Mining induced acquisition of community land, interest conflict and possible institutions of conflict resolution for sustainable development: an analytical approach*

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Abstract

Liberalization of mine licensing policies due to globalization and increasing demand from industrial economies have brought about rapid acquisition of community land for mining. This often leads to interest conflict between miners and traditional community. Governments of developing countries including that of India show their greatest concern about designing the benefit sharing principle to minimize the conflict. Two alternative institutions of conflict resolution with their long term impact on depletion of mine reserve, land use pattern and sustainable development of the society as a whole are analytically discussed and compared. In game theoretic framework, first type of institution leads to the private Nash strategic solution and the second institution results the possible solution through the intervention of social planner. In the first case, given the history of choices of bids and offers on rent and royalty, miner and traditional community each reaches the chosen time path of land acquisition and thereby the path of depletion of mine reserve and finally a Nash agreeable resolution. The socially desirable paths of land acquisition and depletion of mine reserve, if social planner intervenes, are also derived. Whether shadow benefit of depletion of mine reserve and shadow cost of exploration of new reserve by land acquisition under social planning will be less than those under private Nash solution, depend on the proportion of mining benefit that planner chooses to redistribute to the community, relative to the price of mine output. The maximum land a miner may need to acquire for a given quantity of mine output is quantified in terms of geological parameters. It is used to get the maximum socially acceptable area of community land for mining to sustain a targeted level of social welfare. The condition for sustainable path of development is derived and the dynamic rent and royalty along the path that community can deserve from miners are formulated. For resolving conflict, the conditions under which miner and community will opt for social planning rather than for pure Nash settlement have also been derived. All these analytical observations bear significance to the policy makers designing the mechanism to minimize interest conflict in the process of economic development.

Key words: community land, dynamic optimization, land acquisition, mining, rent, royalty, Nash strategy game, shadow cost, shadow benefit

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Introduction

Mining induced land acquisition is bringing forth interest conflict between modern growing industrial economy and long term sustainable traditional economy in most of the developing countries today. Leasing out community land for mining not only causes displacement of local people but also the loss of traditional livelihood due to degradation of the biophysical environment. It leads to the interest conflict between miner and traditional community, and sometimes also the conflict between miner community and the government concerned. We can cite a number of examples of mining induced environmental degradation inflicting the conflict of interests all over the world. Two indigenous Indian communities of northern Brazil - Yanomami and Yekuana are in protest against the illegal invasion by gold miners. Gold mining is polluting the rivers with mercury, contaminating drinking water and destroying fish consumed by them (Survival, 2010). In India in many states (i.e. provinces) like in Orissa, Chhattisgarh, Jharkhand, those being the richest in terms of mineral wealth but ironically the poorest in terms of overall economic conditions- traditional communities are launching protest against miner and industrial corporate and sometimes against the state governments concerned (Sahu, 2008). The Forest Policy of 1988 along with Forest Conservation Rule of 2003 in India have framed up a rule to determine the cost of compensatory afforestation to be paid to the forest department of the government. Many mining sectors like coal, aluminium and bauxite have framed out their rehabilitation resettlement and reclamation policies to acquire land from community. A multi-national limestone mine company had to settle royalty payment with *durbar* (village council) of Nongtarai village Meghalaya, India as the payment of INR 5.00 per ton of limestone extracted from their community land leased out. For mining of aluminous laterite from Belgundi village in Karnataka the mine company had to settle collectively with the villagers for reclamation of agricultural and waste land leased for mining (Banerjee, 2004). Balipara Tract & Frontier Foundation an NGO of Assam (a north-eastern state of India) resolved that mine companies should pay rent (for land) and royalty (for minerals) to the host community (or family) where value of land must be based on the value of ascertained minerals (Balipara Foundation, 2010). Ministry of Environment and Forest (MoEF) and national Mining policy of Government of India charge the cess and royalty from mine company at varying rates (e.g., INR Rs. 64.00 per tonne of bauxite) for different types of desired material (EPGORISSA, 2010). These rent-royalty payments are expected to be used for reclamation and development of host community. In spite of all, at the state level and local level unjust and forced encroachment of community by corporate mining are recurrent phenomena in India. Miners and sometimes also the State governments are found to shirk the livelihood issues of local people, even the traditional rights of local institutions like community forest management (Press Release, 2008; Bhubaneswar, Orissa).

The necessity of extraction of natural resources for development cannot be denied. But the problem is to find out the ways in which environmental devastation can be minimized and community can get a substantial benefit of mining not only for current but also for its future generation. Resolving the interest conflict in the process of development has become the greatest challenge to most of the developing countries today.

The government of India for resolving the interest conflict for the last few years is concerned about designing the principle of benefit sharing of mining with community. It is about whether local people should get the share of royalty or share of profit and in what proportion, and under what type of institutional arrangement. Very recently a bill of sharing 26% of profit in case of nationalized coal mining and 100% royalty sharing in case of other mining to the local community through the district-level fund has got the approval of the ministry of cabinet in India .

With this phenomenon at the backdrop the present research work intends to handle the issue of conflict resolution via benefit sharing of mining with local community in two different institutional frameworks: viz., an institution of private negotiation and an institution where social planner designs a rule of negotiation before the private agents start interaction. The consequences of these two types of institution have been theoretically analyzed and compared in the following sections. The results of this analysis can be used as the guidelines for the policy makers who are concerned with designing the appropriate benefit sharing principle to minimize the miner-community conflict in the mining led development.

2 Mining induced land acquisition, interest conflict and conflict resolution game: A model

2.1 An outline of the model

There exists a hypothetical community of traditional producers who is going to lease out the community land (which is a common property resource) with mine reserve. The community's traditional livelihood so far so good is derived from the community land out of traditional economic activities like cultivation, firewood collection etc. Now there is a miner firm seeking entry into that community land for exploration of some exhaustible mine resources. It is a profit maximizer, facing a competitive market for desired material. It can start negotiation directly with the traditional community to settle the compensatory return for land acquisition or it can acquire land through the 'social planner' as a representative of the government. While leasing out land to the miner firm community may get some compensatory return in terms of royalty and rent payment but at the cost of losing some production values of their traditional economic activities. In the following subsections we consider two possible conflict resolving games. In the first, each of the miner and traditional community is a 'Nash' player, i.e. each from their own individualistic perspective through mutual negotiation is trying to reach an agreement. It is a 2-players -2-stages dynamic game with the assumption of perfect information:

Given the productivity of land with respect to traditional output, its price and amount of mine reserve (which is assumed to be known by the community) community decides how much rent (γ on reserve) and royalty (Ψ i.e. share of mine-output) it will claim. Mining firm on the other hand, at stage I, given price of desired material, geological features of the mine resource, stock of reserve and cost of extraction - it decides how much rent and royalty it will offer to the community. In the second stage after γ and Ψ are determined; community decides how much land it will retain for traditional production and how much it will lease out. And then on the basis of that miner decides how much community land will be taken on lease. In the final stage given the area of land acquired, miner decides how much acquired land it will explore and thereby produce mine output. From the sub-game perfect equilibrium at stage II from traditional community's strategic choice we get the supply path of land acquisition for mining over time. Similarly from miner's strategic choice we get the demand path of land acquisition over time. Taking them together in the backward induction process the solution is rolled back to stage I to get the optimal value of rent γ^* and royalty Ψ^*

Alternatively, we will consider a situation where there is a 'social planner' who is concerned with maximizing the discounted composite social welfare over time. The composite welfare is constituted by miner's net profit and traditional community's net profit. Miner's net profit is calculated after deducting the cost of extraction and the cost of paying the rent and royalty to the community. Community's net profit from traditional production and their earning from rent - is calculated after deducting the loss of traditional production due to leasing out land to the miner. In composite social welfare the relative weight (or importance) given by the social planner to the loss of traditional production is also an important matter for policy decision.

