Opening the Black Box of Household Labour Supply: Is Household Behaviour Unitary or Collective?*

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1 Introduction

In the first part of this chapter we modelled labour supply behaviour for males and females as individuals. The behaviour of an individual was influenced by his/her own desires and rational behaviour are represented by a unique utility function which when maximized subject to their budget constraint results in individual's demand for goods. Traditional microeconomics theory such as Deaton & Muellbauer (1980) treat all economic agents alike i.e., this agent is essentially a consumer and actually may be a household or an individual. Not only theoretical empirical studies treat a single individuals household and multiple individual household in the same manner and thereby determine the household consumption and labour supply (for example Blundell & Walker (1986) and Banks et al. (1997)). However, to get a complete picture of labour supply behaviour it is important to take into account the environment in which the individual lives i.e., the household. The intrahousehold behaviour of individuals can have important effect on household labour supply. One important aspect in modelling household behaviour is the treatment of the household unit. Traditional approach assumes that a household acts as a single decision making unit. Consequently, household preferences are maximized subject to a budget constraint resulting in household consumption and labour supply behaviour of the household. This model is known as the unitary model. This model fits household behaviour as long as household preferences coincide with the preferences of member of this household. However, this is not actually the case. Referring to Arrows' impossibility theorem - an aggregate of individuals does not necessarily behave as a single individual with her own preferences (Vermeulen 2004). It can be said that unitary model is not an appropriate setup to model household behaviour Chiappori (1992). A household is a micro-society of individuals wherein the individuals have their our personal preferences. Methodologically, it has been argued by authors such as Blaug (1980) that the idea of subjective preferences is inseparable from methodological individualism which says that social theories should be formulated in terms of the behaviour of individuals. This ideology has resulted in the development of collective models of household behaviour. It has been found by researchers that the restrictions of the unitary model do not hold in modelling of household behaviour for example Fortin & Lacroix (1997) and Vermeulen (2005).

The issue of treatment of household as a unit or as a micro society of individuals has not been investigated for India. Most extant research considers household as a single decision making unit, thereby adopting a unitary approach to modelling household behaviour. We intend to question the household behaviour i.e., does the household behave as a single decision making unit or does it behave as a set of individuals with their unique preferences. Another important contribution of this chapter is that by incorporating relative bargaining strength of spouse - as proposed in collective model fraomework of Chiappori et al. (2002)- we are able to investigate the effect of relative bargaining strength of household members. In the present chapter we test the unitary and collective models of household labour supply for rural India. This chapter proposes a functional form for the household labour supply system which has a simple non-linear form. The sets of parametric restrictions imposed by both the unitary and collective models are derived and thereby tested on Indian data. We also incorporate intrahousehold bargaining power in our analysis by using distribution factors. One important contribution of this analysis is that we have introduced nutrition in the analysis. This has been done in two ways, firstly, calorie consumption is taken as a factor influencing labour supply and secondly we have defined calorie deprivation as one of the distribution factors. This is very important for policy purposes because it enables us to question whether intrahousehold bargaining power in terms of nutritional status has a significant influence on labour supply behaviour and should it be accounted for in policy making or not? The chapter is organized as follows. The next section provides an extensive literature and discussion of the unitary and collective approach to modelling household behaviour. Section 3 outlines the unitary and the collective model of household labor supply. Parametric specification of the models and derivation of associated testable restrictions are presented in Section 4. The data used for the analysis is discussed in Section 5. Estimates of the different versions of the unitary and the collective models and discussion of the results thereof are reported in Section 6. Conclusions and policy implications are provided in Section 7.

2 Literature Survey

When we expand the dimensions of the analysis and consider not only the individual but also the household then many questions need to be answered. In a household decisions such as allocations of consumption across household members is made according to their type of needs. An example of this is the basis of nutrition wage literature. For every person there is a minimum health threshold below which a person cannot find work but can survive. In and extremely poor household the income would not be sufficient enough to allow everyone to consume at the threshold level. Under situations of equal endowments among household members the situation would not be optimal as no member would be able to find work. It would then be optimal to unequal allocations among members so that atleast one person can earn and get some income into the household. Behrman (1992) and Behrman et al. (1997) provide summaries of differential allocations of health outcomes across different types of individuals. The authors conclude that young children and lactating women are at risk of deprivation in health input allocations. Economists such as Rosenzweig & Schultz (1982) attribute certain type of investment to certain type of return. If households maximize income and no importance is given to the consumption levels of individuals then there is a tendency to allocate more inputs to better endowed members if these health inputs yield higher returns (in terms of wages) rather than to allocate inputs to the less well endowed member where these health inputs will not reap improved returns (Pitt et al. 1990). For a general model of household's welfare maximization other consideration such as weights associated with the well being of an individual and aversion to unequal outcomes have to be addressed. Behrman & Deolalikar (1988) suggests that health investment would depend on health endowments. Difference in health input allocations among household members are suggestive of the different preferences and degree of influence over decision making among household members (Folbre 1984). Similar evidence is found in Thomas (1990) where it is found that the income in the hands of a mother results in a larger impact on the health of children than in the hands of their father. These findings suggest the relevance of a model outside the domain of the assumption that households behave as a unit with a set of well behaved preferences. The relationship between health and labour supply takes a completely new dimension when the analysis takes into account the household rather than just one individual. The reason for which is that the cost of health input will not vary across household members but the level of health input will obviously vary (Pitt & Rosenzweig 1990). Theoretically, it is important to account for the fact that the labour supply of an individual in a household conditional upon health will mean not only the effect of his own health but also the effect of health of other household members on his labour supply i.e., effect of health on this individual's labour supply will be an aggregate effect if his own health and health of other household members. Thus the time allocated to labour work by one individual might be influenced by the fact that another household member is unhealthy and therefore not capable of enough labour supply. Thus when modelling labour supply it is important to take into consideration the intrahousehold effects. Empirically, as health of other members of household also influences the labour supply of an individual it is not easy to find enough instruments particularly in low income settings. Literature suggests that it is not difficult to incorporate multiple household members in a model of health and wages if it is assumed that wages of one member conditional upon own health is not affected by the health of other household members. This assumption rules out externality within the household such as ill health of one household member transmitted to another (Strauss & Thomas 1998).

Models accounting for the heterogeneity within a household are developed in a game theoretic settings by McElroy & Horney (1981), Lundberg & Pollock (1993), Chiappori (1988) and Chiappori (1992). Lundberg & Pollock (1993) use cooperative and noncooperative models of game theory and Chiappori (1988) examines the implications of pareto efficiency in household allocation. These models imply that in addition to household resources, investment in health also depend on the distribution of these resources. Household is a group of individuals with different preferences and among these individuals intra household decision making takes place. Studies, have modelled household behaviour by referring to the presence of a 'household manager'or a 'household leader' when referring to the theory of consumer behaviour. Again as long as the preferences of the household coincide with that of this manager/leader things are simple to model however when the preferences of the members change one needs a better framework for household behaviour. Some of the earliest initiatives taken to account for the fact that household may consist of individuals with heterogeneous preferences are Samuelson (1956) and Becker (1974). The approaches adopted in these studies are closely related, Samuelson (1956) assumes a weakly separable household utility functions when the individuals utility functions are subutility functions. Imposing this type of an aggregation of utility structure on household behaviour results in the structure collapsing to a unitary one. In this form of utility structure it can be assumed that the household members decide to behave as a imaginary single individual with rational preferences. Becker (1974) on the other hand assumes that household members agree to behave as an imaginary individual and thereby considers a benevolent head of the family who takes into account the preferences of all household members resulting in a case of weakly separable rational household preferences. In both of these approaches the Arrows' impossibility theorem and the restrictive unitary model setup emerge. If the household members are trying to reach a rational consequences household model then with both these approaches the problems of Arrows' Impossibility Theorem and the restrictive unitary framework reemerge in terms of household consumption and labour supply. The underlying assumption of an unitary model are 'income pooling hypothesis', 'symmetry of slutsky matrix' and nonparticipation (i.e., case of corner solution). Income pooling hypothesis says that individual nonlabour income of household members are pooled in a single household nonlabor income. This implied that the source of this exogenous income does not play any role in household allocation with regard to labour supply and consumption. This restriction has been rejected in many studies such as, Fortin & Lacroix (1997), Lundberg et al. (1997), Browning et al. (1994), Burguignon et al. (1993). The symmetry of slutsky matrix implies that marginal compensated wage changes of any two individuals in a household have the same effect on each others labour supply. This assertion also has been empirically rejected by Fortin & Lacroix (1997) and Browning & Chiappori (1998). The third assumption of corner solution rule suggests that when an individual does not participate in the labour market (i.e., in case of a corner solution), then it is the reservation wage rather than the market wage of that individual that affects the labour supply decision of another household member. This is a very strong assumption (Blundell & MaCurdy 1999).

From the perspective of welfare economics, in a unitary model framework an implicit assumption would be that the welfare of members within a household is unimportant or that the intrahousehold distribution is optimal for the policy maker Bourguignon & Chiappori (1994). Traditional models for welfare economics only consider the welfare over households but Apps & Rees (1988) and Brett (1998) have shown that when evaluating the welfare effects of tax change it would be wrong to ignore intrahousehold distribution. Haddad & Kanbur (1990) show that taking distribution of welfare within a household into account may affect the level of poverty or inequality. *Alderman et al. (1995) argue that acceptance of the unitary model when it is inappropriate has more consequences for policy prescription than rejecting the unitary model when it is appropriate.* For welfare programs which target individuals such as programs targeting women and children, it is important to know of the intrahousehold process of decision making. Other studies concentrating on the implications of using unitary models to address welfare economic problems are Lundberg & Pollak (1996), Phipps & Burton (1996) and Strauss et al. (2000).

