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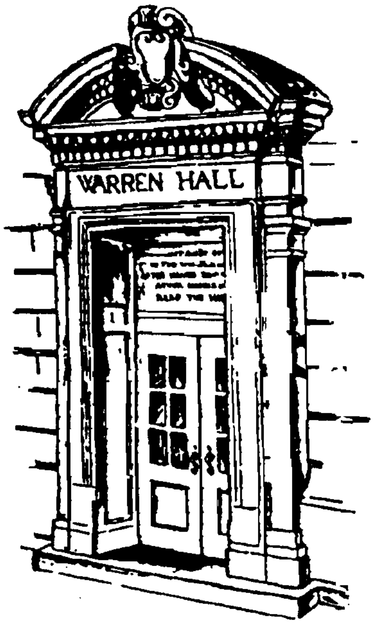

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Conditions for Requiring Separate Green Payments Policies Under Asymmetric Information

by

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Abstract

A general theory of incentive-based policy under risk and asymmetric information is developed. Conditions are derived for when separate policies for producer groups are needed, and when a single policy is sufficient. These conditions have implications for the feasibility and cost of such incentive based programs in specific regions.

Conditions for Requiring Separate Green Payment Policies Under Asymmetric Information

Formulating policies to regulate environmental damage from agricultural production has proved difficult. Recent advances in biophysical transport models have improved our ability to predict the movement of agricultural chemical residues, but we still know little about the extent and geographic distribution of agricultural contamination across major regions, within specific production areas, or across farms. The data requirements for such investigations are substantial.

Policy analysts are beginning to recognize the importance of this spatial diversity. Helfand and House conclude, "The possible cost of using uniform instruments in nonuniform conditions could be quite high; on the other hand, the cost of using nonuniform instruments, in terms of monitoring and enforcement costs, could also be quite high" (p.1031). Since farmers know much more about their land and other resource situations than do even the local policy makers or program administrators (asymmetric information), the challenge is to design creative policies which recognize this fact to accomplish environmental goals at minimum social cost.

Wu and Babcock propose incentive-based "green" payments for farmers to adopt environmentally sound production practices. Separate policies and payments account for different resource situations. The policy maximizes social welfare assuming that net returns and environmental damage are known; the unknown social cost of pollution is set at arbitrary levels.

This paper develops a general theory of incentive-based policy under asymmetric information which recognizes price and yield risk and embodies a standards approach to policy, articulated as a chance constraint limiting the probability of severe environmental damage (Lichtenberg and Zilberman, 1988; Baumol and Oates, 1988; Zhu *et al.*, 1994). Conditions are derived for when separate policies are needed to account for different resource situations and when a single policy is sufficient. These conditions depend on the relative productivity and pollution potential of the resources and are independent of farmers' specific risk preferences. An empirical application providing incentives to reduce fertilizer application on corn production in New York is used to illustrate the theoretical results, estimate government cost from the asymmetric information, and analyze the effect of risk on size of payments.

Theoretical Model

With no loss in generality, consider two groups of farmers (i=1,2) producing corn using nitrogen fertilizer; land differs by group, both by productivity and nitrate contamination potential. To control nitrate contamination, the government regulates fertilizer application, affecting net returns. Farmers are assumed risk averse, with increasing and strictly concave utility functions u_i. Following Collender and Chalfant, we define preferences on empirical distributions of net returns, based on observations of weather and prices over T years. Each observation is net returns if the weather and price conditions in year t were realized (t=1,2,...,T):

(1) $$R_t^i(N_i)=R^i(N_i,W_t,r_t,p_t) = p_t y^i(N_i, W_t) - r_t N_i - V.$$

W_t is a vector of weather variables in year t, p_t and r_t are corn and nitrogen fertilizer prices in year t, y^i is the per acre production function for group i (assumed twice differentiable and strictly concave), N_i is nitrogen fertilizer application for group i, and V is non-nitrogen variable cost.