Deriving the socially desirable land acquisition path and there by the mine extraction path the social planner obtains the socially optimal rent and royalty and offer the miner and community to accept. We assume that there exists an indicative plan model in the economy. The community and farmers enjoy the freedom to accept or not to accept the social planner's offer.

2.2 Conflict resolution game: A Nash solution

2.2.1 Miner's Nash strategy game

With history of choices on the rent on mine reserve γ and royalty Ψ he bids at stage I miner decides how much area of community land A_c it will lease and how much Y, the desired material it will extract from that. The compensatory return it will have to pay terms of Y and value of reserve R is: $(\Psi.Y(A_c)+\gamma R)$. Analytically it's optimization problem is similar to that in the extended framework of Pindyck (1978),:

$$Max_{Y,A}\int_0^\infty [pY - C(Y,R) - \Psi.Y(A_c) - \gamma R]e^{-\delta t}\,dt \text{ …….. (2.1)}$$

subject to:

$$\dot{R} = \dot{x} - Y \text{ ………. (2.1.1)}$$

$$\dot{x} = f(A_c, x) \text{ …….. (2.1.2)}$$

$$Y \geq 0;\ A \geq 0\ R \geq 0;\ x \geq 0 \text{ …….. (2.1.3)}$$

p is the market price of the desired material Y, exogenously determined. C is the cost of extraction which depends upon Y and the reserve level R. $C_Y > 0, C_{YY} > 0$, $C_R < 0$, $C_{RR} > 0$. These imply that marginal cost of extraction is positive and cost of extraction increases as reserve declines. x is the cumulative addition of reserve which over time increases by the production cum exploration function f. f given x depends upon A_c the area of land taken by lease for exploration. $f_A > 0$; $f_{AA} < 0$. These indicate that marginal product of exploration from area of land acquired increase at the decreasing rate. $f_x < 0$, implying that exploration decreases with cumulative addition of reserve. $\Psi(A)$ is the cost of leasing land which is land rent. $\Psi_A > 0$. $\dot{R}$ is the net addition of reserve over time. γ is the effective rent on the reserve.

In optimal control theory framework the Hamiltonian function for this problem, with single control variable $Y(A_c)$ and two state variables R and x is:

$$H = (p-\Psi)Y e^{-\delta t} - C(Y,R)e^{-\delta t} - \gamma R(A_c)e^{-\delta t} + \lambda_1[f(A_c,x) - Y(A_c)] + \lambda_2[f(A_c,x)] \text{ ….. (2.2)}$$

Solving (2.2) we get, $\lambda_1 = (p - C_Y - \Psi)e^{-\delta t}$ …….. (2.2.1)

$$\dot{\lambda}_1 = (C_R + \gamma)e^{-\delta t} \text{ …….. (2.2.2)}$$

$$\dot{\lambda}_2 = -f_x(\lambda_1 + \lambda_2)$$

$$= -[C_R + \gamma]R_{A_c} \frac{f_x}{f_{A_c}} e^{-\delta t} \text{ ……. (2.2.3)}$$

(Appendix 1)

(2.2.3) is the equation of shadow cost path of exploration of new reserves to the miner. Since marginal cost of extraction from each additional unit of reserve $C_R < 0$, $R_{A_c} > 0$, $f_x > 0$ and $f_{A_c} > 0$, shadow cost of exploration will increase over time if $\gamma > -C_R$. The shadow cost decreases if $\gamma < -C_R$.

Again, plugging the value of λ_1 from equation (2.2.1) into equation (2.2.3) we obtain the value of λ_2 from:

$$Or, \lambda_2 = \frac{1}{f_{A_c}}\left[(p - C_Y - \Psi)f_{A_c} - (C_R + \gamma)R_{A_c}\right]e^{-\delta t} \text{ …… (2.2.4)}$$

Differentiating equation (2.2.1) with respect to time and putting the value of $\dot{\lambda}_1$ from equation (2.2.2) we get the optimal mine extraction path:

$$\dot{Y} = \frac{-\delta(p - C_Y - \Psi) + \dot{p} - C_{YR}\dot{R} - (C_R + \gamma)}{C_{YY}} \text{ …… (2.2.5)}$$

Mine production will be declining in the present context if

$$\dot{p} < \delta(p - C_Y - \Psi) + C_{YR}\dot{R} + (C_R + \gamma)$$

$C_{YR}\dot{R}$ shows the impact on marginal cost of depletion of reserve over time. As reserve depletes, cost of extraction increases. Thus $C_{YR}\dot{R} < 0$. $\delta(p - C_Y - \Psi)$ indicates the discounted value of marginal profit which is greater than zero. $C_R < 0$ but $\gamma > 0$. Hence the sign of $(C_R + \gamma)$ may be negative or positive depending upon the relative dominance of C_R and γ. If price rises at the rate of discount, i.e. $\dot{p} = \delta p$ mine production will be still declining if:

$$\gamma > \delta(C_Y - \Psi) - C_{YR}\dot{R} - C_R$$

i.e rent on reserve is greater than the discounted value of net marginal cost of extraction + marginal extraction cost due to reserve depletion net of cost saving effect of having more reserve.

Now differentiating equation (2.2.1) with respect to time we get the time path of land acquisition chosen by miner, which is also the demand path of land acquisition:

$$\left[-\delta\left[(p-C_Y-\Psi)f_{A_c}-(C_R+\gamma)R_{A_c}\right]+\left[(p-C_Y-\Psi)f_{A_cA_c}-(C_R+\gamma)R_{A_cA_c}\right]\dot{A}_c\right]e^{-\delta t}+f_{A_cA_c}\dot{A}_c\lambda_2+f_{A_c}\dot{\lambda}_2=0$$

$$-\delta\left[(p-C_Y-\Psi)f_{A_c}-(1+f_x)(C_R+\gamma)R_{A_c}\right]+\left(\frac{f_{A_cA_c}R_{A_c}}{f_{A_c}}-R_{A_cA_c}\right)(C_R+\gamma)\dot{A}_c=0$$

$$\dot{A}_c^{\mathrm{M}}=\frac{\delta\left[(p-C_Y-\Psi)f_{A_c}-(1+f_x)(C_R+\gamma)R_{A_c}\right]}{\left(\frac{f_{A_cA_c}R_{A_c}}{f_{A_c}}-R_{A_cA_c}\right)(C_R+\gamma)} \quad \ldots\ldots \text{(2.2.6)}$$

(Appendix 2)

In the above expression the relative dominance or non-dominance of C_R i.e. the cost saving effect of having reserve over γ the cost rising effect of rent again determines whether the demand path of land acquisition path by the miner will be rising or falling over time. To simplify the matter let $f_{A_cA_c}=1$ and $R_{A_cA_c}=1$, i.e. rate of exploration of new reserve and the rate of change of reserve both with respect to A_c increases at the same rate as that of the rate of increase of A_c. $\frac{R_{A_c}}{f_{A_c}}>1$ i.e. rate of increase in reserve is greater than rate of exploration of reserve from each additional unit of land leased in. The first component in the numerator i.e. $(p-C_Y-\Psi)f_{A_c}$ is the net marginal return from extraction from the new explored land. The second component $(1+f_x)(C_R+\gamma)R_{A_c}$ is the net cost of having reserve (both from the existing stock and that from the new explored area). The sign of the denominator is negative if $|C_R|>\gamma$. In that case, $\dot{A}_c<0$. Since cost saving effect of having reserve dominates over cost on account of rent payment on reserve, over time miner's urge to acquire more land will be declining. Opposite phenomenon will occur i.e demand path will be rising $\dot{A}_c>0$ if $|C_R|<\gamma$.