In addition to the Samuelson (1956) and Becker (1974) approach, another avenue adopted to account for the heterogeneity of household decision makers is the game theoretic framework. Two approaches have been adopted in the literature when applying game theoretic methods to this issue. The first approach, applied by Ashworth & Ulph (1981), Lundberg & Pollock (1993), Leuthold (1968), Browning (2000) and Chen & Woolley (2001) models the household in a non-cooperative framework. Here, the household members are assumed to maximise their utility ceteris paribus, i.e., taking the other individual's behaviour as given. This Nash equilibrium setting imply other restriction on household behaviour than the unitary approach. These models do not necessarily result in Pareto efficient intrahousehold allocation as in many cases it is possible to make one individual better off without making the other member worse off. The second approach, applied by Manser & Brown (1980) and McElroy & Horney (1981) applies elements of cooperative game theory in the form of axiomatic bargaining theory to household model. It is assumed that household members act as agents and try to reach an aggrement on how to divide the gains of co-operation i.e., gains of living together. Contingent on the bargaining power of household member a specific pareto efficient intrahousehold allocation of welfare is obtained. McElroy & Horney (1981) focus on the Nash bargaining solution and derive conditions for a Nash demand system which collapses to a traditional unitary model. Manser & Brown (1980) derive the implications on demand for bargaining concepts like dictatorial, Nash and

Kalai-Smorodinsky solution. One important drawback of these approaches is of choosing a particular bargaining concept to model household behaviour is that if the corresponding empirical implications are rejected then it would not be possible to determine whether the particular choice was rejected or was it the bargaining setup that was rejected as oppose to the unitary model. To handle this problem Chiappori (1988), Apps & Rees (1988) and Chiappori (1992) take an alternative starting point, it is assumed that household decisions are pareto efficient. This is a weak restriction but it enables the derivation of some testable implications of the model and identify important part of the intrahousehold decision making process and individual preferences. **This is known as the collective approach to household behaviour**. This collective approach has an advantage over the unitary model. Firstly, the income pooling hypothesis no longer needs to be satisfied. Collective approach is widely accepted in the recent microeconomics literature and has been extended in many directions. Chiappori (1988) and Chiappori (1992) started it all off by concentrating on labour supply behaviour in a cross sectional context. Browning et al. (1994) derived a collective model to describe household consumption on cross sections. Browning & Chiappori (1998) consider an environment of relative price variation for a number of commodities. Implications of introducing household production in the model was discussed in Chiappori (1997). Chiappori et al. (2002) show that if all the above conditions are satisfied then it is possible to identify the sharing rule upto an additive constant. The sharing rule result implies that it would be possible to judge the 'percentage change in the individuals share in the non labour income for a one percentage increase in this individuals wage'[1]. It is also possible to identify individual consumption of the Hicksian aggregate commodity upto an additive constant. With the sharing rule result and using observable labour supply behaviour it is possible to define individual indirect utility functions. The beauty of collective

[1] It would be possible to make predictions such as: a x% increase of total household non labour income will be allocated to individual A and (100 - x)% to individual B in a particular wage and nonlabour income setup.

model approach is that other than the restrictions on individual preferences only pareto efficiency of household behaviour is imposed. This approach enables to analyse effects of a policy reform on individual household members in terms of derived individual consumption and individual welfare. These identification results would generally not exist in the unitary approach. Hence collective approach is advantageous over the unitary approach. In presence of these restrictions empirical studies literature either test whether some restrictions of the unitary model such as the pooling restriction, are satisfied (with no comparison of it with an alternative model) or (Chiappori(1988, 1992), Kooreman and Kapteyn(1990)) compare the restrictions of the unitary model against those of the collective model under the assumption of exogenous labour supply (Bourguignon et al(1993), Browning et al (1994)).

Chiappori et al. (2002) investigate intrahousehold bargaining power of household member in a collective model framework by using distribution factors. Considering the case of two distribution factors i.e., sex ratio and divorce legislation they find that it is not possible to reject the collective model. With regard to the sharing rule it was found that there existed a significantly positive relationship between sex ratio and wife's share in nonlabour income. Also, a divorce law favourable to women would increase their share in non labour income.

Chiappori (1988) and Chiappori (1992) assumed that only individual wages of both household members and total non labour income are observable. There were no observable distribution factors in the setup and hence it was not possible to get the partials of sharing rule in terms of first order derivatives of labour supply function. Using second order and third order derivatives of observable labour supply the paper derives a set of testable restrictions of collective approach.

Fortin & Lacroix (1997) tested the Chiappori (1988) model. Within a structural framework the paper attempts to simultaneously test the unitary and collective household labour supply models. The authors postulate a nonlinear household labour supply system against which the two models can be tested. Outlining the drawbacks of the unitary and collective household labour supply models the authors observe that for a suitable unrestricted functional form for household labour supply system, both unitary and collective models impose testable restrictions. Using a sample of two earner households from the 1996 Canadian Census, an empirical model is estimated and restriction are tested for both unitary and collective models. The estimation involves a two step procedure wherein in the first step the wage rate and non labour income of each household member is instrumented with, third order polynomials in each partners age and education, dummies for immigration status of each partner and their year of immigration, and finally regional dummies to account for local labour market conditions. Regression estimates from the first step of estimation is thereby used in Full Information Maximum Likelihood (FIML) estimation of the model in the second step. The data for this study is drawn from the Public use Micro data file on families derived from the 1996 Canadian Census of population and housing. It contains detailed information on labour supply, income, non-labour income and socio-economic variables for around 67000 households. The results reject the income pooling hypothesis for all sub-groups considered except for couples aged between 24 and 35 with no pre-school children. The results suggest evidence in favour of the collective model of labour supply for all age groups with no preschool child suggesting the presence of a preschool child within the family results in non-separability in goods consumed by parents. The restrictions of a unitary framework were strongly rejected whereas the restrictions of collective model were not rejected.

Browning et al. (1994) using Canadian household budget data apply the collective framework to case where the household survey data for individual wages and labour supply are lacking but a detailed informaton on household allocation of expenditure for various commodities is available. Again assuming atleast one distribution factor, no price variation, egoistic and caring preferences and fixed labour supply the paper proceeds by considering that there is atleast one commodity whose individual demand is observable i,e., clothing for men and women. The paper fails to reject the assumption of collective framework of household behaviour. It was found that difference in ages and income of both the household members along with household expenditure had a highly significant impact on the sharing rule. Similar studies are carried out by Browning et al. (1994) and Dauphin & Fortin (2001).

Donni (2003) extends the collective labour supply model to address nonparticipation and income taxation. Accounting for income taxation results in incorporating nonlinear budget constraints in the collective labour supply framework.

Apps & Rees (1996) Apps & Rees (1996) demonstrates the importance of accounting for household productions in the models of labour supply in order to avoid misleading results concerning the intra-household distribution of income and the response to economic policy. In the analysis a model that incorporates household production is outlined and is referred to as an 'exchange model', for the purpose of comparison a model without household production is also derived and this model referred to as a 'transfer model'. The formulation and estimation of an empirical model with household production is esplained. The advantage of exchange model over the transfer model is that under an exchange model a family member can exchange domestic output for market goods within households whereas, in the transfer model, attributed to Chiappori (1988), omit household production and hence time spent at home is allocated entirely to pure leisure. The authors prove that ignoring household production would result in an omitted variable problem. By incorporating household production it is assumed that a price i.e., (imputed price of domestic good at the household equilibrium) is an independent variable in determining consumption demands. Ignoring this would put the terms related to this imputed price in the error term of the demand functions. This would result in inconsistent coefficients of the variable included

in the demand equation i.e., the omitted variable problem. For the empirical analysis a sample of 1,384 families selected from the Australian Bureau of Statistics 1985/86 income distribution survey sample file is used. The results show that there is significant difference in the uncompensated wage and income elasticities for males and females when computed for the exchange and the transfer model.
Apps & Rees (1997) specify the importance of incorporating household production in the collective framework. They analyse data from Australian Bureau of Statistics 1985/86 Income distribution survey sample file for families with atleast ne child under 15 years of age and where the males work which gives a set of 1384 households. Considering only interior solution they find that in families where female is specialised in home production activity then exchange within the family is important. Incorporating the household production in his framework of collective approach Chiappori (1997) derives identification results and some testable conditions for the collective household model incorporating household production. It is possible to derive testable conditions for labour supply behaviour of the household if the domestically produced commodity is marketable and preferences are egoistic and caring. However, if the home produce is not completely marketable or is non marketable then identification of the sharing rule would require additional assumptions to be imposed on intrahousehold decision making process.

Bourguignon (1999) extend the analysis done in Bourguignon & Chiappori (1994) to a situation when children are considered as a public consumption good to the adult household members. Dercon & Krishnan (2000) use Ethiopian panel data to relate collective household model to literature on consumption on smoothing and risk sharing. They test whether individual household members smooth consumption over time and whether they indulge in risk sharing. The authors reject the assumption of risk sharing which implies an absence of Pareto efficient household allocation.

Kooreman & Kapteyn (1990) aims to test the unitary model an thereby recover some parameters of collective preferences. They use 1982 Dutch Survey data to estimate utility weights by specifying a Stone-Geary functional form to these utilities. These weights are assumed to be independent of wages and income. They find an estimated utility weight within the unit interval.

Bourguignon et al. (1993) test the income pooling hypothesis for French data and when the hypothesis is rejected the authors construct a theoretical model of collective decision making i.e., the collective approach to household decision making by nesting the unitary and the collective approach in a family of functional forms. The restrictions of the collective framework were not rejected for the data under consideration.