Toward deriving the tradeoffs between reductions in nitrogen fertilizer and compensation, let S_i be per-acre government payments to group i producers. Then, mean utility for group i is:

(2) $$\overline{u}^i(N_i,S_i) = \frac{1}{T}\sum_{t=1}^{T} u_i(R_t^i(N_i)+S_i)$$

PROPOSITION 1: *The function* $\bar{u}^i(N_i, S_i)$ *possesses the following properties: (a) strictly concave, (b)* $E[\bar{u}^i(N_i, S_i)] = E[u_i(R^i(N_i, W, p, r) + S_i)]$. (Proof is in the appendix.)

By property (*b*) and the expected utility hypothesis, farmers' pre-policy decision problems are:

(3) $\max_{N_i} \bar{u}^i(N_i, 0)$, subject to $N_i \geq 0$ ($S_i = 0$, reflecting no government payments).

By (*a*) unique solutions exist; let N_i^0 be group *i*'s optimal pre-policy nitrogen fertilizer level.

The "green" payment policy requires nitrogen rates for which leaching and runoff by group *i*, $L^i = l^i(N_i, W, C_i)$, satisfy environmental standards, where C_i are soil characteristics. Leaching is random because it depends on W; N_i satisfies the environmental standard, (L^*, α) if:

(4) $Pr[\, l^i(N_i, W, C_i) > L^*] \leq \alpha$,

where α is the significance level. To design this policy, the government must solve the problem:

(5) $\min_{\{S_1, S_2, N_1, N_2\}} A_1 S_1 + A_2 S_2$

subject to:

$$N_i \geq 0,\ S_i \geq 0,\ N_i \leq N_i^*,\quad i = 1,2, \qquad (E_i)$$

$$\bar{u}^1(N_1, S_1) \geq \bar{u}^1(N_1^0, 0), \qquad (P_1)$$

$$\bar{u}^2(N_2, S_2) \geq \bar{u}^2(N_2^0, 0), \qquad (P_2)$$

$$\bar{u}^1(N_1, S_1) \geq \bar{u}^1(N_2, S_2), \qquad (I_1)$$

$$\bar{u}^2(N_2, S_2) \geq \bar{u}^2(N_1, S_1), \qquad (I_2)$$

where A_i is the number of acres of corn in group *i*, and N_i^* is the maximum N_i that meets the environmental standard. The government minimizes the cost of ensuring that environmental damage exceeds L^* with probability α or less (constraints (E_i)). Program payments S_1 and S_2 must be set so that producers in both groups are willing to participate in the program (constraints (P_i)), and have no incentive to select a policy designed for the other group (constraints (I_i)).

For a solution to exist, $\bar{u}^i$ must satisfy the "single-crossing property"; one of the groups must always need more compensation for the same reduction in nitrogen fertilizer. Equivalently:

$$(6) \qquad -\frac{dS}{dN}\bigg|_{\bar{u}^2} \equiv \frac{\bar{u}_N^2(N,S)}{\bar{u}_S^2(N,S)} > \frac{\bar{u}_N^1(N,S)}{\bar{u}_S^1(N,S)} \equiv -\frac{dS}{dN}\bigg|_{\bar{u}^1}, \forall (N,S) \in \Re_+^2.$$

$\bar{u}_N^i$ and $\bar{u}_S^i$ are partial derivatives of $\bar{u}^i$ w.r.t. N and S. See figures 1 and 2 where the level set of $\bar{u}^2$ is steeper than that of $\bar{u}^1$. Expanding the derivatives of $\bar{u}^i$ from equation (2), equation (6) is:

$$(7) \qquad \frac{T^{-1}\sum_{t=1}^{T} u_2'(R_t^2(N)+S)\cdot R_{tN}^2(N)}{T^{-1}\sum_{t=1}^{T} u_2'(R_t^2(N)+S)} > \frac{T^{-1}\sum_{t=1}^{T} u_1'(R_t^1(N)+S)\cdot R_{tN}^1(N)}{T^{-1}\sum_{t=1}^{T} u_1'(R_t^1(N)+S)}.$$