Miner's choice of $(\dot{Y},\dot{A}_c)$ at stage 2 of conflict resolution game depends upon history of choices of (Ψ_A,γ) at stage I, that miner offers to the traditional community, given the community's claim. Unless and until (Ψ_A,γ) are decided we cannot obtain the optimal $(\dot{Y},\dot{A}_c)$.

2.2.2 Traditional community's Nash strategy game

The community has a land based traditional production with the production function: $g(L;A_c)$. Traditional production increases with L, the area of land used for that purpose and decreases with increase in A_c, the area of land leased out to the mining firm. The total available land in the community: $\bar{L}\geq L+A_c$ i.e. L cannot exceed the total available land $\overline{L}$. The change in available land for traditional production is defined by an equation of motion: $\dot{L} = -A_c$

The control problem of the traditional community is to choose a path for the land-leasing that maximizes the following objective function defined as discounted net return from traditional production plus rent and share of mining profit from mine company as compensatory return from land conversion.

$$Max_L \int_0^{\infty} [w.g(L) + \Psi.p.Y(A_c) + \gamma.R(A_c)]e^{-\theta t}\, dt \text{ ; …….. (2.3)}$$

$$\text{subject to: } \dot{L} = -A_c \text{ ……. (2.3.1)}$$

$$L(0) \in [\overline{L}, 0]$$

The present value Hamiltonian for this problem with the single control variable L is:

$$H = w.g(L)e^{-\theta t} + \Psi.p.Y(A_c)e^{-\theta t} + \gamma R(A_c)e^{-\theta t} - \xi_1 A_c \text{ ….. (2.3.2)}$$

Differentiating H with respect to A_c and L we get:

$$H_{A_c} = (\Psi.p.Y_{A_c} + \gamma R_{A_c})e^{-\theta t} - \xi_1 = 0 \text{ ……… (2.3.3)}$$

$$H_L = -\dot{\xi}_1 = w.g_L.e^{-\theta t}$$

The optimal path is found from the necessary conditions by substituting the equation of motion $\dot{L} = -A_c$ into (2.3.2) and taking the time derivative of the resulting equation. Finally we get the land acquisition path chosen by the community which is to be considered as the supply path of land acquisition by the community as:

$$\dot{A}_c^{\,G} = \frac{w.g_L - \theta(\Psi Y_{A_c} + \gamma R_{A_c})}{(\Psi Y_{A_c L} + \gamma R_{A_c L})} \text{ …… (2.3.4)}$$

(Appendix 3)

Rolling back from stage 2 to stage 1 game i.e solving the miner's demand path $\dot{A}_c^{\,M}$ with traditional community's supply path $\dot{A}_c^{\,G}$ finally they reach the equilibrium rate of royalty Ψ^* and rent on in situ reserve γ^*.

$$\dot{A}_c^{\,G} = \dot{A}_c^{\,M} \rightarrow$$

$$\frac{w.g_L - \theta(\Psi Y_{A_c} + \gamma R_{A_c})}{(\Psi Y_{A_c A_c} + \gamma R_{A_c A_c})} = \frac{\delta[(p - C_Y - \Psi)f_{A_c} - (1 + f_x)(C_R + \gamma)R_{A_c}]}{\left(\frac{f_{A_c A_c} R_{A_c}}{f_{A_c}} - R_{A_c A_c}\right)(C_R + \gamma)} \text{ ….. (2.3.5)}$$

For simplification let $\Psi = 0$ i.e. we assume that there is no compensation to be paid on the basis of the value of mine output but only on in situ reserve, and the rate of discount of miner and the community is the same, i.e. $\theta = \delta$. To illustrate the fact let us further assume, $Y_{A_cL} = 1$, $f_{A_cA_c} = 1$ $R_{A_cA_c} = 1$ and $C_R = 0$ i.e. marginal cost of extraction for having reserve is nil(say cost of mine production due to reserve is negative but constant, i.e. $C(R) = -\overline{C}$) . Then from (2.3.5) we get:

$$\gamma^* = \frac{f_{A_c}{}^2(p - C_Y) - (R_{A_c} - f_{A_c})\frac{w.g_L}{\theta}}{R_{A_c}\left[R_{A_c} - f_{A_c} f_x\right]} \text{ ……… (2.3.6)}$$

2.3 Conflict resolution game through the social planner

Social planner has to choose socially desirable Y and A_c and there by determine ψ and γ in such a way that maximizes the aggregate welfare or benefit of the society. In our present context, one component of that social benefit is the net profit of the miner i.e. $P.Y(A_c) - C(Y(A_c), R(A_c))$. A part of this goes back to the social planner in the form of rent and royalty payment which is $[\psi.p.Y(A_c) + \gamma R(A_c)]$. A proportion of $[\psi.p.Y(A_c) + \gamma R(A_c)]$ again goes back to the community say ρ to compensate the loss of traditional production. ρ is arbitrarily chosen by the social planner. $\rho < 1$. It is the weight or importance given by the planner to the welfare loss of the traditional community (vis-à-vis the loss of production) due to leasing out land. Now the optimization dynamic problem of the social planner is:

$$Max \int_0^T e^{-\delta t}\left[P.Y(A_c) - C(Y(A_c), R(A_c)) + g(L) - [\psi.p.Y(A_c) + \gamma R(A_c)](1-\rho)\right] \text{ ……… (2.4)}$$

$$\text{subject to : } \dot{R}(A_c) = \dot{x} - Y \text{ ……… (2.4.1)}$$

$$\dot{x} = f(x, A_c) \text{ ……… (2.4.2)}$$

The Hamiltonian function with the single control variable $Y(A_c)$ and two state variables R and x is:

$$\widetilde{H} = e^{-\delta t}\left[P.Y(A_c) - C(Y(A_c), R(A_c)) - [\psi.p.Y(A_c) + \gamma R(A_c)](1-\rho.) + g(\overline{L} - A_c)\right] + \mu_1[f(x, A_c) - Y] + \mu_2.f(x, A_c) \text{ … (2.4.3)}$$

Differentiating (2.4.3) with respect to A_c and Y we get the shadow cost of depletion of mine reserve:

$$\mu_1 = [p - C_Y - \psi.p.(1-\rho)]e^{-\delta t} \text{ …….. (2.4.4)}$$

compared to the shadow cost of depletion of mine reserve under Nash solution $\lambda_I = (p - C_Y - \Psi)e^{-\delta t}$ … (2.2.1)

The shadow cost of depletion of mine reserve in case of social planning will be higher than that determined through Nash equilibrium if $p.(1-\rho)<1 \rightarrow \rho>1-\frac{1}{p}$.

