0.6400 | 30 | 0.3485 | 0.9718 | 0.6233 |
| 5 | Banaskhandi | 0.4896 | 46 | 0.2510 | 0.8936 | 0.6426 |
| 6 | Bansgopal | 0.5388 | 43 | 0.2799 | 0.9316 | 0.6518 |
| 7 | Basuki | 0.7693 | 12 | 0.4719 | 0.9902 | 0.5182 |
| 8 | Betkholsi | 0.8079 | 5 | 0.5232 | 0.9929 | 0.4697 |
| 9 | Bhagawan thumki | 0.7174 | 20 | 0.4153 | 0.9850 | 0.5697 |
| 10 | Bhairabkali | 0.7749 | 11 | 0.4788 | 0.9906 | 0.5118 |
| 11 | Bhotekhola | 0.8021 | 8 | 0.5149 | 0.9925 | 0.4776 |
| 12 | Bhutan devi | 0.3923 | 53 | 0.1986 | 0.7646 | 0.5660 |
| 13 | Bungdal | 0.5103 | 45 | 0.2629 | 0.9116 | 0.6487 |
| 14 | Chakradevi | 0.4700 | 49 | 0.2401 | 0.8735 | 0.6334 |
| 15 | Chhanauta | 0.4723 | 48 | 0.2413 | 0.8760 | 0.6347 |
| 16 | Chhilli bans | 0.7362 | 14 | 0.4344 | 0.9871 | 0.5527 |
| 17 | Chhitrepani | 0.7330 | 15 | 0.4311 | 0.9868 | 0.5557 |
| 18 | Chuchekhola | 0.8298 | 1 | 0.5567 | 0.9941 | 0.4374 |
| 19 | Chulipran | 0.8076 | 6 | 0.5228 | 0.9928 | 0.4701 |
| 20 | Chunnidevi | 0.7285 | 16 | 0.4265 | 0.9863 | 0.5599 |
| 21 | Churekalilek | 0.7180 | 19 | 0.4159 | 0.9851 | 0.5692 |
| 22 | Dangdunage | 0.6741 | 24 | 0.3759 | 0.9787 | 0.6029 |
| 23 | Dhaneshwar | 0.3250 | 56 | 0.1641 | 0.6424 | 0.4783 |
| 24 | Dipat | 0.5409 | 42 | 0.2812 | 0.9330 | 0.6518 |
| 25 | Dovan khola | 0.5451 | 41 | 0.2837 | 0.9354 | 0.6517 |
| 26 | Ektare | 0.3739 | 54 | 0.1891 | 0.7329 | 0.5438 |
| 27 | Gosaikunda | 0.2942 | 57 | 0.1485 | 0.5826 | 0.4341 |
| 28 | Hariyali | 0.7190 | 18 | 0.4169 | 0.9852 | 0.5683 |
| 29 | Jarungshakti | 0.7121 | 21 | 0.4102 | 0.9844 | 0.5742 |
| 30 | Jyoti | 0.8233 | 3 | 0.5464 | 0.9938 | 0.4474 |
| 31 | Kalabanzar | 0.6116 | 35 | 0.3276 | 0.9641 | 0.6365 |
| 32 | Kalika | 0.6418 | 29 | 0.3498 | 0.9722 | 0.6224 |
| 33 | Kalika chandika | 0.6718 | 25 | 0.3739 | 0.9783 | 0.6044 |
| 34 | Kalika hariyali | 0.6319 | 31 | 0.3424 | 0.9698 | 0.6274 |
| 35 | Kalilek | 0.4587 | 50 | 0.2339 | 0.8606 | 0.6267 |
| 36 | Kotthumki | 0.7810 | 9 | 0.4865 | 0.9911 | 0.5046 |
| 37 | Laljhadi | 0.5634 | 39 | 0.2952 | 0.9452 | 0.6500 |
| 38 | Lother | 0.5990 | 36 | 0.3188 | 0.9599 | 0.6412 |
| 39 | Mahila srijana | 0.7102 | 22 | 0.4083 | 0.9841 | 0.5758 |
| 40 | Manakamana (Manahari) | 0.3564 | 55 | 0.1801 | 0.7014 | 0.5213 |
| 41 | Mangleshar | 0.6281 | 32 | 0.3395 | 0.9688 | 0.6293 |
| 42 | Mankamana( Gadi) | 0.7755 | 10 | 0.4795 | 0.9906 | 0.5111 |
| 43 | Namuna | 0.7050 | 23 | 0.4034 | 0.9835 | 0.5800 |
| 44 | Navalpur sarswati | 0.4775 | 47 | 0.2443 | 0.8816 | 0.6373 |
| 45 | Newreni chisapani | 0.5961 | 37 | 0.3167 | 0.9589 | 0.6422 |
| 46 | Parbati mahila | 0.6182 | 33 | 0.3323 | 0.9660 | 0.6338 |
| 47 | Patleshar | 0.5203 | 44 | 0.2688 | 0.9192 | 0.6505 |
| 48 | Rani | 0.6715 | 26 | 0.3737 | 0.9783 | 0.6046 |
| 49 | Resheswar | 0.7205 | 17 | 0.4184 | 0.9854 | 0.5670 |
| 50 | Saradidevei | 0.4421 | 51 | 0.2249 | 0.8396 | 0.6148 |
| 51 | Shikaribas | 0.8036 | 7 | 0.5170 | 0.9926 | 0.4756 |
| 52 | Siddhakali | 0.6135 | 34 | 0.3289 | 0.9647 | 0.6357 |
| 53 | Simpani devkot | 0.4115 | 52 | 0.2086 | 0.7956 | 0.5870 |
| 54 | Soltu | 0.5566 | 40 | 0.2909 | 0.9418 | 0.6509 |
| 55 | Subhlaxmi | 0.8241 | 2 | 0.5476 | 0.9938 | 0.4462 |
| 56 | Sundar | 0.5759 | 38 | 0.3033 | 0.9509 | 0.6477 |
| 57 | Thakaldanda | 0.8165 | 4 | 0.5359 | 0.9934 | 0.4575 |

*Notes:* LCB= Lower confidence bound, UCB= Upper confidence bound