R_{tN}^i is the partial derivative of R_t^i w.r.t. N. Rearranging, condition (7) is:

$$(8) \qquad \sum_{t=1}^{T}\sum_{s=1}^{T} u_1'(R_t^1(N)+S)u_2'(R_s^2(N)+S)[R_{sN}^2(N)-R_{tN}^1(N)] > 0,$$

requiring in all possible pairs of years, 'on average', the marginal value product of group 2 is larger than for group 1, when the difference is weighted by the derivative of u_i at the respective net returns. Proposition 2 relates this condition to yield functions y^i (proof in appendix).

PROPOSITION 2: *If* $\frac{\partial y^2(N,W)}{\partial N} > \frac{\partial y^1(N,W)}{\partial N}$, *all (N,W), the single crossing property is satisfied.*

If group 2's marginal product of nitrogen is higher at every fertilization level and for all weather conditions, the average of marginal returns across years of observed weather will also be higher.

With this result, the optimal "green" payments depend on relationships between land productivity and initial fertilization levels. In reality, the relationships are an empirical question. We assume initial conditions, but highlight the implications when the conditions are otherwise.

CONDITION 1: $\frac{\partial y^2(N,W)}{\partial N} > \frac{\partial y^1(N,W)}{\partial N}$; **CONDITION 2**: $N_2^0 > N_1^0$; **CONDITION 3**: $0 \le N_i^* \le N_i^0$.

By Proposition 2, condition 1 is sufficient for the single crossing property to hold. Condition 2 is for simplicity; it is sufficient but not necessary for what follows. Condition 3 means producers decrease fertilization rates to meet environmental standards, ruling out uninteresting cases. Since we do not know *a priori* which group must fertilize at a lower rate to satisfy environmental standards, we must consider two cases: $N_2^* \le N_1^*$, and $N_1^* < N_2^*$.

PROPOSITION 3: *The constraints* (E_2) *and* (P_2) *will bind in the optimal policy for group 2.*

This result is verified graphically. Figures 1(a) and 1(b) represent the cases $N_2^* \le N_1^*$ and $N_1^* < N_2^*$; (E_2) and (P_2) are satisfied in the region aA^*b in both figures. Suppose, contrary to the claim, an optimal policy for group 2 is chosen where (E_2) and (P_2) are slack, at a points such as A in both figures. To satisfy (I_1), (I_2), and (E_1), group 1's policy must lie in regions *cAd*. Consider now offering group 2 the policy *A'*, which also satisfies (P_2) and (E_2), but with strictly lower payments. Associated with *A'* there is a group 1 policy *B'* which satisfies (I_1), (I_2), and (E_1), with lower payments than in regions *cAd*. Therefore, if (P_2) and (E_2) do not bind, the solution cannot be optimal, since another feasible policy has strictly lower government cost.

PROPOSITION 4: *If* $N_2^* \le N_1^*$, *group 1 will share group 2's policy; if* $N_1^* < N_2^*$, *group 1 will have a separate policy, with the constraints* (I_1) *and* (E_1) *binding, and* (P_1) *nonbinding.*

Figures 2(a) and 2(b) represent the two cases; the feasible sets that satisfy the remaining constraints (I_1), (I_2), and (E_1) are regions eA^*f, and ehB^*f, respectively. To prove the claim, suppose that in the first case, group 1 does *not* share group 2's policy, and that in the second case (I_1) or (E_1) is slack. Points B correspond to such a policy, but B could not