Again in the present context, $\frac{\partial \widetilde{H}}{\partial R}=\dot{\mu}_1=[C_R-\gamma(1-\rho)]e^{-\delta t}$ .... (2.4.5)

compared to $\dot{\lambda}_1=(C_R+\gamma)e^{-\delta t}$ in the former case.

Since $\rho<1$, $\dot{\mu}_1<\dot{\lambda}_1$ which implies under social planning the shadow cost of depletion of mine reserve declines at the rate slower than that under Nash solution. Greater the value on ρ is attached by the social planner, greater will be the value of $\dot{\mu}_1$. Differentiating (2.4.3) with respect to x we have,

$$\dot{\mu}_2=-f_x(\mu_1+\mu_2) \text{........ (2.4.6)}$$

Plugging the value from (2.4.6) into (2.4.4) we get:

$$\widetilde{H}_{A_c}=e^{-\delta t}\left[\left[P-C_Y-\psi.p.(1-\rho)\right]Y_{A_c}-\left[C_R+\gamma(1-\rho)\right]R_{A_c}-g\right]-\left[p-C_Y-\psi.p.(1-\rho)\right]Y_{A_c}e^{-\delta t}-\dot{\mu}_2\frac{f_{A_c}}{f_x}=0$$

...... (2.4.7)

Since, $\mu_1=[(p-C_Y+\psi.p(1-\rho))]e^{-\delta t}$ from (2.4.4), plugging it into (2.4.6) we have:

$$\dot{\mu}_2=-\left[(C_R+\gamma(1-\rho))R_{A_c}+g\right]\frac{f_x}{f_{A_c}}e^{-\delta t} \text{ ..... (2.4.8)}$$

$$\text{Compared to } \dot{\lambda}_2=-\left[C_R+\gamma\right]R_{A_c}\frac{f_x}{f_{A_c}}e^{-\delta t}$$

Since $\rho<1$, $\dot{\mu}_2>\dot{\lambda}_2$. Thus the shadow benefit path of exploration of new reserve through the land acquisition under social planning will lie above the shadow benefit path of exploration by Nash solution. And there might be no differences between those two shadow cost paths if $\rho=1$. After rearrangement (2.4.7) can be expressed as:

$$\widetilde{H}_{A_c}=e^{-\delta t}\left[\left[-\left[C_R+\gamma(1-\rho)\right]R_{A_c}-g\right]+\left[(p-C_Y+\psi.p(1-\rho))\right]f_{A_c}\right]+\mu_2.f_{A_c}=0 \text{ ...... (2.4.9)}$$

Differentiating (2.4.9) with respect to time and plugging the values of $\dot{\mu}_2$ and μ_2 we get the land acquisition path under social planning:

$$\dot{A}_c^{\,SO}=\frac{f_{A_c}(\delta-f_x)\left[\left[C_R-\gamma(1-\rho)\right]R_{A_c}+g\right]}{(1-\rho)\left[\gamma R_{A_cA_c}+\psi.p.f_{A_c}((1+\rho)-1)\right]\left[\left[\left[C_R+\gamma(1-\rho)\right]R_{A_c}-g\right](p-C_Y)\right]} \text{ ..... (2.4.10)}$$

From the results above, we can make a comparison of the shadow benefit of mining under social planning and that under Nash solution. The results are summarized in Table 1.

Shadow benefit of	**Under social planning**	**Under Nash solution**	**Condition : Social benefit≥ Nash benefit**
Depletion of mine reserve	$[p - C_Y - \psi . p.(1-\rho)]e^{-\delta t}$	$(p - C_Y - \Psi)e^{-\delta t}$	$p \leq \frac{1}{1-\rho}$
Exploration of new reserve by land acquisition	$-[(C_R + \gamma(1-\rho))R_{A_c} + g]\frac{f_x}{f_{A_c}}e^{-\delta t}$	$-[C_R + \gamma]R_{A_c}\frac{f_x}{f_{A_c}}e^{-\delta t}$	$\rho < 1$

Table1: Comparison of shadow benefit of mining under social planning and that under Nash solution

Whether the social benefit (shadow) from depletion of mine reserve and exploration of new reserve by land acquisition will be greater under the socially planned mine extraction path than that under Nash determined path, depends the value of ρ in relation to the market price p. It is already explained that ρ is the weight / importance (in terms of percentage) chosen to be given by the social planner on mining induced loss of traditional livelihood. It is the proportion of rent and royalty payment that social planner will redistributed from himself to the community. $\rho < 1$ is the condition for lesser social cost (vis-à-vis greater social benefit) from exploration of new reserve under social planning than under Nash solution. But ρ must be such that $p \leq \frac{1}{1-\rho}$ i.e. $\rho \geq 1 - \frac{1}{p}$ for getting greater social benefit from depletion of mine reserve. For a miner of a developing country, p is determined exogenously by the market forces. From the above condition it is clear that, ρ has to be adjusted accordingly i.e. to be increased with increase in price to get the positive social benefit from depletion of reserve.

3 How much land does a miner need to extract the desired material?

When a mining firm takes decision regarding how much land it will take lease from the community and explore, it needs a-prior information about the mine reserve in the land concerned. In mining, area of excavation (A_E) and volume of waste materials (W) increase with increase in extraction of the desired material (Y). How much A_E will increase with Y and W again depends on the shape of the excavation. In our hypothetical context, if we assume that there is a surface mining and the shape of the excavation is cubic, then:

$$A_E = \left(\frac{Y}{\rho_E} + \frac{W}{\rho_W} \right)^{\frac{2}{3}} \text{..................(3.1)}$$

where ρ_E and ρ_W are the average densities of desired material and waste material respectively.

If the strip ratio (quantity of waste material produced per unit production of the desired material) is assumed to be constant (k_{WY}), then

$$W = k_{WY} Y \text{................. (3.2)}$$

$$A_E = \left(\frac{Y}{\rho_E} + \frac{k_{WY} Y}{\rho_W} \right)^{\frac{2}{3}} \text{.............. (3.3)}$$

Again the area of land for waste dump (A_W) is functionally determined by the mining production (Y). Assuming that the waste dump is conical with its slope being θ,

$$A_W = \left(\frac{3\sqrt{\pi}\, k_{WY}\, Y}{\tan\,\theta\,\rho_W} \right)^{\frac{2}{3}} = \left(\frac{3\sqrt{\pi}\, k_{WY}}{\tan\,\theta\,\rho_W} \right)^{\frac{2}{3}} Y^{\frac{2}{3}} \text{...... (3.4)}$$

Taking (3.3) and (3.4) together, we get the relation between the area of the land to be needed for excavation and waste dumping and mining output as:

$$A_E + A_W = \left[\left(\frac{1}{\rho_E} + \frac{k_{WY}}{\rho_W}\right)^{\frac{2}{3}} + \left(\frac{3\sqrt{\pi}k_{WY}}{tan\theta\,\rho_W}\right)^{\frac{2}{3}} \right] Y^{\frac{2}{3}} \text{........... (3.5)}$$

(Appendix 6)

From the above expression we find that for a given amount of Y, the area of community land it needs:

$$A_c \geq \left[\left(\frac{1}{\rho_E} + \frac{k_{WY}}{\rho_W}\right)^{\frac{2}{3}} + \left(\frac{3\sqrt{\pi}k_{WY}}{tan\theta\,\rho_W}\right)^{\frac{2}{3}} \right] Y^{\frac{2}{3}}$$

$$\geq k.Y^{\frac{2}{3}} \text{ where } k = \left[\left(\frac{1}{\rho_E} + \frac{k_{WY}}{\rho_W}\right)^{\frac{2}{3}} + \left(\frac{3\sqrt{\pi}k_{WY}}{tan\theta\,\rho_W}\right)^{\frac{2}{3}} \right] \text{.......(3.6);}$$

(3.6) is purely geological information, which although may not be perfectly known but for simplification in our given model is assumed to be known. This information however is required by the ‘social planner’ to decide how much land the community should be allowed to lease from the community to achieve a sustainable path of development.

