Fondazione Eni Enrico Mattei

Input Use and Capacity Constraint under Uncertainty: The Case of Irrigation

Philippe Bontems and Pascal Favard
NOTA DI LAVORO 72.2002

SEPTEMBER 2002
NRM – Natural Resources Management

Philippe Bontems, *University of Toulouse (INRA, IDEI)*
Pascal Favard, *University of La Rochelle and LEERNa*

Input Use and Capacity Constraint under Uncertainty: The Case of Irrigation

Summary

In this paper we consider a two periods model of cropping using irrigation. The farmer takes two kind of decisions, one related to the level of investment in irrigation capacity and the other one to the irrigation level in each period. In the first period, decisions are taken under uncertainty on the rainfall level which is resolved at the beginning of the second period. Assuming a CARA utility function, we show that taxing the investment may entail an increase in preventive irrigation although the investment decreases. Moreover, in the case of a logistic production function, the total water use is non monotonic with respect to the price of investment. Indeed, taxing capital may induce the farmer to increase the total level of irrigation although the irrigation capacity decreases. Surprisingly, the impact of an increase of water price is generally ambiguous even assuming risk neutrality.

Keywords: Irrigation, investment, uncertainty and risk aversion

JEL: D8, Q15

Address for correspondence:

Pascal Favard
LEERNa
Department of Economics
21 allée de Brienne
31000 Cedex
France
Phone: 33561128517
Fax: 33561128520
E-mail: pfavard@cict.fr

1 Introduction

Uncertainty and risk play a huge role in agricultural production and especially on input choices. It is well-known, for example, that rainfall uncertainty induces the farmer to have a self-insurance behavior. Uncertainty leads him to invest in irrigation capital in order to prevent yield losses due to plant hydric stress. Many techniques are available to provide additional water to the plant such as flat irrigation or sprinkler irrigation. The cost of capital usually prevents the farmer to choose the stock of capital which renders him insensitive to the risk. This level of stock would be the one that provides the exact quantity of water to the plant at the right time such that the weather uncertainty has no impact on the farmer's objective. Of course, this corner solution is barely the optimum for the farmer due to the cost of this investment. This under-investment has a direct effect on the irrigation pattern. Because the level of capital is not sufficient to bring water at the right level or\and on all the cropping surface it could be optimal for the farmer to make preventive irrigation. Indeed soils have more or less the physical property to store water called field capacity. Ex-post this preventive supply may be too important and so the farmer has wasted water.

During the last years the number of water usage conflicts has considerably increased. This leads decision makers to limit water wastage. In order to restore the property rights on water usage the economist usually advocates for market. This kind of market already exist for water consumption by firms and households. These consumers require a given water quality and it is compulsory for them to buy water from a provider. There quantities are usually individually observable. As irrigation is less demanding in term of water quality, farmers usually have their own harnessing. This implies for the planner a tremendous cost of observability of the consumption level. This cost of observability may induce large distortions in the optimal policy of water regulation. One solution for reducing regulation costs is to use indirect instruments: instead of water quantities the planner may choose to regulate irrigated surfaces or the level and/or the nature of the irrigation investment.[1] We call the decision to irrigate before knowing the rainfall level as *preventive irrigation.* Similarly let us call *curative irrigation* the level of water use after the revelation of information. If the level of preventive irrigation appears to be too high ex-post then farmers overuse water resources, as indicated above. The cost of capital leads farmers to under-invest that constraints the level of curative irrigation. To alleviate this constraint farmers may use preventive irrigation. Whatever their attitude towards risk this trade-off applies. When farmers are risk averse income effect obviously complicate this trade-off.

In order to highlight these points we consider a two periods model of cropping. The farmer has to take two kinds of decision, one related to the level of investment in irrigation capacity and the other to the level of irrigation. The uncertainty on the rainfall level is resolved at the beginning of period two. So when the farmer irrigates in period one he makes preventive irrigation and when he makes it in period two it is curative irrigation. Note that the farmer could irrigate one or two times an acre.