Figure 1. Geometry of Proposition 3

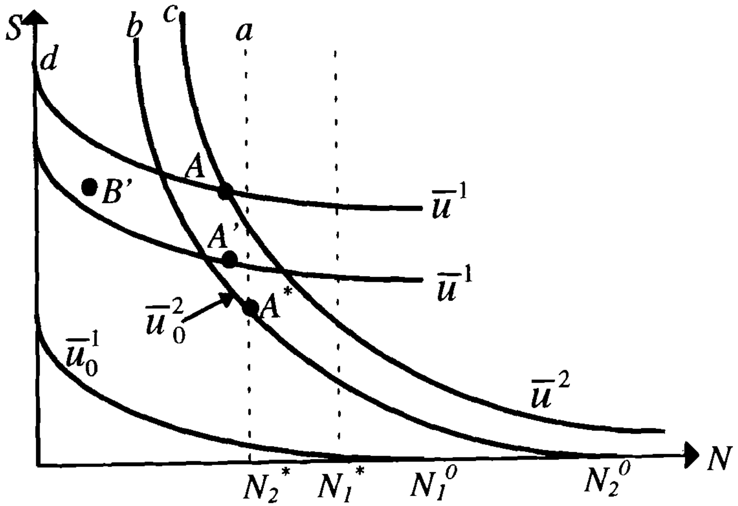

Figure 1(a)

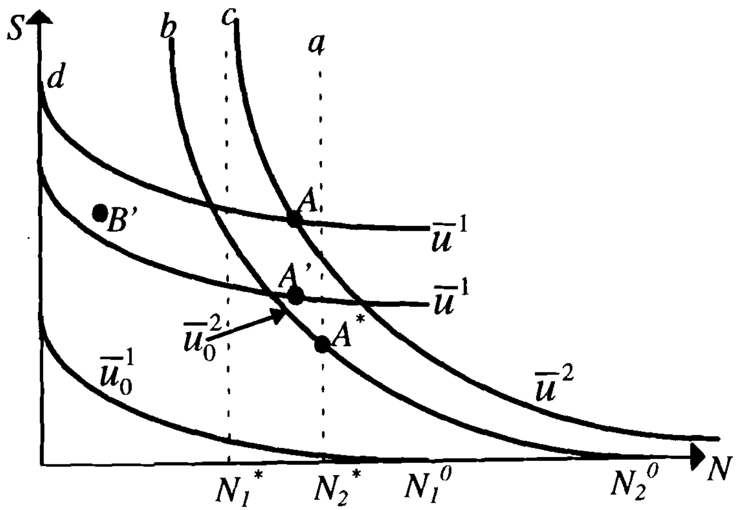

Figure 1(b)

Figure 2. Geometry of Proposition 4

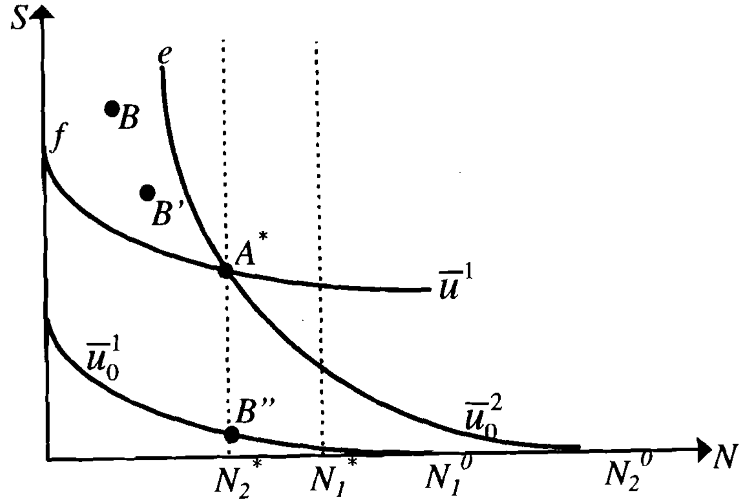

Figure 2(a)