4 Sustenance of a targeted level of traditional production and sustainability issue in social planning of land acquisition

4.1 Land acquisition with a targeted level of traditional production

In order to foster industrial growth in the economy the society has to make a tradeoff: how much loss in traditional production they will allow for the expansion of mining sector. The social planner can target to assure a constant level of social welfare due to land acquisition: $\overline{U} = U^M(A_c) + U^G(A_c)$. It is constituted by the welfare of miner U^M and that of the traditional community U^G. As defined above in our present context,

$$U^M(A_c) = P.Y(A_c) - C(Y(A_c), R(A_c)) - [\psi .p.Y(A_c) + \gamma R(A_c)] \text{ and}$$

$$U^G = g(L) + \rho .[\psi .p.Y(A_c) + \gamma R(A_c)]$$

At the constant level of welfare,

$$\frac{d\overline{U}}{dA_c} = \frac{dU^M}{dA_c} + \frac{dU^G}{dA_c} = 0 \rightarrow \frac{dU^M}{dA_c} = -\frac{dU^G}{dA_c} \ldots\ldots (4.1)$$

From the above expression

$\frac{dU^M}{dA_c} = p(1-\psi - C_Y).\frac{\partial Y}{\partial A_c} - (C_R + \gamma)\frac{\partial R}{\partial A_c}$ and $\frac{\partial U^G}{\partial A_c} = g_L \frac{\partial L}{\partial A_c} + p.\left(\rho .\psi .\frac{\partial Y}{\partial A_c} + \gamma .\frac{\partial R}{\partial A_c}\right)$. Adding them together we get the revised form of the equation (4.1) as:

$$p(1 - C_Y - (1-\rho).\psi).\frac{\partial Y}{\partial A_c} - (C_R + (1-p)\gamma)\frac{\partial R}{\partial A_c} = -g_L \frac{\partial L}{\partial A_c} \ldots.. (4.1.1)$$

The first component of the LHS of (4.1.1) is the marginal benefit to the society in terms of depletion of mine reserve Y (which is mine output) by land acquisition and the second component is the marginal cost of maintaining reserve acquired by land acquisition. The LHS is therefore the net marginal benefit to the society due to land acquisition. Due to decrease in availability of land L, the loss of traditional production at the marginal level is $-g_L \frac{\partial L}{\partial A_c}$ which is the marginal cost to the society due to land acquisition. If social planner wants to fix this loss at some constant level K to assure sustainable level of production,

$$p(1 - C_Y - (1-\rho).\psi).\frac{\partial Y}{\partial A_c} - (C_R + (1-p)\gamma)\frac{\partial R}{\partial A_c} = \mathrm{K} \ldots.. (4.1.2)$$

This will occur (taking the second order derivative of the above equation with respect to A_c) if the rate of increase of depletion of mine reserve for each unit of rate of conservation of mine reserve due to acquisition of community land

$$.\frac{\partial^2 Y}{\partial A_c^{\ 2}} / \frac{\partial^2 R}{\partial A_c^{\ 2}} = \frac{\left(C_R + (1-p)\gamma\right)}{p\left(1 - C_Y - (1-\rho).\psi\right)} \text{ ….. (4.1.3)}$$

From equation 3.6, we can get $\frac{\partial Y}{\partial A_c} = \frac{3}{2} k.A_c^{\ 1/3}$. Thus $\frac{\partial^2 Y}{\partial A_c^{\ 2}} = \frac{k}{2 A_c^{\ 2/3}}$. Plugging this value into (4.1.2), we get $A_{c|max}$, the maximum area of community land that can be leased out for mining after ensuring a minimum targeted level of traditional production, as:

$$A_{c|max} = \left(\frac{k.p\left(1 - C_Y - (1-\rho).\psi\right).\frac{\partial^2 R}{\partial A_c^{\ 2}}}{2.\left(C_R + (1-p)\gamma\right)} \right)^{3/2} \text{ ……… (4.2)}$$

4.2 Land acquisition and sustainable path of development

The sustainability criterion as reported by the Brundtland Commission1987, after the name of its chairperson is the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." In economic theory analytically, the approach to the sustainability issue has been made by deriving the "stationary equivalent" of the utilitarian optimal welfare path. Some constraints on social objectives i.e. optimization of social utility or welfare are set so that two important components of sustainability (Stavins et.al. 2003), viz., inter generational equity and efficiency - can be assured. As proposed by Solow (1974) it is obtained in terms of non-decreasing utility over time and optimizing the discounted value of utility (economic well-being).

In our present context when acquisition of community land takes place to foster the growth of mining sector at time $t = T_1 > 0$ and the social planner wants to maximize the social utility:

$$U(T_1) = \int_{T_1}^{\infty} \left[U^M(A_c) + U^G(A_c) \right] e^{-\delta(s - T_1)} ds \ ,$$

$$= \int_{T_1}^{\infty} \left[P.Y(A_c) - C\left(Y(A_c), R(A_c)\right) - \left[\psi.p.Y(A_c) + \gamma R(A_c)\right] + g(L) + \rho.\left[\psi.p.Y(A_c) + \gamma R(A_c)\right] \right] e^{-\delta(s - T_1)} ds$$

Brundtland condition of sustainability requires that, inter temporal social utility U would not decrease over time T_1, i.e. $U'(T_1) \geq 0$. This is obtained by differentiating the above expression with respect to time:

$$U'(T_1) = -\left[U_t^{\ M} + U_t^{\ G} \right] + \delta U(T_1) \geq 0$$

This yields, $U(T_1) \geq \frac{\left[p.Y_t - C(Y_t, R_t) + (1-\rho)\left[\psi.p.Y_t + \gamma R_t\right] + g_t\right]}{\delta}$ ……… (4.3)

The condition for an optimal sustainable utility path (when it exists) is obtained by optimizing the utilitarian social welfare function in an infinite time horizon: $\int_{T_1}^{\infty}[p.[1+(1-\rho).\psi]Y_t - C(Y_t, R_t)+(1-\rho)\gamma R_t + g_t]e^{-\delta t}dt$. The condition is that this optimal path is to be constant over time (Farzin 2006). Following Weitzman (1976) the maximized current-value Hamiltonian, is the "stationary equivalent" of the utilitarian optimal welfare path. And in this approach, the necessary and sufficient condition for permanently sustaining the highest consumption path (i.e., the maximin path) is that the maximized current-value Hamiltonian remaining constant over time, i.e. that $\frac{\partial \widetilde{H}}{\partial t} = 0$ (Farzin, 2006). This implies:

$$\frac{d\widetilde{H}}{dt} = \frac{\partial \widetilde{H}}{\partial t} - \delta\left[\mu_1 \dot{R} + \mu_2 \dot{x}\right] = 0 \text{ .... (4.4)}$$