The importance of nutrition affecting labour supply of individuals has been reiterated in Strauss & Thomas (1995) and Strauss & Thomas (1998). In these studies it has been argued that health and nutrition might affect the outside behaviour of household members. Boom et al. (1996) investigate the nutrition-productivity relationship for Ghana and conclude that the relationship is not weak. In the present chapter we argue that the level of health of the members of household might affect their household bargaining and decision making and thereby affect outcomes. As explained in the previous section the traditional unitary model cannot capture the intrahousehold decision making and hence researchers have proposed alternative approaches to tackle intrahousehold decision making process. Models based on cooperative game theory with its assumption of pareto efficiency were developes and analysed by Chiappori (1988), Bourguignon et al. (1993) and Browning & Chiappori (1998). Accounting for the variables that affect the intrahousehold distribution of power 'distribution factors'[2]. Prowse (2004) investigates the implications of a corner solutions in individuals non market time allocates on their labour supply behaviour. This is the situation wherein some individuals face binding constraints or rations on their non-

[2]Introduced in Browning & Chiappori (1998).

market time allocations i.e., when there are corner solutions in the individuals and non market time allocation. The author emphasizes upon the effects of ignoring corner solutions in individuals non market time allocation. This ignorance results in less variation in the unconstrained demand for time which corresponds to smaller wage effect, smaller effect of demographic variables and a smaller effect of the non-labour market wage effect leading to upward or downward bias in the estimated wage elasticity of labour supply. Assuming the preferences to be of Stone-Geary type the authors concludes that the wage elasticity of labour supply is biased downwards when the corner solution in the time allocated to market activities are ignored. However, the author admits that the results can be driven by the Stone-Geary functional form imposed on individual preferences.

2.1 Literature on India

There has been no study thus far addressing collective model for labour supply suply framework for India. A study attempting to address the importance of intrahousehold allocation but using the traditional unitary model approach to modeling household behaviour is Behrman & Deolalikar (1993). A model of the preference tradeoff underlying the intra household distribution of market work has been studied by Behrman & Deolalikar (1993). Using 'village level studies' (VLS) panel data collected by the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) for rural semi-arid South India, the paper estimates two preference parameters regarding taste of distribution of work within a household. These parameters are: an overall inequality aversion in the intra-household aversion and household distribution preference with asymmetric or unequal concern for leisure of different members. Considering a CES form of household utility function it is assumed that the preference weights of household is dependent on observed and unobserved individual characteristics. To incorporate this specification household fixed effects log market labour supply equation is estimated. These market labour supply functions are estimated using both actual and predicted wages. Wage rates are considered to be endogenous and identifying instruments used are caste, time, average rainfall and its variance in the village of residence, and interaction of these variables with age, schooling, and gender. An important inference drawn is that the response of individual market labour supply to change in market wage is less than what it would be if household maximizes only wage income because the household attempt to equalize the internal distribution of work effort among their members. The authors conclude that in an empirical analysis of labour supply and time allocation decisions treat the households as a relevant decision making unit will bear misleading results because as intrahousehold distribution is important.

3 Collective and Unitary Approach to household behaviour

3.1 Unitary Model

The basic premise of economic theory is that households have needs and desires that they want to satisfy. To do so households have to make choices as there are limitations to all their needs being satisfied. In the unitary approach to household behaviour it is assumed that households needs are completely captured by a rational preferences[3] ordering over alternative consumption and leisure bundles.

Consider a household comprising of two working age individuals who maximise a unique, price independent social utility function subject to the family budget constraint. The

[3]Rational preferences are defined as preferences ordering that is both complete and transitive. Completeness says that the consumer possesses a well defined preference between two bundles in the consumption and leisure set. Transitivity excludes cyclical preferences in sequences of pairwise choices between bundles.

members i $\in \{m, f\}$ consumes private composite good C^i price of which is set to 1 and supplies h^i hours of work to the labour market. Let w_i and y_i denote member i's exogenous wage rate and non labour income respectively. Household behaviour is solution to the following programme:

$$\max_{c^m, c^f, h^m, h^f} U = \tilde{U}(C^m, C^f, h^m, h^f)$$

s.t.

$$w_1 h^1 + w_2 h^m + y_m + y_f \geq C^m + C^f \tag{1}$$

$\frac{\partial \widetilde{U(.)}}{\partial C_m} > 0$; $\frac{\partial \widetilde{U(.)}}{\partial C_f} > 0$; $\frac{\partial \widetilde{U(.)}}{\partial h^m} < 0$; $\frac{\partial \widetilde{U(.)}}{\partial h^f} < 0$; strictly quasi concave and twice differentiable in all arguments. Most practical situations C^m and C^f are not observed only aggregate consumption $C = C^m + C^f$ is known. Applying Hicks composite commodity theorem[4] one can define a well behaved reduced form utility function $U = U(C, h^m, h^f)$. Thus the household solves the programme:

$$U = U(C, h^m, h^f) \tag{2}$$

$$w_m h^m + w_f h^f + y_m + y_f \geq C \tag{3}$$

If the uncompensated labour supply functions of the two individuals are $h^m(w_m, w_f, y_m, y_f)$ and $h^f(w_m, w_f, y_m, y_f)$. Then solving the above program results in:

$$h^m(w_m, w_f, y_m, y_f) = H^m(w_m, w_f, y_m + y_f) \tag{4}$$

$$h^f(w_m, w_f, y_m, y_f) = H^f(w_m, w_f, y_m + y_f) \tag{5}$$

In this unitary framework there are two restrictions imposed on h^m and h^f i.e.,

- Distribution of non labour income across family members play no role in determining individual labour supply only level of y does. Thus, $\frac{\partial h^m}{\partial y_m} = \frac{\partial h^m}{\partial y_f}$ and $\frac{\partial h^f}{\partial y_f} = \frac{\partial h^f}{\partial y_m}$

[4]Hicks composite commodity theorem: If a group of prices move parallel to each other then the corresponding group of consumption goods can be treated as a single commodity known as the Hicksian Aggregate Commodity (Deaton & Muellbauer 1980).

- Since it is assumed that household behaves as predicted by standard theory of individual behaviour i.e., assuming interior solution for h^m and h^f the usual slutsky restrictions must hold.

$$\begin{cases} S_{mf} = S_{fm}, & \text{Symmetry of compensated cross wage effects;} \\ S_{ii} \geq 0, & \text{where i} = \{\text{m, f}\}\text{,no negatively of compensated own wage effect;} \\ S_{mm}S_{ff} - S_{mf}^{f} \geq 0, & \text{non-negativity of the determinant of slutsky matrix.} \end{cases} \tag{6}$$

$S_{ij} = h^i_{w_j} - h^j h^i_y$ i and $j \in \{m, f\}$ is the compensated own or cross wage effect. These restrictions characterize the set of labour supply function.

3.2 Collective Model

Let h^i be the labour supply and C^i the consumption of Hicksian composite commodity for $i = \{m, f\}$ and $0 \leq h^i \leq 1$. The price of the composite commodity is 1 and it is assume that the only price variation can take place in the form of variation in the wages of the two household members.. Assuming that the welfare of member i depends on consumption and labour supply of both the members along with scope for externalities, public consumption of leisure etc. If z is the k-vector of preferences factors such as age, education, health indicators, state/region of residence etc. Household wages and total income is represented by w_m, w_f and y. The household maximises the following program:

$$\max_{h^m, h^f, C^m, C^f} \mu U^m + (1 - \mu) U^f \tag{7}$$

subject to

$$w_m h^m + w_f h^f + y \geq C^m + C^f \tag{8}$$

for $0 \leq h_i \leq 1$ and $i = \{m, f\}$. Where $\mu(w_m, w_f, y, \mathbf{z}, \mathbf{s})$ is a weighing function, representing the intrahousehold bargaining power. $\mathbf{z}$ is the vector of environmental variables and $\mathbf{s}$ is a vector of distribution factors. The case where μ is constant the collective model becomes the unitary model with weakly separable household preferences. These weights are dependent on $\mathbf{w}$, $\mathbf{y}$, $\mathbf{z}$ and $\mathbf{s}$. An interpretation of these weights represent the bargaining power of the individuals in the intrahousehold allocation process. Any change in wages, nonlabour income or the distribution factor s may shift the bargaining power amongst household members which consequently has an effect on household consumption and labour supply. It is assumed that the function $\mu(w, y, s, z)$ is continuously differentiable in its arguments. This will ensure a unique solution to maximisation of household utility function subject to budget constraint. This solution will be a set of demand functions differentiable and homogenous of degree zero[5]. Another assumption is that only total purchased household commodity consumption is observed. This assumption is useful because household surveys do not distinguish the method of consumption in the household. As a pareto efficient solution of to the household allocation problem one can derive the marshallian labour supply function as:

$$h^i = H^i(y, \mathbf{w}, \mathbf{z}, \mathbf{s}) \tag{9}$$

where $i = \{m, f\}$

3.2.1 Distribibition Factor

The weighting function μ is dependent in a vector of variables $\mathbf{s}$ known as the distribution factors. These distribution factors appear only in this weighing function implying that distribution factors do not affect the Pareto frontier but only the exact location on it. For unitary model setup the distribution factor have no effect on the behaviour of the household. Interior solution is assumed. In the program for household it is generally assumed that the welfare weights μ and $(1 - \mu)$ representing the bargaining power of household

[5]This assumption implies that the unit in which prices, wages and income are expressed doesnot have any effect on the household allocation process.

member is dependent on wages nonlabour income[6] and environmental variables. However, it has been suggested in the literature that variables other than 'relative income' can affect the intrahousehold decision process. Variables that affect the household's environment and the bargaining position of household members. Chiappori et al. (2002) show that marriage market variables and sex ratio are other variables that affect bargaining power of household members. As suggested by McElroy & Horney (1990) extra household environment parameters such as laws on alimony and child benefits, tax laws that differ according to the divorce laws and marital status. This variable can affect the outside opportunity of the household members and may influence bargaining power. Termed as "distribution factors" by Bourguignon & Chiappori (1994) these variables are defined as the variables that affect the bargaining power function μ but do not have any effect on individual's preference and household budget constraint. For example, individual's non labour income may affect his bargaining power in the household but does not have any effect on their preferences.