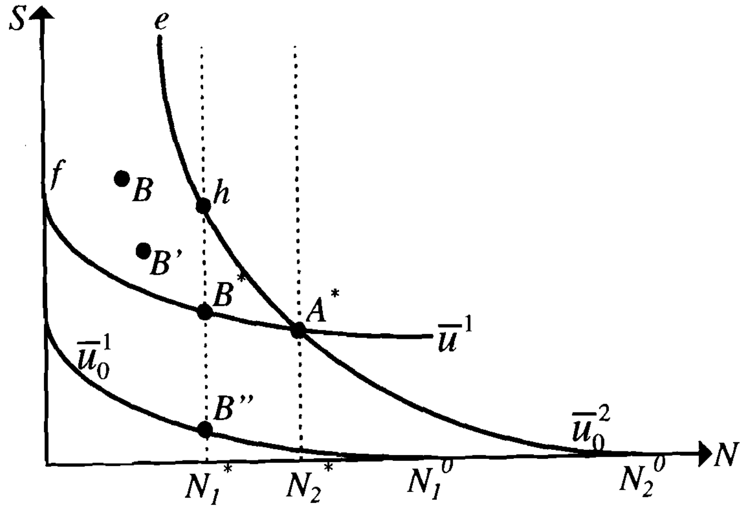

Figure 2(b)

be optimal since the policy B' satisfies the same constraints with lower payments to group 1. To see that (P_1) is slack, suppose to the contrary that it binds at the optimal policy, at points B''. If this were true, group 2's policy would have to lie on or below the curve $\bar{u}_0^1$ to satisfy (I_1) (group 1 cannot prefer group 2's policy), but these policies are not feasible since they do not satisfy (P_2).

To summarize, if N is more productive at the margin for group 2, separate policies are needed only if $N_1^* < N_2^*$. In this case, optimal policies are A^* and B^* in Figure 2(b), group 2 producers will be indifferent between participating and having no program, and the program will make group 1 producers strictly better off.

An Application to Corn Production in New York

This model is applied to production of corn silage in central New York, the two groups of producers having soils (in hydrologic groups A or B) with different yield and nitrogen leaching potential. Distributions of yields, nitrate contamination, and net returns are simulated using corn equivalent and fertilizer prices (1992 dollars) and weather data for 30 years, beginning 1963.

Silage yields (tons/acre) for the groups (Y_i) depend on nitrogen application in lbs./acre (N) and growing season rainfall in inches (W), growing degree days (G) and a dummy variable for soils, and were estimated from 66 observations of field trial data; $R^2 = 0.72$ (t-ratios):

$$\underset{(10.1)}{Y = 16.32} \; \underset{(-3.2)}{- 5.15D_B} \; \underset{(6.3)}{+ .096N} \; \underset{(-4.4)}{- .0003N^2} \; \underset{(1.2)}{+ .0001\, D_B N^2} \; \underset{(5.5)}{+ 1.56W} \; \underset{(-5.3)}{- 1.49\, D_B W} \; \underset{(3.2)}{+ .0066G} \; \underset{(-1.5)}{- .0018WN}$$

The sum of leaching (NL) and runoff (NR) are from (Boisvert *et al.*) (R^2's, .51 and .49):

$$\ln(NR) = -4.576 \; \underset{(-23.1)}{- .453D_A} \; \underset{(-22.1)}{- .359D_B} \; \underset{(7.1)}{+ .628\ln(N)} \; \underset{(15.3)}{+ .652\ln w}$$

$$\ln(NL) = -43.042 \; \underset{(2.8)}{+ 2.90D_A} \; \underset{(-4.4)}{- 6.739\ln(NR)} \; \underset{(1.8)}{+ 2.119(\ln NR)^2} \; \underset{(4.8)}{+ 4.824\ln(N)} \; \underset{(9.3)}{+ 5.768\ln w}$$

For simplicity, except for nitrogen (N) rainfall (w), and the dummies for soils, the effects of five soil characteristics, and other rain variables at mean levels are incorporated into the constants.