Assuming a CARA utility function, we show that taxing the investment may entail an increase in preventive irrigation although the investment decreases. Moreover, using a logistic production function, the total water use is non monotonic with respect to the price of investment. So taxing capital may induce the farmer to increase the total level of irrigation despite that the irrigation capacity de-

---

[1] Another way to increase water use efficiency in agriculture is to promote adoption of new and more efficient irrigation technologies through water price reforms (see Green et al., Caswell and Zilberman). Note that here we are interested in analysing the level of investment in irrigation and not the particular technology adopted.

creases. One instrument for the decision maker in order to reduce the water consumption could be to tax the investment if the level of preventive irrigation is constrained or if there is no preventive irrigation at all. On the contrary when the level of preventive irrigation is positive and not constrained the decision maker should subsidy the irrigation investment. More surprising is the impact of an increase of water price which is generally ambiguous even assuming risk neutrality.

Our model is closely related to the literature on the impact of production risk on input decisions by a competitive firm (e.g. Feinerman et al., Ramaswami, Loehman and Nelson or more recently Roosen and Hennessy).[2] There, the main goal is to analyze the impact of uncertainty and risk aversion on inputs choices and especially to compare farmer's behaviors under risk neutrality and risk aversion. The different inputs can usually be freely adjusted from farmer's point of view. Here, we have basically two inputs, water use and irrigation capacity and the key feature of our model is that water use is constrained by the level of irrigation capacity in each period. This special relationship between inputs has not been analyzed in the literature up to our knowledge.

This paper proceeds as follows. Section two is devoted to the model and to the benchmark case of no uncertainty. The impact of the cost of capital is analyzed in section three while section four is devoted to the impact of water price. The last section concludes. All proofs are collected together in the appendix.

2 The model

Let us consider a homogeneous field of size unity. On this field the farmer crops a plant which needs a certain amount of water. If the level of rainfall is not sufficient

---

[2] Not to mention the more general work of Chambers and Quiggin using the state-contigent approach.

the farmer can invest in capital in order to provide additional water to the plant by irrigation. Our model is a two-periods one where the farmer has to take three decisions. At the beginning of the first period the farmer chooses K the maximal level of water that he could bring in each period. The corresponding investment is $\tau\Gamma(K)$, where τ is a positive parameter and Γ is an increasing and convex function. At the beginning the rain is not fallen and the farmer has to determine the preventive irrigation level x_1, which is constrained by the maximal capacity K. The rainfall level is known with certainty at the beginning of the second period. Thus the farmer chooses the curative irrigation level (x_2), conditionally to the rainfall level ε which is random with the cumulative distribution function G and g the density over $[0, \overline{\varepsilon}]$.

Assume that f is the production function per acre. The unique input is water. The production function is assumed to be concave with respect to the pair (x_1, x_2). Note that the production is a function of the total water available for the plant and not a sum of production function by period. Moreover we assume that the preventive and the curative irrigation are imperfect substitutes with the marginal productivity of curative irrigation is always greater than the preventive one. So whatever (x_1, x_2, ε) we have:

$$\frac{\partial^2 f(x_1, x_2, \varepsilon)}{\partial x_1 \partial x_2} < 0 \text{ and } \left|\frac{\partial f(x_1, x_2, \varepsilon)}{\partial x_2}\right| > \left|\frac{\partial f(x_1, x_2, \varepsilon)}{\partial x_1}\right|,$$

which implies the same inequality on marginal profitabilities.

Contrary to the most part of the literature we assume that the production level decreases when the total amount of water brought to the plant is too large, which is more realistic. In this case, the farmer faces two risks of losses in yield: one caused by over-irrigation and the other one by sub-irrigation.

The ex-post profit is:

$$\pi(x_1, x_2, K; \varepsilon, c, \tau) = pf(x_1, x_2, \varepsilon) - cx_1 - cx_2 - \tau\Gamma(K)$$

where p is the production price and c is the per acre irrigation price.

2.1 The ex post program

Farmer's risk preferences are represented by a VNM utility function u. The ex post program of the producer is:

$$\max_{\{x_2\}} u(\pi)$$

subject to the capital constraint in the second period:

$$K - x_2 \geq 0$$

with $\pi \equiv \pi(x_1, x_2, K; \varepsilon, c, \tau)$.