In the general form of collective model, as considered thusfar, there were no restrictions on individual preferences and the individual utility function incorporated externalities and public goods. However, it is not possible to uniquely identify this general version of the model because there are a myriad of different structural models that can generate identical labour supply function i.e., are 'observationally equivalent' Chiappori et al. (2002). Thus some restrictions are imposed on the general model which will help in derivation of some important identification results pertaining to individual preferences and the allocation of process within the household.

Another cause of imposing restrictions on the general model is the availability of datasets. Many statistical datasets of household labour supply are not explicit on the information needed for the identification of the collective model in its general form. For example,

[6] Thomas (1990) and Browning et al. (1994) provide evidence suggesting that distribution of total intrahousehold income has an effect on the household decision making.

household surveys are not clear on allocation of total expenditure to different consumption goods, individual wages, hours worked, individual nonlabour income etc.

The first assumption imposed to the household behaviour towards getting a unique structural model is the assumption of Egositic or Caring Preferences of the household members:

`ASSUMPTION`: *Egoistic and Caring preferences*: Members of a household are said to have 'egoistic preferences' if their preferences depend only on their own consumption and leisure. These preferences are representative as:

$$U^i = u^i(C^i, 1 - h^i, \mathbf{z}) \tag{10}$$

where i $\in$ {m, f} suggesting that the welfare of member i does not depend on the consumption of member $j \neq i$.

Caring preferences a la Becker (1974) also known as 'Beckerian Caring Preference' are a generalisation of the case under egoistic preferences. The utility preferences of household depend both on the individual's own egoistic utility and the utility of their spouse. The utility function of individual i is expressed as:

$$U^i = f^i(u^m(C^i, 1 - h^i, z), u^f(C^i, 1 - h^i, z)) \tag{11}$$

where f^i is a continous, increasing and quasi-concave in the egoistic utilities of individuals. This form of utility functions impose separability between the private goods of member i and the private goods of member j $(i \neq j)$. With caring preferences a household member values the increase in welfare of other members but they are not primarily interested in the means of this welfare i.e., how this welfare is obtained.

To be more precise, as shown in Chiappori et al. (2002) assuming interior solution is possible to derive testable restrictions for the collective model. The first restriction is derived in proposition I.

`PROPOSITION I`: If the reduced form labour supplies of the members is $h^i(w_m, w_f, y, z, s)$

$i = \{m, f\}$ derived for program equation 7 and 8 is :

$$\frac{\frac{\partial h^m}{\partial s_k}}{\frac{\partial h^m}{\partial s_1}} = \frac{\frac{\partial h^f}{\partial s_k}}{\frac{\partial h^f}{\partial s_1}} \tag{12}$$

for $k = (2...L)$.

Proof: For any fixed μ, h^m and h^f are well behaved Marshallian labour supplies. In particular:

$$h^i(w_m, w_f, y, \mathbf{z}, \mathbf{s}) = H^i(w_m, w_f, y, \mathbf{z}, \mu(w_m, w_f, y, \mathbf{z}, s)) \tag{13}$$

$i = \{m, f\}$.

$$\Rightarrow \qquad \frac{\partial h^i}{\partial s_j} = \frac{\partial H^i}{\partial \mu} \cdot \frac{\partial \mu}{\partial s_j} \tag{14}$$

$$\Rightarrow \qquad \frac{\frac{\partial h^i}{\partial s_k}}{\frac{\partial h^i}{\partial s_1}} = \frac{\frac{\partial \mu}{\partial s_k}}{\frac{\partial \mu}{\partial s_1}} \tag{15}$$

$$\Rightarrow \frac{\frac{\partial h^m}{\partial s_k}}{\frac{\partial h^m}{\partial s_1}} = \frac{\frac{\partial h^f}{\partial s_k}}{\frac{\partial h^f}{\partial s_1}} \tag{16}$$

This results suggests that the distribution factors affect the consumption and labour supply through the weightage of each spouse's utility. These restrictions can be imposed only when there are atleast two distribution factors.

PROPOSITION II: Sharing Rule Interpretation: If the preference of household members are egoistic or caring then it is possible to represent the Pareto efficient household allocation problems of an individual alternatively. Assuming that there exists some function $\psi(\mathbf{w}, \mathbf{y}, \mathbf{s})$ such that each member solves the following program:

$$\max_{h^i, C^i} u^i(C^i, 1 - h^i, \mathbf{z}) \tag{17}$$

subject to

$$w^i h^i + \psi^i(\mathbf{w}, y, \mathbf{s}, \mathbf{z}) \geq C^i \tag{18}$$

where $\psi^f(\mathbf{w}, y, \mathbf{s}, \mathbf{z}) = \psi(\mathbf{w}, y, \mathbf{s}, \mathbf{z})$ and $\psi^m(\mathbf{w}, y, \mathbf{s}, \mathbf{z}) = y - \psi(\mathbf{w}, y, \mathbf{s}, \mathbf{z})$

Proof: Chiappori (1992) proved that this assumption amounts to say that the household allocation is done in two stages. In the first stage the household non labour income is divided among the household members according to the sharing rule ψ and in the second stage the individuals independently allocate their share of full income so as to maximise their individual welfare. The sharing rule result comes handy in identification of individual preference and intrahousehold allocation process.

Under assumption of egoistic preferences of household members and with the assumption of the presence of a sharing rule labour supply equation can be formulated as :

$$h^f = H^f(\psi(\mathbf{w}, \mathbf{y}, \mathbf{s}, \mathbf{z}), w^f, \mathbf{z}) \tag{19}$$

$$h^m = H^m(y - \psi(\mathbf{w}, \mathbf{y}, \mathbf{z}, \mathbf{s}), w^m, \mathbf{z}) \tag{20}$$

ψ representing intrahousehold allocation process is assumed to be twice continuously differentiable. These equations suggest that,

1. A marginal change in the distribution factor $\mathbf{s}$ affect the labour supply indirectly through the sharing rule ψ .

2. marginal change in nonlabour income $\mathbf{y}$ also has an indirect effect on labour supply through the sharing rule of nonlabour income of household members.

3. marginal change in the household member's wage has an income effect on the labour supply of another household member.

Using these results one can retrieve the marginal rate of substitution among the variables of the set $\{w^m, w^f, y, \mathbf{z}\}$ of sharing rule ψ in terms of the observable labour supplies h^m and h^f. Using these marginal substitution effects one can get the partial derivatives of sharing rule ψ. For these partial differential equations to integrate to ψ it is assumed that:

$$\frac{\partial(\frac{\partial\psi}{\partial y})}{\partial s} = \frac{\partial(\frac{\partial\psi}{\partial s})}{\partial y} \tag{21}$$

The structural form of the reduced form labour supply equations makes it possible to recover the partials of the sharing rule. For a change in one members wage rate will affect the labour supply of the other member via the sharing rule (similar effect takes place when other arguments of the sharing rule function i.e., y, $\mathbf{s}$ change). This form of relationship between labour supply behaviour of one member helps in estimating the marginal rate of substitution between the wage of the other household member and nonlabour income and between distribution factor and nonlabour income in sharing rule. Partials of sharing rule appear in two sets of equations (one set for each member). Four partials of sharing rule are identifiable and constraints on sharing rule derivatives result in testable restriction. Define $A = \frac{h^m_{w_f}}{h^m_y}$; $B = \frac{h^f_{w_m}}{h^f_y}$; $C_l = \frac{h^m_{s_l}}{h^m_y}$; $D_l = \frac{h^f_{s_l}}{h^f_y}$; such that $h^m_y.h^f_y \neq 0$ where $l = (1...L)$. It is possible to estimate these variables and the following proposition is obtained.

`PROPOSITION III`: (i) For exactly one distribution factor such that $C \neq D$ the following conditions are necessary for any set (h^m, h^f) to be a solution of equation 17 and 18 for some sharing rule ψ:

$$\frac{\partial}{\partial s}\frac{D}{(D-C)} = \frac{\partial}{\partial y}\frac{CD}{(D-C)} \tag{22}$$

$$\frac{\partial}{\partial w_m}\frac{D}{(D-C)} = \frac{\partial}{\partial y}\frac{BC}{(D-C)} \tag{23}$$

$$\frac{\partial}{\partial w_f}\frac{D}{(D-C)} = \frac{\partial}{\partial y}\frac{AD}{(D-C)} \tag{24}$$

$$\frac{\partial}{\partial w_m}\frac{CD}{(D-C)} = \frac{\partial}{\partial s}\frac{BC}{(D-C)} \tag{25}$$

$$\frac{\partial}{\partial w_f}\frac{CD}{(D-C)} = \frac{\partial}{\partial s}\frac{AD}{(D-C)} \tag{26}$$

$$\frac{\partial}{\partial w_f}\frac{BC}{(D-C)} = \frac{\partial}{\partial w_m}\frac{AD}{(D-C)} \tag{27}$$

$$h^m_{w_m} - h^m_y(h^m + \frac{BC}{D-C})(\frac{D-C}{D}) \geq 0 \tag{28}$$

$$h^f_{w_f} - h^f_y(h^f - \frac{AD}{D-C})(-\frac{D-C}{C}) \geq 0 \tag{29}$$

These conditions are analogous to slutsky restrictions in the general form as they provide a set of partial differential equations and inequalities that need to be satisfied by labour supply functions so that they are consistent with collective framework. The identification is more robust than in Chiappori (1992). The above proposition and the derived results thereof are based on an assumption of egoistic preferences. These propositions are also going to hold for caring preference setup because any decision that is pareto efficient under assumption of caring preferences shall also be pareto efficient for egoistic preferences of the household members. It has been proved in Chiappori (1992) that the pareto frontier of caring agents is a subset of the pareto frontier of egoistic agents.

(ii) With the above restrictions imposed and for given z vector the sharing rule can be defined upto an additive constant. $\kappa(z)$ which depends only on preference factor z.