For simplicity if we heuristically assume that direct and exogenous effects of time on the economy i.e. net "pure time effect" is nil, i.e. the economy is time- autonomous, the maximin sustainability cum optimality criterion (which also leads to Rawlsian criterion of intergenerational justice) that follows from equation (4.3) simply leads to:

$$\frac{\partial \widetilde{H}}{\partial t} = \left[p.[1+(1-\rho).\psi - C_Y]Y_{A_c} + g_{A_c}\right]\frac{\partial A_c}{\partial t} - [C_R + (1-\rho).\gamma]\frac{\partial R}{\partial t} = \delta\left[\mu_1 \dot{R} + \mu_2 \dot{x}\right] = 0 \text{ .... (4.4.1)}$$

If the sustainability condition (4.4.1) is satisfied, from left hand side of this equation we get:

$$\frac{\partial R}{\partial A_c} = \frac{p.[1+(1-\rho).\psi - C_Y]Y_{A_c} + g_{A_c}}{C_R + (1-\rho).\gamma} \text{ ...... (4.4.2)}$$

The RHS of the numerator of (4.4.2) is the net return at the marginal level from land acquisition $(g_{A_c} < 0)$ and the denominator is the net cost of maintaining reserve $(C_R < 0)$. From the condition given by (4.4.2) we reach a conclusion that in order to achieve the sustainable path of development change in mine reserve (∂R) (depletion or expansion) per unit change in the area of land acquired over time must be in proportion of net marginal return from land acquisition to net marginal cost of maintaining reserve. Utilizing (4.4) we can also find out the rent on mine reserve (γ_S) and royalty on mine output (ψ_S) that the traditional community deserve along the path of sustainable development. To simplify the matter, let us again assume $\psi = 0$. From (4.4) we get:

$$\gamma_S = \frac{1}{(1-\rho)}\left[p.[1-C_Y]Y_{A_c} + g_{A_c}\right]\left(\frac{\dot{A}_c}{\dot{R}}\right)_S - C_R \text{ ...... (4.5)}$$

γ_S is the dynamic rent as it depends on $\left(\frac{\dot{A}_c}{\dot{R}}\right)_S$

4.3 Community-miner resolution game under social planning and under the private Nash solution

For miner-community conflict resolution two possible types of economic institution viz., 'private' and 'private' but under socially planned way with their resulting impacts are analytically discussed. There are both advantages and disadvantages of each of these institutions. In case of privately resolved institution i.e. by Nash solution, miner and traditional community gets opportunity to interact directly with each other. There are at least two advantages of that. Since community has greater interest for and better knowledge about local environment, by this resolution local environment may be better protected. Since the interaction is direct the process of reaching the conflict resolution may be less time consuming. But there are so many disadvantages. Firstly since there is no authority to monitor the process of miner-community negotiation, the terms and condition settled by them may not be followed by both parties. So there is every possibility to break the path of conflict resolution. Secondly in the terms and conditions the localized issues may get the highest priorities and those may not be conformable with the national and global objectives. Finally In the whole process of negotiation the relative bargaining power will determine who will get the maximum benefit. In that case, it may happen that traditional community with weaker bargaining power may not get the benefit at all. In the alternative institution on the basis of socially desirable rate of mine extraction and land acquisition determines and collect the rent and royalty from miner. It further decides how much of the collected rent and royalty they will redistribute to the miner. One of the advantages of this method is that it would be backed by the government's rules and regulations it is easily implementable. Secondly, Sharing o benefit from mining between miner community and government may be better entwined with national and global objectives. But among the disadvantages, a complaint is often raised bty the miners and communities that government is much more interested with their own coffer rather than with the benefit of the miners and communities. Secondly due to bureaucratic involvement the process of resolving conflict may be unnecessarily lengthy. Now the most practical question is under what condition the conflict resolution in the recommended path of social panning will be acceptable to both miner and traditional community?

Given mine reserve, prices, land productivity with respect to traditional output and the relative weight (or importance) on the net loss of traditional production - social planner derives the socially desirable paths (taking into account the socially determined rule of sustainability) of land acquisition and mine extraction, rent, royalty and sharing the value of mine output with community. If it is an indicative planning the miner and community are free to accept and reject the solution indicated by social planner. The miner- community conflict is resolved in the socially planned path if both parties accept the socially planned solution. If either of them rejects it no resolution occurs. If both of them reject, then the possibility of conflict resolution may occur by opting for Nash strategy game. Now in this particular context, whether the miner and traditional community will opt for resolution in the socially planned way $(S*)$ rather than that through Nash solution $(N*)$ depends on whether each of them is getting the payoff (i.e. benefit) from $S*$ given it's opponent option greater than or equal to the payoff from opting for $N*$ or not (Table 2). It is therefore the vital task of the

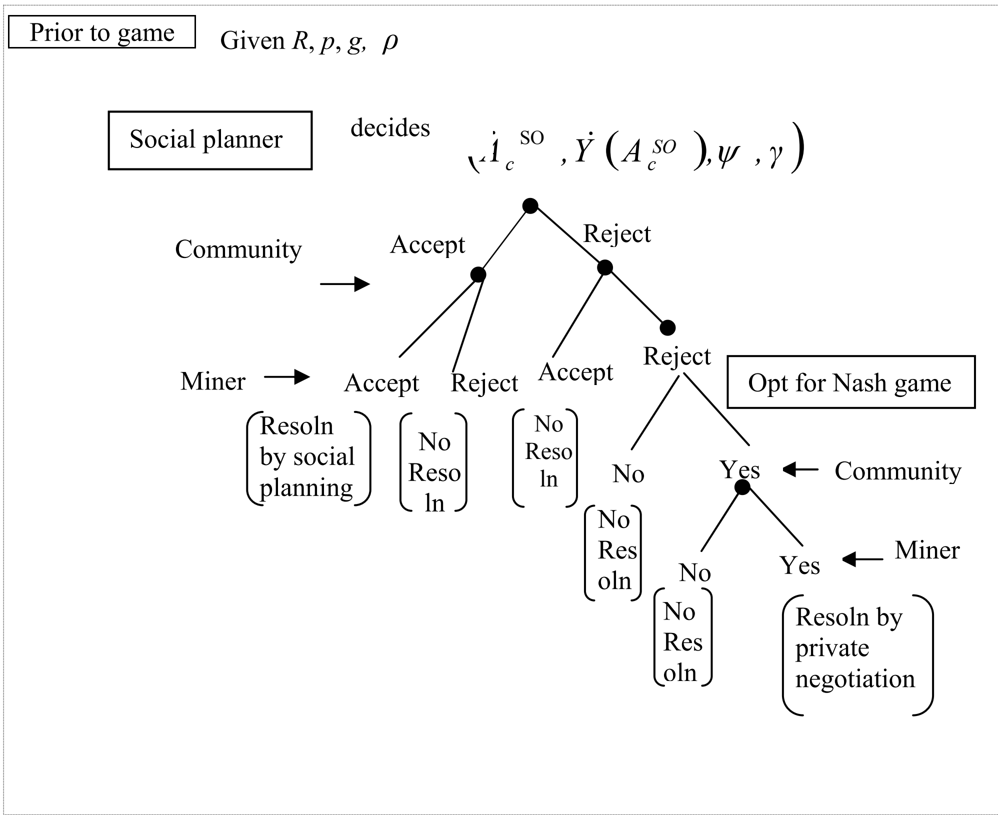


Table 2: Miner –community option for socially planned solution vs. private Nash solution

social planner to design the benefit sharing principle in such a way that neither of the miner and community will like to opt for Nash strategic solution or no solution to resolve the interest conflict

5 Summary and conclusion

In the context of acquisition of community land for mining, two types of negotiation games to settle the compensation for traditional community's loss, area of acquired land, and quantity of mining production have been modeled. The first game results a Nash solution. Given the rate of compensatory return the community claims, miner individualistically chooses the paths of land leased-in and depletion of mine reserve. The traditional community as a single agent also, given the land productivity and expected rate of compensatory return from miner, individualistically chooses the paths of land leased-out. The second game results a solution through the intervention of social planner who assigns some weight or value to the loss of traditional production due to land acquisition. This weight plays a pivotal role in the second type model.