The Lagrangian of this program is:

$$L(x_2, \mu) = u(\pi) + \mu\,(K - x_2)$$

where μ is the shadow cost of capital corresponding to the use of capital in the second period. The first-order condition, which is also sufficient[3], is:

$$\frac{\partial L(x_2, \mu)}{\partial x_2} = u'(\pi)\frac{\partial \pi}{\partial x_2} - \mu = 0 \tag{1}$$

meaning that the farmer equalizes the marginal value of the curative irrigation level with the shadow cost μ of capital. To determine the optimal value of curative irrigation use, three cases need to be considered.

---

[3] The corresponding second-order condition is

$$\frac{\partial^2 L(x_2, \mu)}{\partial^2 x_2} = u''(\pi)(\frac{\partial \pi}{\partial x_2})^2 + u'(\pi)\frac{\partial^2 \pi}{\partial x_2^2} \leq 0$$

which is true under our assumptions.

Case 1: No curative irrigation ($x_2^* = 0$)

Then $\mu^* = 0$ and $\pi \equiv \pi(x_1, 0, K; \varepsilon, c, \tau)$, then (1) implies

$$\frac{\partial \pi}{\partial x_2} < 0.$$

Case 2: Unconstrained curative irrigation ($x_2^* \in (0, K)$)

Then $\mu^* = 0$ and $\pi \equiv \pi(x_1, x_2, K; \varepsilon, c, \tau)$, then (1) implies x_2^* is solution of

$$\frac{\partial \pi}{\partial x_2} = 0$$

and so

$$\frac{dx_2^*}{dx_1} = -\frac{\frac{\partial^2 \pi}{\partial x_2 \partial x_1}}{\frac{\partial^2 \pi}{\partial x_2^2}} < 0.$$

Then, at the optimum, curative and preventive irrigation levels are imperfect substitutes.

Case 3: Constrained curative irrigation ($x_2^* = K$)

Then $\mu^* > 0$ and $\pi \equiv \pi(x_1, K, K; \varepsilon, c, \tau)$, then (1) implies

$$\mu^*(x_1, K, \varepsilon) = u'(\pi)\frac{\partial \pi}{\partial x_2} > 0, \text{ so } \frac{\partial \pi}{\partial x_2} > 0.$$

2.2 The ex ante program

Having determined the optimal use of curative irrigation in the second period, we now solve the ex-ante program of the producer which is:

$$\max_{\{x_1, K\}} \mathsf{E}\left[u(\pi) + \mu^*(x_1, K, \varepsilon)(K - x_2^*)\right]$$

subject to the capital constraint in the first period:

$$K - x_1 \geq 0$$

with $\pi \equiv \pi(x_1, x_2^*, K; \varepsilon, c, \tau)$.

The Lagrangian of this program is:

$$L(x_1, K, \lambda) = \mathsf{E}\left[u(\pi)\right] + \lambda\left(K - x_1\right)$$

because $\mu^*(x_1, K, \varepsilon)(K - x_2^*)$ is in any case equal to zero, so the first-order conditions, which are sufficient[4], are as follows:

$$\tfrac{\partial L(x_1,K,\lambda)}{\partial x_1} = \mathsf{E}\left[u'(\pi)\frac{\partial \pi}{\partial x_1}\right] - \lambda = 0 \qquad (2)$$

and[5]

$$\tfrac{\partial L(x_1,K,\lambda)}{\partial K} = \mathsf{E}\left[u'(\pi)\left(\frac{\partial \pi}{\partial K} + \frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K}\right)\right] + \lambda = 0 \qquad (3)$$

Equation (2) indicates that the farmer equalizes the expected marginal value of preventive irrigation use to the shadow cost denoted by λ, corresponding to the first-period capital constraint. Equation (3) means that the optimal level of capital is determined by equalizing the expected marginal cost of capital with the shadow cost λ. Note that the expected marginal cost of capital is composed of two terms: increasing the capital level leads to an increase of the investment cost $(\frac{\partial \pi}{\partial K})$ but in the same time alleviates the capital constraint in the second period, when it is binding $(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K})$.