Sharing Rule: For a given set of demographic and household characteristics i.e., z the sharing rule can be defined upto an additive constant. The partial differential of sharing rule with respect to wages, nonlabour income and all the distribution factors are given by:

- $$\psi_y = \frac{D}{D-C} \tag{30}$$

- $$\psi_s = \frac{CD}{D-C} \tag{31}$$

- $$\psi_{w_m} = \frac{BC}{D-C} \tag{32}$$

- $$\psi_{w_f} = \frac{AD}{D-C} \tag{33}$$

- In presence of more than one distribution factor the partial derivative of sharing rule with respect to additional distribution factor are:

$$\psi_{sl} = \frac{C_l D_l}{D_l - C_l} \tag{34}$$

  This result was proved in Chiappori et al. (2002).

This says that relative effects of distribution factors on each labour supply are equal, where $l = (2...L)$. Solving the above differential equations the ψ function can be obtained upto an additive constant.

4 Parametric Specification of the Model

In order to test the collective and the unitary model we have to provide a functional form specification to the individual labour supply functions. The empirical model for unitary model setup and collective model accounting for the caveats imposed in the previous section are presented next. We consider a quadratic labour supply system.

4.1 Unitary Model Specification and Restriction

The unitary model specification of the model to be estimated would be the one where the distribution factor do not affect labour supply and restriction of unitary model shown in equation 6 are imposed. Thus the unrestricted unitary model to be estimated is:

$$h_m = \gamma_0 + \gamma_1 w_m + \gamma_2 w_f + \gamma_3 {w_m}^2 + \gamma_4 {w_f}^2 + \gamma_5 w_m w_f + \gamma_6 y + \gamma_7^{'} \mathbf{z} \tag{35}$$

$$h_f = \eta_0 + \eta_1 w_m + \eta_2 w_f + \eta_3 w_m^2 + \eta_4 w_f^2 + \eta_5 w_m w_f + \eta_6 y + \eta_7^{'} \mathbf{z} \tag{36}$$

The restricted unitary model will be the estimation of this above system of equations with unitary model restrictions imposed i.e., the restrictions in equation (6). The symmetry restrictions of the unitary model for the above quadratic specification is represented by the following set of restrictions:

$$\gamma_2 - \gamma_6\eta_0 = \eta_1 - \eta_6\gamma_0 \tag{37}$$

$$\gamma_5 - \gamma_6\eta_1 = 2\eta_3 - \eta_6\gamma_1 \tag{38}$$

$$2\gamma_4 - \gamma_6\eta_2 = \eta_5 - \eta_6\gamma_2 \tag{39}$$

$$\gamma_6\eta_3 = \eta_6\gamma_3 \tag{40}$$

$$\gamma_6\eta_4 = \eta_6\gamma_4 \tag{41}$$

$$\gamma_6\eta_5 = \eta_6\gamma_5 \tag{42}$$

The unitary model will be estimated both in the unrestricted form i.e., estimating the system of equations (41) and (42), and the restricted form i.e., imposing the Slutsky Symmetry restrictions. The validity of these restrictions will be tested, if we fail to reject the symmetry restrictions then it can be said that the unitary model holds for rural India. However, if the symmetry restrictions are rejected then it can be inferred that the unitary model is not consistent for India i.e., households do not behave as a single decision making unit. Therefre, in the bext step we can proceed to test for the Collective model of household labour supply for our quadratic labour supply specification.

4.2 Collective Model Specification and Restrictions

If the unitary model does not hold for the data under consideration then the validity of the collective model has to be investigated. The unrestricted collective model can be represented in the following reduced form system of equations for husband and wife:

$$h_m = \alpha_0 + \alpha_1 w_m + \alpha_2 w_f + \alpha_3 {w_m}^2 + \alpha_4 {w_f}^2 + \alpha_5 w_m w_f + \alpha_6 y + \alpha_7 s_1 + \alpha_8 s_2 + \alpha_9 s_3 + \alpha_{10}^{'}\mathbf{z} \tag{43}$$

$$h_f = \beta_0 + \beta_1 w_m + \beta_2 w_f + \beta_3 w_m^2 + \beta_4 w_f^2 + \beta_5 w_m w_f + \beta_6 y + \beta_7 s_1 + \beta_8 s_2 + \beta_9 s_3 + \beta_{10}^{'}\mathbf{z} \tag{44}$$

The above system of equations will be estimated as the unrestricted collective labour supply model.

For collective model, the restrictions imposed in the last section in equations (26) to (32) can be derived for our quadratic parametric specification. Using the definition of A, B, C_l, D_l from previously we get the following specification:

$$A = \frac{\alpha_2 + 2\alpha_4 w_f + \alpha_5 w_m}{\alpha_6} \tag{45}$$

$$B = \frac{\beta_1 + 2\beta_3 w_m + \beta_5 w_f}{\beta_6} \tag{46}$$

$$C_1 = \frac{\alpha_7}{\alpha_6} \tag{47}$$

$$D_1 = \frac{\beta_7}{\beta_6} \tag{48}$$

$$C_2 = \frac{\alpha_8}{\alpha_6} \tag{49}$$

$$D_2 = \frac{\beta_8}{\beta_6} \tag{50}$$

$$C_3 = \frac{\alpha_9}{\alpha_6} \tag{51}$$

$$D_3 = \frac{\beta_9}{\beta_6} \tag{52}$$

On deriving the symmetry conditions in equations (22) to (29) we can say that the restrictions for the collective model are[7]:

1. The distribution factor proportionality restriction is:

$$\frac{\alpha_8}{\beta_8} = \frac{\alpha_9}{\beta_9} = \frac{\alpha_7}{\beta_7} \tag{53}$$

2. The necessary and sufficient conditions for Collective model with caring will boil down to the following restriction,

$$\frac{\alpha_8}{\beta_8} = \frac{\alpha_9}{\beta_9} = \frac{\alpha_7}{\beta_7} = \frac{\alpha_5}{\beta_5} \tag{54}$$

[7]Derivations of symmetry restrictions for quadratic labour supply model are shown in Appendix A

4.2.1 Sharing Rule for Quadratic Labour Supply Model

To provide the sharing rule interpretation we need to recover the sharing rule ψ for our labour supply specification. Using the values of A, B, C and D and the partials of ψ from equations (30) - (34) we get the following values for partial derivatives of sharing rule with quadratic labour supply system.

$$\psi_y = \frac{\alpha_6\beta_5}{\alpha_6\beta_5 - \alpha_5\beta_6} \tag{55}$$

$$\psi_{s_1} = \frac{\alpha_5\beta_7}{\beta_5\alpha_6 - \alpha_5\beta_6} \tag{56}$$

$$\psi_{w_m} = \frac{(\beta_1 + 2\beta_3 w_m + \beta_5 w_f)\alpha_5}{\alpha_6\beta_5 - \alpha_5\beta_6} \tag{57}$$

$$\psi_{w_f} = \frac{(\alpha_2 + 2\alpha_4 w_f + \alpha_5 w_m)\beta_5}{\alpha_6\beta_5 - \alpha_5\beta_6} \tag{58}$$

$$\psi_{s_2} = \frac{\alpha_5\beta_8}{\alpha_6\beta_5 - \alpha_5\beta_6} \tag{59}$$

$$\psi_{s_3} = \frac{\alpha_5\beta_9}{\alpha_6\beta_5 - \alpha_5\beta_6} \tag{60}$$

Solving the above differential equations the ψ function identified upto an additive constant.

$$\psi = \frac{1}{\Delta}[\alpha_5\beta_1 w_m + \alpha_5\beta_3 w_m^2 + \alpha_2\beta_5 w_f + \beta_5\alpha_4 w_f^2 + 2\alpha_5\beta_5 w_m w_f + \beta_5\alpha_6 y + \alpha_5\beta_7 s_1 + \alpha_5\beta_8 s_2 + \alpha_5\beta_9 s_3] + \kappa(z) \tag{61}$$

where $\Delta = (\alpha_6\beta_5 - \alpha_5\beta_6)$. The premise that the sharing rule can be identified upto an additive constant is explained by the fact that the function $\kappa(\mathbf{z})$ is not identifiable because the variables $\mathbf{z}$ affects both the sharing rule and the preferences of the individual. Using the above results it is possible to recover the individual labour supply function for the sharing rule settings. Since they most have the specification suggested in equation (14) and (15), from equation (47), (48) and (91) we can infer the following quadratic specification:

$$h^m = a_1 w_m + a_2 w_m^2 + a_3(y - \psi) + a_4^{'}(\mathbf{z}) \tag{62}$$

$$h^f = b_1 w_f + b_2 w_f^2 + b_3 \psi + b_4^{'}(\mathbf{z}) \tag{63}$$

The partials of ψ and that of the restricted system with sharing rule interpretation can be used to recover the parameters of the above equations. We get the following parameter values: $b_1 = \frac{2\beta_2\alpha_5 - \alpha_2\beta_5}{2\alpha_5}$, $b_2 = \frac{2\alpha_5\beta_4 - \alpha_4\beta_5}{2\alpha_5}$, $b_3 = \frac{\Delta}{2\alpha_5}$, $a_1 = \frac{2\alpha_1\beta_5 - \alpha_5\beta_1}{2\beta_5}$, $a_2 = \frac{2\alpha_3\beta_5 - \alpha_5\beta_3}{2\beta_5}$ and $a_3 = \frac{-\Delta}{2\beta_5}$. The slutsky conditions on compensated individual labour supply conditions (32) and (33) are:

$$(a_1 + 2a_2 w_m) - a_3 h^m \geq 0 \tag{64}$$

$$(b_1 + 2b_2 w_f) - b_3 h^f \geq 0 \tag{65}$$

The global conditions for these inequalities are $a_1 \geq 0$; $a_2 \geq 0$; $a_3 \leq 0$; $b_1 \geq 0$; $b_2 \geq 0$; $b_3 \leq 0$.