For the policy experiment, farmers in both groups are assumed to have negative exponential utility functions, and receive payments to reduce N rates so that combined nitrate leaching and runoff exceeds 40 and 20 lbs./acre with no more than a 10% probability. Initial fertilization rates are determined by solving equation (3); optimal payments are determined by solving the design problem in equation (5). Payments under symmetric information are found by solving (5) without the self selection conditions (I_i), since the government knows each producer's group. Risk neutrality is compared with risk averse cases; the Arrow-Pratt coefficients are 0.01 and 0.03, consistent with empirical evidence (Buccola, 1982 and Love and Buccola, 1991).

The results are in Table 1. For risk neutral producers, pre-policy N rates are about 30 lbs higher for group 2 than for group 1, but implied nitrate contamination safety levels are somewhat

Table 1. Yield, Net Returns, and Nitrogen Fertilizer Levels by Group and Level of Risk Aversion

		Group 1				Group 2			
Risk	Safety	N-	Mean[c]	Green Payments[d]		N-	Mean[c]	Green Payments[d]	
Coefficient[a]	Level	Level	Net Return	Asymm.	Symm.	Level	Net Return	Asymm.	Symm.
0.00	61/57[b]	129[e]	$188	$0	$0	160[e]	$121	$0	$0
0.00	40	99	184	8	4	128	118	4	4
0.00	20	63	165	37	24	80	96	25	25
0.01	66/54[b]	133[e]	188	0	0	156[e]	121	0	0
0.01	40	99	184	8	5	128	118	3	3
0.01	20	63	165	34	26	80	96	22	22
0.03	68/50[b]	135[e]	188	0	0	150[e]	121	0	0
0.03	40	99	184	7	6	128	118	2	2
0.03	20	63	165	29	26	80	96	17	17

[a] Arrow-Pratt Risk Aversion Coefficient. [b] Implied nitrate contamination safety level, group1/group2.
[c] Excludes green payments. [d] Payments under asymmetric and symmetic information. [e] Pre-policy optimal levels.

lower, meaning that the level of environmental quality is somewhat higher. Interestingly, based on the estimated yield equations, nitrogen is a risk reducing input for group 1, and a risk increasing input for group 2; consequently, optimal pre-policy nitrogen levels increase with the level of risk aversion for group 1, but decrease for group 2. The reverse is true for the implied pre-policy nitrate contamination levels.

Following directly from *Condition 1* (at the margin nitrogen is more productive for group 2 than for group 1) and *Proposition 4* ($N_1^* < N_2^*$), separate policies are needed for the two groups. Optimal green payments decrease with the level of risk aversion; to meet environmental standards group 2's *reduction* in N (and expected utility) decreases as farmers become more risk averse. Furthermore, the payments exactly restore the pre-policy expected utility levels for group 2 (P_2 binds), but in the asymmetric information case, group 1 producers, those with the highest pre-policy nitrate contamination levels, receive a windfall and are strictly better off (P_1 is slack). In the risk neutral case and the most strict environmental standard, payments to group 1 producers are almost 55% above what would be needed if information were symmetric. The differential (and thus the value of information on which producers are in each group) drops to about 12 % for the most risk averse case.

Perhaps one of the most striking results is that the cost, in terms of forgone farm income or green payments, needed to achieve a significant reduction in nitrate contamination (down to a 40 lbs. per acre safety level) is relatively low, at most $8 per acre for both groups and risk aversion levels. In the case of group 1 producers, the nitrate contamination is reduced by more that a third. The next incremental improvement in environmental quality is at significantly higher cost to the government. Payments are as high as $37 per acre for group 1 producers.

Policy Implications

In this paper, we develop a general theory of incentive based environmental policy tools which recognize price and yield risk and are based on a standards approach to policy in the form of a chance constraint on environmental damage. In applying this theory to a system of green payments to cut nitrogen fertilizer application to achieve voluntary reductions in nitrate contamination, the conditions under which separate policies are needed depends only on the relative productivity of fertilizer and the pollution potential of the different soils, and not on the farmer's level of risk aversion. The size of the payments needed, of course, does depend on the level of risk aversion.