In the Nash settlement game, traditional community's choice of the time path determining the rate of leasing out land to the miner to maximize the return from traditional production plus compensation for land conversion depends upon the history of choices of rent and royalty that traditional community offers to the miner. Similarly miner's choice of time path of mine extraction through land acquisition depends upon history of choices of rent and royalty that miner bids to the traditional community.

The relative dominance or non-dominance of the cost saving effect of having reserve over cost rising effect of rent determines whether land acquisition path chosen by the miner will be rising or falling over time. If cost saving effect of having reserve dominates over cost on rent for reserve, miner's urge to acquire more land will be declining over time.

In second type of game where miner - community settlement occurs through social planning, it is found that the shadow benefit of depletion of mine reserve declines at the rate slower than that under Nash settlement game. Shadow cost path of exploration of new reserve through land acquisition under social planning lies above the shadow cost path of exploration by Nash solution. At a particular point of time whether the shadow benefit of depletion of mine reserve will be higher than that under Nash solution depends on the proportion of benefit from mining the planner chooses to redistribute to the community relative to the price of mine output.

A quantifiable relation in terms of the geological parameters has been derived to show how much land a miner needs to extract the desired material. This relation has been utilized to find out the maximum socially acceptable area of community land that can be leased out for mining that ensures a minimum targeted level of traditional production

In order to achieve the sustainable path of development change in mine reserve (i.e., depletion or expansion) per unit change in the area of land acquired over time must be in proportion of net marginal return from land acquisition to net marginal cost of maintaining reserve.

A dynamic rent on mine reserve and royalty on mine output that the traditional community deserves to move the society along the path of sustainable development has been formulated. If indicative planning exists in the society where miner and the community have freedom to opt for conflict resolution through the social planning and that through private Nash solution, each of them will voluntarily opt for the first if at least one of them get greater payoff (i.e benefit) from this with no lesser payoff (benefit) for other.

The results of the analytical exercises identify four key factors that play the important role in designing the benefit sharing principle to resolve the interest conflict. They are: (i) relative dominance or non-dominance of cost saving effect of mine reserve over cost rising effect of rent on miner, (ii) productivity of traditional output in the community land, (iii) geological parameters determining the relation between the quantity of mine output and the area of land to be extracted and (iv) social planner's choice of the proportion of benefit to be redistributed from mining to the traditional community. Examining these key factors, the policy makers can decide whether the government should promote mutual negotiation between miner and traditional community or a settlement through the social planner to settle the miner-community conflict in the process of development. One of the restrictive but simplifying assumptions however we have made throughout our analysis that price of mine and traditional output remains unchanged over time. It is competitive and stable. Price is such that miner always earns a positive profit throughout the whole period. The effect of change in price particularly that of mine output can play a significant role in determining the time path of mining induced land acquisition which will be taken into account in future research

Appendix

Appendix1

The Hamiltonian for this problem is:

$$H = (p-\Psi)Y e^{-\delta t} - C(Y,R)e^{-\delta t} - \gamma R(A_c)e^{-\delta t} + \lambda_1[f(A_c,x) - Y(A_c)] + \lambda_2[f(A_c,x)]$$

Differentiating H with respect to Y, R, x and A_c we get:

$$pe^{-\delta t} - C_Y e^{-\delta t} - \Psi e^{-\delta t} - \lambda_1 = 0$$

Solving this, we get, $\lambda_1 = (p - C_Y - \Psi)e^{-\delta t}$

$$\dot{\lambda}_1 = (C_R + \gamma)e^{-\delta t}$$

$$\dot{\lambda}_2 = -f_x(\lambda_1 + \lambda_2)$$

Again differentiating H with respect to A_c we obtain:

$$\left[(p - C_Y - \Psi)Y_{A_c} - (C_R + \gamma)R_{A_c}\right]e^{-\delta t} + f_{A_c}(\lambda_1 + \lambda_2) - \lambda_1 Y_{A_c} = 0$$

Plugging the value of λ_1 in the above expression we get:

$$\left[(p - C_Y - \Psi)Y_{A_c} - (C_R + \gamma)R_{A_c}\right]e^{-\delta t} + f_{A_c}(\lambda_1 + \lambda_2) - (p - C_Y - \Psi)e^{-\delta t}\, Y_{A_c} = 0$$

$$\left[-(C_R + \gamma)R_{A_c}\right]e^{-\delta t} + f_{A_c}(\lambda_1 + \lambda_2) = 0$$

$$\left[-(C_R + \gamma)R_{A_c}\right]e^{-\delta t} - \frac{f_{A_c}}{f_x}\dot{\lambda}_2 = 0$$

$$\dot{\lambda}_2 = -\left[C_R + \gamma\right]R_{A_c}\frac{f_x}{f_{A_c}}e^{-\delta t}$$

Appendix 2

Now differentiating equation (2.2.1) with respect to time we get the time path of land acquisition chosen by miner:

$$\left[-\delta\left[(p - C_Y - \Psi)f_{A_c} - (C_R + \gamma)R_{A_c}\right] + \left[(p - C_Y - \Psi)f_{A_cA_c} - (C_R + \gamma)R_{A_cA_c}\right]\dot{A}_c\right]e^{-\delta t} + f_{A_cA_c}\dot{A}_c\,\lambda_2 + f_{A_c}\,\dot{\lambda}_2 = 0$$

$$-\delta\left[(p - C_Y - \Psi)f_{A_c} - (1 + f_x)(C_R + \gamma)R_{A_c}\right] + \left(\frac{f_{A_cA_c}R_{A_c}}{f_{A_c}} - R_{A_cA_c}\right)(C_R + \gamma)\dot{A}_c = 0$$

$$\dot{A}_c^{\,\mathrm{M}} = \frac{\delta\left[(p - C_Y - \Psi)f_{A_c} - (1 + f_x)(C_R + \gamma)R_{A_c}\right]}{\left(\frac{f_{A_cA_c}R_{A_c}}{f_{A_c}} - R_{A_cA_c}\right)(C_R + \gamma)}$$

Appendix 3

The present value Hamiltonian for this problem with the single control variable L is:

$$H = w.g(L)e^{-\theta t} + \Psi.p.Y(A_c)e^{-\theta t} + \gamma R(A_c)e^{-\theta t} - \xi_1 A_c \text{ ….. (2.3.2)}$$