4.3 Indirect Utility Function

It has been shown in Stern (1986) that indirect utility functions consistent with quadratic labour supply equations (88) and (89) can be recovered and are represented as:

$$v^m(w_m, \psi_m, \mathbf{z}) = \exp^{a_3 w_m}[y - a_m + b_m w_m + g_m w_m^2] \tag{66}$$

where, with no constant term in the labour supply equations, $a_m = \frac{a_1}{a_3^2} - \frac{2a_2}{a_3^2}$, $b_m = \frac{-a_1}{a_3} + \frac{2a_2}{a_3^2}$ and $g_m = \frac{-a_2}{a_3}$.

$$v^f(w_f, \psi_f, \mathbf{z}) = \exp^{b_3 w_f}[y - (a_f + b_f w_f + g_f w_f^2)] \tag{67}$$

where with no constant term in the labour supply equation (89), $a_f = \frac{b_1}{b_3^2} - \frac{2b_2}{b_3^2}$, $b_f = \frac{-b_1}{b_3} + \frac{2b_2}{b_3^2}$ and $g_f = \frac{-b_2}{b_3}$. Using these indirect utility functions one can get the labour supply equations (88) and (89). An intrahousehold welfare analysis of change in exogenous variables can be performed using these functions (Chiappori et al. 2002).

5 Data

The data for the present analysis has been extracted from the household survey conducted by National Council for Applied Economic Research, New Delhi(India)NCAER (1993-94). Single couple families with dependent children under 15 years of age have been selected. Cases where children participate in labour force, children who are less than 16 year of age and are married are removed from the sample. Calorie consumption of adult males nd adult females has been considered to represent the nutrient intake of the individual. Other environmental variables considered in the alalysis are state dummies. The major states of India are divided into 3 categorical variables - Bimaru, Coastal and Noncoastal. Bimaru states are the states forming the poorest and economically backward states of the country i.e., Bihar, Madhya Pradesh, Rajasthan and Uttar Pradesh. Coastal states are the states that form the coastline of India and Noncoastal states are the states which are neither Bimaru nor Coastal. taking que from past literature (Morz 1987), wages, non labour income and calorie intake are considered to be endogenous variables. The instruments for these variables are second order polynomials in age, education, interaction terms of age and education, adequate water availability and quality of drink water, state dummies, social background of household (i.e., whether SC/ST or not). Three distribution factors are considered in the analysis i.e., age difference between the couples (Age_Diff), difference in wages of the couple($Wage_Diff$) and calorie deprivation ($CalDepr$). The variables age difference and wage difference have also been used are distribution factors elsewhere in literature, see Vermeulen (2005). Age difference and wage difference are said to affect household decision making and do not directly affect the individual decision making hence they qualify as distribution factors. In order to account for the caveat that difference in health of household members might influence household decision making - for example, if one family member is in ill health then there is a possibility that household decision regarding labour supply accounts for the ill member and results in lesser labour supply by the ill member and more days are worked by the healthy member- we consider a third distribution factor calorie deprivation ($Cal_D epr$). To construct this variable first a ratio of calorie consumption ($CalCon$) of the individual and their recommended calorie intake ($RecCal$) (i.e., 2400 KCal/day for men and 2100 KCal/day for women) is found. This would give an indication as to what proportion of the recommended calorie consumption is consumed by an individual. Then in the second step a gap of the proportion of calorie consumption to recommended calorie intake of males to that of females is calculated forming the 'deprovation gap'. $CalDeprGap = (\frac{CalCon}{RecCal})_{Male} - (\frac{CalCon}{RecCal})_{Female}$. This gap will tell us whether the female in the household is calorie deprived or not. $CalDeprGap > 0$ suggests that females are calorie deprived, $CalDeprGap < 0$ suggests that males are calorie deprived and for $CalDeprGap = 0$ with $\frac{CalCon}{RecCal} > 1$ suggests overnourished couple and $\frac{CalCon}{RecCal} < 1$ with $CalDeprGap = 0$ suggest both men and women are over nourished. This gap is referred to as $CalDepr$ in our analysis.

6 Empirical Methodology and Results

The system of 2 equations (i.e., the husband's and wife's labour supply equations) for various versions of the unitary and collective labour supply models have been estimated simultaneously using Generalized Method of Moments (GMM) technique. The reason for using GMM is that it has some advantages over other technique i.e, firstly it takes into account heteroskedasticity of unknown for in the errors and secondly, GMM gives estimators that are asympotically more efficient than Three Stage Least Square (3SLS) and Full Information Maximum Likelihood (FIML) estimator.

The results for unitary model are presented in Tables 1 and 2. Table 1 reports the unrestricted model and Table 2 reports the results for Slutsky symmetry restricted model.

These results suggest that in the unitary mode of household labour supply the wife's wage affects labour supply for both spouses. Non-labour income reduces the labour supply of the couple. Higher calorie consumption improves the labour supply and presence of children in the household also improves labour supply of the males and females. Being literate does improve the labour supply of husbands but literacy of females does not significantly influence her labour supply. With higher age females are seen to reduce their labour supply. Also if the household belongs to a backward class i.e., Scheduled Caste or Scheduled Tribe(SC/ST) then the labour supply of both spouse reduces. In the symmetry restricted version of the model, own wage affects the labour supply of the couple positively. Higher wage of the husband seems to result in higher labour supply of wife. However, husbands labour supply is not influenced by the wife's wage. Before we can rely on these results it is important to test whether the unitary model fits the data under consideration or not? The test for the validity of the symmetry restriction gives a χ^2 Statistic of 14.9159. Since $\chi^2_{0.10}(6) = 10.6446$ we reject the null hypothesis of Slutsky symmetry. We can infer that the unitary model does not hold for labour supply of household in rural India.

As the Unitary model is rejected for India we proceed to test for the suitability of Collective model. The results of the Collective model are presented in Table 3 to 5. Table 3 has the results for unrestricted collective labour supply model from equations (43) and (44). The fact that the distribution factor variable age difference,($Age - Diff$) affects labour supply of males and females significantly suggests that the collective model suits the labour supply behaviour of rural Indian households[8]. The labour supply of each individuals is affected by the wage of the spouse household nonlabour income and presence of both preschool and older children. Calorie consumption and Age affect the labour supply of husbands only. For every unit of calorie consumption labour supply of men increases and with age

[8] As noted earlier, distribution factors affect labour supply only under collective model of household behaviour.

labour supply reduces. Women's labour supply is not significantly influenced by calorie consumption. This results is very important as it suggests that nutrition and health of women is not given adequate importance in rural Indian households.

On imposing the assumption that household members have caring preferences, GMM estimates show that calorie consumption only influences the labour supply of men. The spouse's wage affects the labour supply of individuals linearly, for higher husband's wage labour supply of wives fall and for an increase in the wife's wage the labour supply of husband's increases. Nonlabour income of the household has a small and negative effect on labour supply of both spouses. An important and crucial test in this analysis is to test for suitability of collective model of labour supply. The results pertaining to the model when the restriction of distributional factor proportionality are imposed (shown in equation (79)) reported in Table 4. Testing for the validity of these restriction gives the χ^2-Statistic of 0.4854. With 2 degrees of freedom the test statistic is less than $\chi^2_{0.10}(2)$ i.e., 4.6054 suggesting that we cannot reject the null hypothesis of distributional factor proportionality. Therefore, our results do not reject the general collective model. This version of the collective model allows for externalities.

Results for Collective model with caring i.e., when the restrictions in equation (80) are imposed are reported in Table 5. In this version of the model in addition to distribution factor proportionality an additional restriction that the ratio of the effect of cross wage variable (i.e., $w_h * w_f$) on labour supply is equal to the proportion of distribution factors is imposed. The test for the validity of these restriction gives a χ^2-statistic of $3.3714 < \chi^2_{0.10}(3) = 6.2514$. This indicates that we fail to reject the null hypothesis of 'collective model with caring'. Thus we can conclude that rural household's in India adopt the collective approach in household labour supply decision making. Therefore it can be said that past studies for India adopting the unitary approach to modelling household labour supply behaviour might provide misleading results.

In Table 6 we report the implicit parameters of the women's sharing rule as derived from the restricted parameters of the collective model with caring. These estimates represent the impact of variables on the nonlabour income accruing to the wife after sharing. It is also possible to get marginal effects of these variables on the nonlabour income making way to the wives hands. Majority of parameter estimates,i.e., other than $Child6to15$, $Child < 6$, $Calorie$, $Literacy$, Age are statistically significant. The results suggest that a unit increase in the wife's wage rate, w_f will translate in more transfer to the husband whereas an increase in the husband's wage will result in a reduced nonlabour income accruing to wives. The results show that wives behave in a more altruistic way as compared to their husbands. These results are however not precisely estimated because as stated earlier the sharing rule is estimated only upto an additive constant.

The elasticity estimates for wage and non labour income variables for all the models estimated previously are presented in Table 7. The elasticities are estimated at the sample mean. In the unitary model women's own wage and men's cross wage elasticities are positive and statistically significant in the unrestricted model. The non labour income elasticity is however negative and statistically significant. In the restricted unitary model men's own wage elasticity is positive and statistically significant but are smaller than the estimates for unrestricted model. The elasticities for women are not significant but are much smaller than their unrestricted unitary model counterparts. In the elasticity estimates for the collective model we see that labour supply of both men and women are not responsive to any of the wages. Suggesting that labour supply is responsive to variables other than wages. As can be seen in the estimates for non labour income, labour supply for men and women is responsive to non labour income although the effect is negative. This result is similar to the one suggested in Bardhan (1979) for the case of India. Table 8 presents the own wage elasticity estimates of female and male labour supply, conditional on sharing and non labour income (ψ and $y - \psi$ respectively). These elasticities depend only on individual preferences as they, by definition, ignore any effect that wages might have on intrahousehold decision making process. Both male and female wage elasticities are smaller than the ones reported in Table 7 but are statistically insignificant.