In our application, the group of producers which can satisfy environmental standards with higher fertilization rates (group 2) has a larger net returns response from changes in nitrogen fertilizer, implying that separate policies must be offered. Under asymmetric information, group 1 benefits from the program while group 2 does not. If information were symmetric between producers and the government, optimal payments to group 1 would decrease so that producers in this group are indifferent between their pre- and post-policy situations.

In our New York case, if farmers are indeed risk averse but are assumed risk neutral, payments would be set higher than necessary; the magnitude of government cost thus depends on risk attitudes. Further, group 1, whose payments are substantially above those under assumptions of symmetric information, control only about one-tenth of the total resource base, but that would not be true in regions such as the Midwest (Thomas and Boisvert, 1995). Therefore, in some other regions, the implications of information asymmetry for total government costs may be even more sustantial, and the size of the payment differential is a good indication of the value of collecting information needed to classify farms for policy design purposes. The value of this information must be weighted against the cost of collecting it.

Appendix: *Proof of Proposition 1:* To show property (*a*), the Hessian matrix of $\bar{u}^i$ must be negative definite: $\bar{u}^i_{NN} < 0$, $\bar{u}^i_{SS} < 0$, and $\begin{vmatrix} \bar{u}^i_{NN} & \bar{u}^i_{NS} \\ \bar{u}^i_{SN} & \bar{u}^i_{SS} \end{vmatrix} = \bar{u}^i_{NN}\bar{u}^i_{SS} - \bar{u}^i_{SN}\bar{u}^i_{NS} > 0, \quad i = 1,2$.

Using the definition of $\bar{u}^i$ from equation (2), the corresponding derivatives w.r.t. N and S are:

$\bar{u}^i_N = \frac{1}{T}\sum_{t=1}^{T} u_i'(R_t^i(N_i) + S_i)R^i_{tN}(N_i)$; $\bar{u}^i_S = \frac{1}{T}\sum_{t=1}^{T} u_i'(R_t^i(N_i) + S_i)$; R^i_{tN} = derivative of R^i_t w.r.t. N.

$$\bar{u}^i_{NN} = \frac{1}{T}\sum_{t=1}^{T} \left\{u_i''(R_t^i(N_i) + S_i)[R^i_{tN}(N_i)]^2 + u_i'(R_t^i(N_i) + S_i)R^i_{tNN}(N_i)\right\},$$

$\bar{u}^i_{SS} = \frac{1}{T}\sum_{t=1}^{T} u_i''(R_t^i(N_i) + S_i)$, and $\bar{u}^i_{NS} = \bar{u}^i_{SN} = \frac{1}{T}\sum_{t=1}^{T} u_i''(R_t^i(N_i) + S_i)R^i_{tN}(N_i)$,

R^i_{tNN} = 2nd derivative of R^i_t w.r.t. N. In the expression for $\bar{u}^i_{NN}$, the first term in the sum is negative because $u_i''<0$; the second term is negative since $u_i'>0$ and $R^i_{tNN} < 0$ ($R^i_{tNN} = py^i_{NN} < 0$). Thus, $\bar{u}^i_{NN}<0$, and $\bar{u}^i_{SS} <0$. To check the remaining condition, we must determine the sign of:

$$\frac{1}{T^2}\sum_{t=1}^{T} \left\{u_{it}''[R^i_{tN}]^2 + u_{it}'R^i_{tNN}\right\}\sum_{t=1}^{T} u_{it}'' - \frac{1}{T^2}\sum_{t=1}^{T} u_{it}''R^i_{tN}\sum_{t=1}^{T} u_{it}''R^i_{tN} ,$$

where u_{it}' is the derivative of u_i evaluated at $(R^i_t + S_i)$. This expression can be rewritten:

$$\sum_{t=1}^{T}\sum_{s=1}^{T} u_{it}''u_{is}''[R^i_{tN}]^2 + \sum_{t=1}^{T}\sum_{s=1}^{T} u_{is}''u_{it}'R^i_{tNN} - \sum_{t=1}^{T}\sum_{t=1}^{T} u_{it}''u_{is}''R^i_{tN}R^i_{sN}$$

$$\text{(A1)} = \sum_{t=1}^{T}\sum_{s=1}^{T} u_{is}''u_{it}'R^i_{tNN} + \sum_{t=1}^{T}\sum_{s=1}^{T} u_{it}''u_{is}''R^i_{tN}[R^i_{tN} - R^i_{sN}].$$