Differentiating H with respect to A_c and L we get:

$$H_{A_c} = \left(\Psi.p.Y_{A_c} + \gamma R_{A_c}\right)e^{-\theta t} - \xi_1 = 0 \quad H_L = -\dot{\xi}_1 = w.g_L.e^{-\theta t}$$

The optimal path is found from the necessary conditions by substituting the equation of motion $\dot{L} = -A_c$ into (2.3.2) and taking the time derivative of the resulting equation.

$$\left(\Psi Y_{A_c}(-\dot{L}) - \gamma R_{A_c}(-\dot{L})\right)e^{-\theta t} - \xi_1 = 0$$

$$\left(\Psi Y_{A_cL}(-\dot{L})\ddot{L} + \gamma R_{A_cL}(-\dot{L})\ddot{L} - \theta\left(-w.g_{A_c} + \Psi Y_{A_c}(-\dot{L}) + \gamma R_{A_c}(-\dot{L})\right)\right) - w.g_L = 0$$

$$\left(\Psi Y_{A_cL} + \gamma R_{A_cL}\right)\ddot{L} = \theta\left(\Psi Y_{A_c} + \gamma R_{A_c}\right) - w.g_L$$

As defined in (2.3.1), $\ddot{L} = -\dot{A}_c$, i.e. rate of change of available land for traditional production is the change of acquired land over time.

$$\left(\Psi Y_{A_cL} + \gamma R_{A_cL}\right)\dot{A}_c = w.g_L - \theta\left(\Psi Y_{A_c} + \gamma R_{A_c}\right)$$

Appendix 4

The Hamiltonian function with the single control variable $Y(A_c)$ and two state variables R and x is:

$$\widetilde{H} = e^{-\delta t}\left[P.Y(A_c) - C(Y(A_c), R(A_c)) - \left[\psi.p.Y(A_c) + \gamma R(A_c)\right](1 - \rho.) + g(\overline{L} - A_c)\right] + \mu_1\left[f(x, A_c) - Y\right] + \mu_2.f(x, A_c)$$

Differentiating it with respect to A_c and Y we get:

$$\widetilde{H}_{A_c} = e^{-\delta t}\left[\left[P - C_Y - \psi.p(1 - \rho)\right]Y_{A_c} - \left[C_R + \gamma(1 - \rho)\right]R_{A_c} - g\right] - \mu_1 Y_{A_c} + (\mu_1 + \mu_2).f_{A_c} = 0$$

$$\widetilde{H}_Y = e^{-\delta t}\left[(p - C_Y - \psi.p(1 - \rho))\right] - \mu_1 = 0$$

$$Or, \mu_1 = \left[p - C_Y - \psi.p.(1 - \rho)\right]e^{-\delta t}$$

Appendix 5

Differentiating $\widetilde{H}$ with respect to A_c, we get:

$$\widetilde{H}_{A_c} = e^{-\delta t}\left[\left[-\left[C_R + \gamma(1 - \rho)\right]R_{A_c} - g\right] + \left[(p - C_Y + \psi.p(1 - \rho))\right]f_{A_c}\right] + \mu_2.f_{A_c} = 0$$

Again differentiating the above expression with respect to time we get:

$$e^{-\delta t}(1-\rho)\left[\gamma R_{A_cA_c} + \psi .pf_{A_cA_c} .\right]\dot{A}_c + \delta\left[\left[C_R - \gamma(1-\rho)\right]R_{A_c} + g\right] + \mu_2 .f_{A_cA_c}\dot{A}_c + f_{A_c}\dot{\mu}_2 = 0$$

Plugging the value of $\dot{\mu}_2 = -\left[\left[C_R + \gamma(1-\rho)\right]R_{A_c} + .g\right]\frac{f_x}{f_{A_c}}e^{-\delta t}$ and μ_2 into it we get the land acquisition path under social planning:

$$\dot{A}_c^{\text{SO}} = \frac{(\delta - f_x)\left[\left[C_R - \gamma(1-\rho)\right]R_{A_c} + g\right]}{(1-\rho)\left[\gamma R_{A_cA_c} + \psi .p\left(1+\rho - \frac{1}{.f_{A_c}}\right) + \left[\frac{1}{f_{A_c}}\left[\left[C_R + \gamma(1-\rho)\right]R_{A_c} - g\right](p - C_Y)\right]\right]}$$

$$= \frac{f_{A_c}(\delta - f_x)\left[\left[C_R - \gamma(1-\rho)\right]R_{A_c} + g\right]}{(1-\rho)\left[\gamma R_{A_cA_c} + \psi .p.f_{A_c}((1+\rho)-1)\right]\left[\left[C_R + \gamma(1-\rho)\right]R_{A_c} - g\right](p - C_Y)\right]}$$

Appendix 6

If the shape of the excavated material to be cubic with sides is a, V_E is the total volume of material excavated from the mine that includes the volumes of desired material and that of the waste material, where volume of a material may be expressed as the ratio of its mass and density,

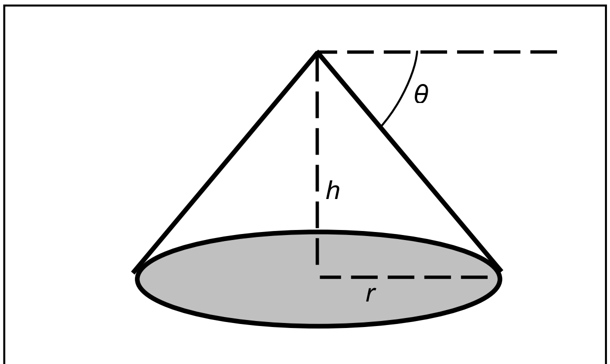
$$A_E = a^2 = \left(a^3\right)^{2/3} = (V_E)^{2/3} \quad .... (1)$$

Therefore the volume of the desired material and the waste materials are $\frac{Y}{\rho_Y}$ and $\frac{W}{\rho_W}$ respectively.

Therefore from (1)

$$A_E = \left(\frac{Y}{\rho_Y} + \frac{W}{\rho_W}\right)^{\frac{2}{3}} = \left(\frac{1}{\rho_Y} + \frac{k_{WY}}{\rho_W}\right)^{\frac{2}{3}} Y^{\frac{2}{3}}$$, where k_{WY} is the strip ratio.

If the area of an waste dump is having conical shape, let the height and radius of conical waste dump be h and r respectively, and its slope is θ. (i.e. suibvertical angle is $90^O - \theta$)



Then its volume (V_W) is :

$$V_W = \frac{1}{3}\pi r^2 h = \frac{1}{3}\pi r^2 .r.\tan\theta = \frac{1}{3}A_W\left(\sqrt{\frac{A_W}{\pi}}\right)\tan\theta = \frac{1}{3\sqrt{\pi}}(A_W)^{\frac{3}{2}}\tan\theta$$

The volume of the waste dump can be expressed as the ratio of its mass and density, i.e. $V_W = \frac{W}{\rho_W}$

Therefore $A_W = \left[\frac{3\sqrt{\pi}}{\tan\ \theta}(V_W)\right]^{\frac{2}{3}} = (\frac{3\sqrt{\pi}W}{\tan\ \theta\rho_W})^{\frac{2}{3}} = (\frac{3\sqrt{\pi}k_{WY}}{\tan\ \theta\rho_W})^{\frac{2}{3}}Y^{\frac{2}{3}}$

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