7 Conclusion

In implementation of various development programs, such as programs in health sector development, the aim of the government is for the benefits of these programs to reach the household. Consider human development, India seems to have made substantial progress in the post independence period. Life expectancy has improved, mortality has declined and nutritional status has also improved. Yet 60 percent of women remain anemic, 30 percent of newborn babies are underweight and around 50 percent of children in the age group 0 to 5 years are malnourished. Nutritional status does not only affect the physical wellbeing of the individual but also affects their stamina, capacity to work and hence labour supply and productivity. Thus for a productive labour force it is important to improve health and nutrition of the people. Despite all the efforts of the government of India and organizations such as the World Bank and UNICEF to improve nutrition via programs such as Public Distribution Scheme (PDS), Targetted Public Distribution Scheme (TDPS) have failed to combat malnourishment adequately Measham & Chatterjee (1999). One reason for this inadequate effect of development programs is the fact that the implementation of these programs have been weak. It is important to understand why policy prescriptions fail to reach the target. One reason lies in the design and aim of these policies. Most policy prescriptions such as PDS are designed with the aim of reaching the poorest household. What happens to this subsidy once it reaches a household is not given importance. In India where the status of women is poor and not adequate importance is given to child nutrition it is likely that the intrahousehold distribution is done inadequately. With the premise that it is not only the household that matters but also the intrahousehold decision making process nd individual preferences that affect the behaviour of the houeshold, we investigated household labour supply behaviour in this chapter. The purpose of this chapter has been two fold. Firstly, we investigate the household behaviour by questioning the traditional unitary model of household labour supply against the collective model. Secondly, we investigate the intrahousehold bargaining power of couples. The bargaining power will aid in the understanding of the black box of household decision making.

The analysis in this chapter throws some light in the understanding of the reason as to why goverment spending and policy is not adequately effective. The first important result is that the unitary model of household behaviour does not fir the case of India. Thereby, policy suggestions based on the treatment of household as a single decision maker will not render fruitful results. Secondly, in investigating intrahousehold bargaining power we find that women are more altruistic than men. This sugggests that all policy where the intention is improvement in the human development status of household members it is better to be targeted to reach the hands of women. This suggestion is in line with the extant experience of policy implementation that child nutrition improves if food subsidy reaches the mother. Our analysis also suggests that calorie consumption does not effect women's labour supply. This aspect has to be carefully targetted by policy makers. If women are more altruistic than men then for am overall development of households women should be adequately nourished.

From our analysis of the black box of household decision making we can conclude that in estimating labour supply of individuals it is important to take into account the variation of the labour supply distribution, as shown in the quantile regression analysis. Policy targeted in the improvement of labour supply should account for the distributional variation of labour supply as different variables influence labour supply at different levels. Also, it is important account for the intrahousehold behaviour and bargaining process of the households when modelling labour supply.

Table 1: Unrestricted Unitary Model: GMM Parameter Estimates

Variables	Husband	Wife
$WageM$	-2.970	-2.376
	(2.069)	(1.718)
$WageF$	$\mathbf{3.541}^{**}$	$\mathbf{2.399}^{**}$
	(1.290)	(1.168)
$WageM2$	0.105	-0.039
	(0.088)	(0.079)
$WageF2$	-0.001	$-\mathbf{0.200}^{*}$
	(0.144)	(0.113)
$WageM * F$	-0.131	0.221
	(0.222)	(0.181)
$Nonlabincome$	$-\mathbf{0.002}^{**}$	$-\mathbf{0.002}^{**}$
	(0.0005)	(0.0004)
$Child6to15$	$\mathbf{1.900}^{**}$	$\mathbf{2.250}^{**}$
	(0.962)	(0.753)
$Child < 6$	$\mathbf{4.145}^{**}$	$\mathbf{2.902}^{**}$
	(1.179)	(0.977)
$Calorie$	$\mathbf{0.021}^{**}$	$\mathbf{0.018}^{**}$
	(0.003)	(0.004)
$Literacy$	$\mathbf{4.694}^{*}$	-0.335
	(2.743)	(3.563)
Age	-0.146	$-\mathbf{0.221}^{*}$
	(0.138)	(0.123)
SC/ST	$-\mathbf{4.016}^{*}$	$-\mathbf{3.626}^{**}$
	(2.052)	(1.570)
$Const$	-9.493	9.825
	(20.867)	(16.523)

$*$: statistically significant at 10% level of significance.

$**$: statistically significant at 5% level of significance.

Standard errors are in parentheses.

Table 2: Restricted Unitary Model: GMM Parameter Estimates

Variables	Husband	Wife
WageM	**1.244***	**0.757***
	(0.6573)	(0.4556)
WageF	0.737	**0.718****
	(0.4559)	(0.3330)
WageM2	$-$**0.014***	$-$**0.010***
	(0.0078)	(0.0052)
WageF2	$-$**0.007***	$-$**0.005***
	(0.0036)	(0.0026)
$WageM * F$	$-$**0.019***	$-$**0.014***
	(0.0105)	(0.0072)
Nonlabincome	$-$**0.002****	$-$**0.002****
	(0.0003)	(0.0003)
Child6to15	**2.082****	**2.158****
	(0.8610)	(0.6441)
$Child < 6$	**3.508****	**1.751***
	(1.0974)	(0.9471)
Calorie	**0.020****	**0.017****
	(0.0030)	(0.0034)
Literacy	**5.041***	0.580
	(2.7334)	(3.2644)
Age	-0.162	-0.182
	(0.1377)	(0.1194)
SC/ST	$-$**3.048***	$-$**2.645***
	(1.6425)	(1.3610)
Const	$-$**29.721****	-12.240
	(12.7646)	(9.3115)

$*$: statistically significant at 10% level of significance.

$**$: statistically significant at 5% level of significance.

Standard errors are in parentheses.

Table 3: Unrestricted Collective Model: GMM Parameter Estimates

Variables	Husband	Wife
WageM	-4.202	$-\mathbf{5.504}^{*}$
	(3.394)	(3.085)
WageF	4.602	$\mathbf{5.761}^{*}$
	(3.441)	(3.337)
WageM2	0.068	-0.124
	(0.097)	(0.077)
WageF2	-0.052	$-\mathbf{0.276}^{**}$
	(0.159)	(0.114)
WageMF	-0.041	$\mathbf{0.381}^{**}$
	(0.244)	(0.180)
Nonlabincome	$-\mathbf{0.002}^{**}$	$-\mathbf{0.001}^{**}$
	(0.0005)	(0.0004)
Wage Diff	1.265	4.266
	(3.398)	(3.305)
Age Diff	$\mathbf{0.713}^{**}$	$\mathbf{0.557}^{**}$
	(0.361)	(0.259)
Cal Depri	-49.922	-634.672
	(831.200)	(653.300)
Child6to15	$\mathbf{1.987}^{*}$	$\mathbf{1.498}^{**}$
	(1.058)	(0.761)
$Child < 6$	$\mathbf{3.910}^{**}$	$\mathbf{2.085}^{**}$
	(1.217)	(0.927)
Calorie	$\mathbf{0.019}^{*}$	0.004
	(0.010)	(0.010)
Literacy	3.967	-1.592
	(2.821)	(3.456)
Age	$-\mathbf{0.276}^{*}$	-0.187
	(0.152)	(0.114)
SC/ST	$-\mathbf{3.613}^{*}$	$-\mathbf{3.065}^{**}$
	(2.011)	(1.444)
Const	-1.336	43.310
	(44.295)	(35.722)

$*$: statistically significant at 10% level of significance.

$**$: statistically significant at 5% level of significance.

Standard errors are in parentheses.

Table 4: Collective Model Distributional Factor Proportionality Imposed: GMM Parameter Estimates

Variables	Husband	Wife
$Wage_M$	-4.9664	-5.0307
	(3.0670)	(3.1380)
WageF	**5.6368***	5.0032
	(2.8954)	(3.3672)
WageM2	0.0577	-0.1006
	(0.0935)	(0.0811)
WageF2	-0.0464	$-\mathbf{0.2693}^{**}$
	(0.1496)	(0.1178)
WageMF	-0.0385	**0.3547***
	(0.2318)	(0.1868)
Nonlabincome	$-\mathbf{0.0021}^{**}$	$-\mathbf{0.0014}^{**}$
	(0.0005)	(0.0004)
Wage Diff	2.5279	3.1479
	(2.7769)	(3.3319)
Age Diff	**0.5372***	**0.6689****
	(0.3179)	(0.2745)
Cal Depri	-422.7330	-526.4000
	(583.3000)	(705.9000)
Child6to15	**1.8007***	**1.6497****
	(0.9894)	(0.7784)
$Child < 6$	**3.6481****	**2.2161****
	(1.1678)	(0.9446)
Calorie	**0.0147****	0.0056
	(0.0074)	(0.0101)
Literacy	**4.4051***	-1.6886
	(2.6792)	(3.4723)
Age	$-\mathbf{0.2460}^{*}$	-0.1876
	(0.1423)	(0.1157)
SC/ST	$-\mathbf{3.3939}^{*}$	$-\mathbf{3.2699}^{**}$
	(1.9732)	(1.4604)
Const	14.5535	41.1650
	(35.2791)	(38.0011)

$*$: statistically significant at 10% level of significance.

$**$: statistically significant at 5% level of significance.

Standard errors are in parentheses.