The first sum is positive since $u_i''<0$, $u_i'>0$ and $R^i_{tNN}<0$. The second sum can be separated into terms where $t=s$ and where $t\neq s$. The terms where $t=s$ will equal zero since $[R^i_{tN} - R^i_{sN}] = 0$. For the remaining terms, note that any two years $k\neq l$ will appear in the sum exactly twice. That is,

$$\sum_{t=1}^{T}\sum_{s\neq t} u_{it}''u_{is}''R^i_{tN}[R^i_{tN} - R^i_{sN}] = \cdots + u_{ik}''u_{il}''R^i_{kN}[R^i_{kN} - R^i_{lN}] + \cdots + u_{ik}''u_{il}''R^i_{lN}[R^i_{lN} - R^i_{kN}] + \cdots$$

Combining these two terms,

$$\cdots + u_{ik}''u_{il}''[R^i_{kN}(R^i_{kN} - R^i_{lN}) - R^i_{lN}(R^i_{kN} - R^i_{lN})] + \cdots = \cdots + u_{ik}''u_{il}''(R^i_{kN} - R^i_{lN})^2 + \cdots > 0,$$

since $u_i''<0$. Each pairwise combination is positive; the sum is also. Thus, (A1) > 0, completing the proof of property (*a*). To prove property (*b*), take expectations of $\bar{u}^i$ from equation (2):

$$E[\bar{u}^i(N_i,S_i)] = E\left[\frac{1}{T}\sum_{t=1}^{T} u_i(R^i(N_i,W_t,p_t,r_t)+S_i)\right] = \frac{1}{T}\sum_{t=1}^{T} E[u_i(R^i(N_i,W_t,p_t,r_t)+S_i)].$$

$$= \frac{TE[u_i(R^i(N_i,W,p,r)+S_i)]}{T} = E[u_i(R^i(N_i,W,p,r)+S_i)]$$ since obs. (W_t,p_t,r_t) are i.i.d., Q.E.D.

Proof of Proposition 2: Suppose $\frac{\partial y^2(N,W)}{\partial N} > \frac{\partial y^1(N,W)}{\partial N}$. Multiplying by p_t and subtracting r_t,

$p_t\frac{\partial y^2(N,W_t)}{\partial N} - r_t > p_t\frac{\partial y^1(N,W_t)}{\partial N} - r_t$, (e.g. for any N, $R^2_{tN} - R^1_{tN} > 0$). Summing across years:

$$\sum_{t=1}^{T} R^2_{tN} - \sum_{t=1}^{T} R^1_{tN} > 0, \text{ and } \sum_{s=1}^{T}\sum_{t=1}^{T} R^2_{tN} - \sum_{s=1}^{T}\sum_{t=1}^{T} R^1_{tN} > 0.$$

Interchanging the roles of s and t in the first sum, and reversing the order of summation, we have:

$$\sum_{t=1}^{T}\sum_{s=1}^{T} R^2_{sN} - \sum_{t=1}^{T}\sum_{s=1}^{T} R^1_{tN} > 0 \iff \sum_{t=1}^{T}\sum_{s=1}^{T}[R^2_{sN} - R^1_{tN}] > 0.$$ Since $u_i'>0$, we have the desired result:

$$\sum_{t=1}^{T}\sum_{s=1}^{T} u_1'(R^1_t + S)u_2'(R^2_s + S)[R^2_{sN} - R^1_{tN}] > 0.$$

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