Table 5: Collective Model With Caring: GMM Parameter Estimates

Variables	Husband	Wife
WageM	-4.6852	$-\mathbf{5.6838}^{*}$
	(2.9920)	(3.1922)
WageF	$\mathbf{5.2375}^{*}$	5.6134
	(2.9026)	(3.4783)
WageM2	-0.0193	-0.0390
	(0.0758)	(0.0866)
WageF2	-0.1713	-0.1933
	(0.1099)	(0.1296)
WageMF	0.1638	0.2176
	(0.1696)	(0.2057)
Nonlabincome	$-\mathbf{0.0022}^{**}$	$-\mathbf{0.0014}^{**}$
	(0.0004)	(0.0004)
Wage Diff	2.4556	3.2623
	(2.7722)	(3.4614)
Age Diff	$\mathbf{0.4976}^{*}$	$\mathbf{0.6611}^{**}$
	(0.2994)	(0.2735)
Cal Depri	-462.8780	-614.9430
	(564.1000)	(714.1000)
Child6to15	$\mathbf{1.9163}^{**}$	$\mathbf{1.6389}^{**}$
	(0.9647)	(0.7664)
$Child < 6$	$\mathbf{3.8646}^{**}$	$\mathbf{2.0587}^{**}$
	(1.1162)	(0.9374)
Calorie	$\mathbf{0.0135}^{*}$	0.0045
	(0.0072)	(0.0101)
Literacy	3.7727	-1.8210
	(2.6153)	(3.4106)
Age	$-\mathbf{0.2336}^{*}$	-0.1851
	(0.1408)	(0.1137)
SC/ST	$-\mathbf{3.6050}^{**}$	$-\mathbf{3.1637}^{**}$
	(1.7967)	(1.4490)
Const	19.3181	46.7087
	(34.0290)	(38.1826)

$*$: statistically significant at 10% level of significance.

$**$: statistically significant at 5% level of significance.

Standard errors are in parentheses.

Table 6: Sharing Rule for Female: Estimates

Variables	Coefficient
WageM	$-\mathbf{0.4460}^{**}$
	(7.4500)
WageF	$\mathbf{0.5459}^{**}$
	(6.8900)
WageM2	$-\mathbf{0.0031}^{**}$
	(0.2210)
WageF2	$-\mathbf{0.0179}^{**}$
	(0.3630)
WageMF	$\mathbf{0.0341}^{**}$
	(0.5470)
Nonlabincome	$-\mathbf{0.0034}^{**}$
	(0.0011)
Wage Diff	$\mathbf{0.2560}^{**}$
	(6.0500)
Age Diff	$\mathbf{0.0519}^{**}$
	(0.7650)
Cal Depr	$-\mathbf{48.2513}^{**}$
	(0.0004)
Child6to15	-1.7200
	(2.9300)
$Child < 6$	2.4700
	(2.8900)
Calorie	0.0051
	(0.0081)
Literacy	-6.3400
	(7.4100)
Age	0.2400
	(0.3950)
Constant	$-\mathbf{9.6000}^{**}$
	(4.1300)

Standard errors are in parentheses.

All standard errors of sharing rule are multiplied by 10^8 .

The Constant term for sharing rule is multiplied by 10^7.

Coefficient of the sharing rule for $Child < 6$,

Child6to15, literacy, age, calorie are multiplied by 10^8.

Constant is multiplied by 10^7.

Table 7: Elasticity Estimates for Unitary and Collective Models

	Unitary Unrest. Model		Unitary Rest. Model		Unrest. Collective Model		General Collective Model		Collective Model with Caring		Co c
	Husb.	Wives	Husb.	Wives	Husb.	Wives	Husb.	Wives	Husb.	Wives	Husl
w_m	-0.5438	-0.3715	**0.2577****	0.1076	-1.5049	-3.7204	-2.4269	-2.7439	-2.2193	-3.2021	0.260
	(0.3511)	(0.3130)	(0.1441)	0.1305	(2.3173)	(2.5325)	(2.04)	(2.5624)	(1.9213)	(2.6979)	(0.2493
w_f	**0.4531****	**0.3554***	0.0627	0.1775	1.2149	3.0517	1.970	2.2594	1.8404	2.6017	
	(0.2104)	(0.1834)	(0.0902)	0.0807	(1.8956)	(2.0338)	(1.6400)	(2.0624)	(1.5447)	(2.1732)	
y	**−0.0039****	**−0.0030****	**−0.0043****	-0.0033	**−0.0036****	**−0.0027****	**−0.0037****	**−0.0027****	**−0.0037****	**−0.0027****	
	(0.0008)	(0.0007)	(0.0006)	0.0005	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0007)	

Standard Errors are in Parenthesis.

*: statistically significant at 10% level of significance.

**: statistically significant at 5% level of significance.

Table 8: Elasticity for Model with Sharing Rule

Variable	Conditional on $\psi(.)$ Model	
	Husbands	Wives
w_m	0.2605	
	(0.2493)	
w_f		-0.0486
		(0.2684)
y		

Standard Errors are in Parenthesis.

Elasticity estimates for model in equation 88 and 89.

8 Appendix A

$$\frac{D_1}{D_1 - C_1} = \frac{\beta_7 \alpha_6}{(\alpha_6 \beta_7 - \alpha_7 \beta_6)} \tag{68}$$

$$\frac{C_1 D_1}{D_1 - C_1} = \frac{\alpha_7 \beta_7}{\alpha_6 \beta_7 - \alpha_7 \beta_6} \tag{69}$$

$$\frac{AD_1}{D_1 - C_1} = \frac{\beta_7(\alpha_2 + 2\alpha_4 w_f + \alpha_5 w_m)}{\alpha_6 \beta_7 - \alpha_7 \beta_6} \tag{70}$$

$$\frac{C_1}{D_1 - C_1} = \frac{\alpha_7 \beta_6}{\alpha_6 \beta_7 - \alpha_7 \beta_6} \tag{71}$$

$$\frac{BC}{D - C} = \frac{\alpha_7(\beta_1 + 2\beta_3 w_m + \beta_5 w_f)}{\alpha_6 \beta_7 - \alpha_7 \beta_6} \tag{72}$$

Derivation of Conditions (26) to (30):

1.

$$\frac{\partial}{\partial s}\left(\frac{D}{D - C}\right) = \frac{\partial}{\partial y}\left(\frac{CD}{D - C}\right) \tag{73}$$

$$\Rightarrow \frac{\partial}{\partial s}\left(\frac{\beta_7 \alpha_6}{\alpha_6 \beta_7 - \alpha_7 \beta_6}\right) = \frac{\partial}{\partial y}\left(\frac{\beta_9 \alpha_9}{\alpha_8 \beta_9 - \alpha_9 \beta_8}\right) \tag{74}$$

$$\Rightarrow L.H.S = R.H.S = 0 \tag{75}$$

2.

$$\frac{\partial}{\partial w_1}(\frac{D}{D-C}) = \frac{\partial}{\partial y}(\frac{BC}{D-C}) \tag{76}$$

$$\Rightarrow L.H.S = R.H.S = 0 \tag{77}$$

$$\frac{\partial}{\partial w_2}(\frac{D}{D-C}) = \frac{\partial}{\partial y}(\frac{AD}{D-C}) \tag{78}$$

$$\Rightarrow \frac{\partial}{\partial w_2}(\frac{\beta_7\alpha_6}{\alpha_6\beta_7 - \alpha_7\beta_6}) = \frac{\partial}{\partial y}(\frac{\beta_7(\alpha_2 + 2\alpha_4 w_f + \alpha_5 w_m)}{\alpha_6\beta_7 - \alpha_7\beta_6}) \tag{79}$$

$$\Rightarrow L.H.S = R.H.S = 0 \tag{80}$$

3.

$$\frac{\partial}{\partial w_1}(\frac{CD}{D-C}) = \frac{\partial}{\partial s_1}(\frac{BC}{D-C}) \tag{81}$$

$$\frac{\partial}{\partial w_1}(\frac{\alpha_7\beta_7}{\alpha_6\beta_7 - \alpha_7\beta_6}) = \frac{\partial}{\partial s}(\frac{\alpha_7(\beta_1 + 2\beta_3 w_m + \beta_5 w_f)}{\alpha_6\beta_7 - \alpha_7\beta_6}) \tag{82}$$

$$L.H.S = R.H.S = 0 \tag{83}$$

4.

$$\frac{\partial}{\partial w_2}(\frac{CD}{D-C}) = \frac{\partial}{\partial s}(\frac{AD}{D-C}) \tag{84}$$

$$\frac{\partial}{\partial w_2}(\frac{\alpha_7\beta_7}{\alpha_6\beta_7 - \alpha_7\beta_6}) = \frac{\partial}{\partial s}(\frac{\beta_7(\alpha_2 + 2\alpha_4 w_f + \alpha_5 w_m)}{\alpha_6\beta_7 - \alpha_7\beta_6}) \tag{85}$$

$$L.H.S = R.H.S = 0 \tag{86}$$

5.

$$\frac{\partial}{\partial w_f}(\frac{BC}{D-C}) = \frac{\partial}{\partial w_m}(\frac{AD}{D-C}) \tag{87}$$

$$\Rightarrow \frac{\partial}{\partial w_f}(\frac{\alpha_7(\beta_1 + 2\beta_3 w_m + \beta_5 w_f)}{\alpha_6\beta_7 - \beta_6\alpha_7}) = \frac{\partial}{\partial w_m}(\frac{\beta_7(\alpha_2 + 2\alpha_4 w_f + \alpha_5 w_m)}{\alpha_6\beta_7 - \alpha_7\beta_6}) \tag{88}$$

$$\Rightarrow \frac{\alpha_5}{\beta_5} = \frac{\alpha_7}{\beta_7} \tag{89}$$

6. With more than one distribution factors the additional conditions to be satisfied are:

$$\frac{C_2}{D_2} = \frac{C_1}{D_1} \tag{90}$$

$$\Rightarrow \frac{\frac{\alpha_8}{\alpha_6}}{\frac{\beta_8}{\beta_6}} = \frac{\frac{\alpha_7}{\alpha_6}}{\frac{\beta_7}{\beta_6}} \tag{91}$$

$$\Rightarrow \frac{\alpha_8}{\alpha_7} = \frac{\beta_8}{\beta_7} \tag{92}$$

7. For the third distribution factor similar equation can be derived so that we get the following restriction for proportionality of distribution factors:

$$\frac{\alpha_8}{\beta_8} = \frac{\alpha_9}{\beta_9} = \frac{\alpha_7}{\beta_7} \tag{93}$$

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