2.3 Benchmark case: no uncertainty

To better understand the farmer's behavior under uncertainty, it is worth studying the benchmark case of perfect information. When the rainfall level ε is perfectly known, there is at least one capacity constraint binding. By assumption

---

[4] The second-order conditions are

$$\frac{\partial^2 L(x_1, K, \lambda)}{\partial^2 x_1} < 0$$

$$\frac{\partial^2 L(x_1, K, \lambda)}{\partial x_1^2}\frac{\partial^2 L(x_1, K, \lambda)}{\partial K^2} - \left(\frac{\partial^2 L(x_1, K, \lambda)}{\partial x_1 \partial K}\right)^2 > 0$$

which are true under our assumptions.

[5] We denote the indicator function $\mathsf{I}_{\mathsf{x}_2^* = \mathsf{K}}$ which is equal to 1 when $x_2^* = K$ and to 0 otherwise.

the marginal profitability of x_2 is greater than the marginal profitability of x_1, thus $x_2^* = K$. There are three cases to consider.

Case 1: No preventive irrigation ($x_1^* = 0$)

Then $\lambda^* = 0$ and so K is solution of $\frac{\partial \pi(0,K,K;\varepsilon,c,\tau)}{\partial K} + \frac{\partial \pi(0,K,K;\varepsilon,c,\tau)}{\partial x_2} = 0$. Differentiating the latter equation with respect to τ we obtain $\frac{dK}{d\tau} < 0$ and $\frac{dK}{dc} < 0$.

Case 2: Unconstrained preventive irrigation ($x_1^* \in (0, K)$)

Then $\lambda^* = 0$ and so K is solution of $\frac{\partial \pi(x_1,K,K;\varepsilon,c,\tau)}{\partial K} + \frac{\partial \pi(x_1,K,K;\varepsilon,c,\tau)}{\partial x_2} = 0$ and x_1 is solution of $\frac{\partial \pi(x_1,K,K;\varepsilon,c,\tau)}{\partial x_1} = 0$. Straightforward computation implies $\frac{dK}{d\tau} < 0$, $\frac{dK}{dc} > 0$, $\frac{dx_1}{dc} < 0$ and $\frac{dx_1}{d\tau} > 0$.

Case 3: Constrained preventive irrigation ($x_1^* = K$)

Then $\lambda^* > 0$ and so K is solution of $\frac{\partial \pi(K,K,K;\varepsilon,c,\tau)}{\partial K} + \frac{\partial \pi(K,K,K;\varepsilon,c,\tau)}{\partial x_1} + \frac{\partial \pi(K,K,K;\varepsilon,c,\tau)}{\partial x_2} = 0$, so $\frac{dK}{d\tau} < 0$ and $\frac{dK}{dc} < 0$.

As expected, increasing the cost of capital leads unambiguously to a decrease in the investment level. However, this does not lead necessarily to a decrease in the preventive water use. Indeed, when the preventive irrigation level is unconstrained, it is optimal for the farmer to increase this level in order to compensate the decrease in curative irrigation level.

Finally, an increase in the per acre irrigation price leads the farmer to increase his investment level when the optimal preventive irrigation level is interior. Indeed, when the per acre irrigation price increases, the farmer optimally reacts by substituting curative irrigation to preventive irrigation because the former is more productive than the latter. This leads the farmer to alleviate the second period capital constraint by investing in irrigation capacity. This is no longer true when the preventive irrigation level is not interior.

3 Comparative statics

Having characterized the optimal farmer's behavior, we turn now to some comparative statics with regards to the investment cost parameter τ and to the per acre irrigation price c.

3.1 The impact of capital taxation

One of the different ways to reduce water consumption in an imperfection information setting could be to reduce the farmer's incentives to invest in irrigation capacity. In order to do so, the regulator could modify through taxation the cost of capital. We capture the effect of capital taxation through the increase of parameter τ.

As will be clear below, it is difficult to sign the variation of farmer's decisions with respect to the cost of capital for a general utility function u. Restricting our analysis to the CARA case allows us to obtain some interesting results.

Proposition 1 *When the farmer's utility u is CARA (including risk neutrality) comparative statics with respect to the cost of capital (τ) reveals that:*

(i) *the level of capital (K) is monotonically decreasing and is nil for sufficiently high level of τ,*

(ii) *the path of preventive irrigation (x_1) is composed of four phases (see the figure 1). In the first phase the level of the preventative irrigation is nil and thus independent of τ. In the second phase this level is increasing whereas it is decreasing during the third phase. After this phase there is no irrigation at all.*

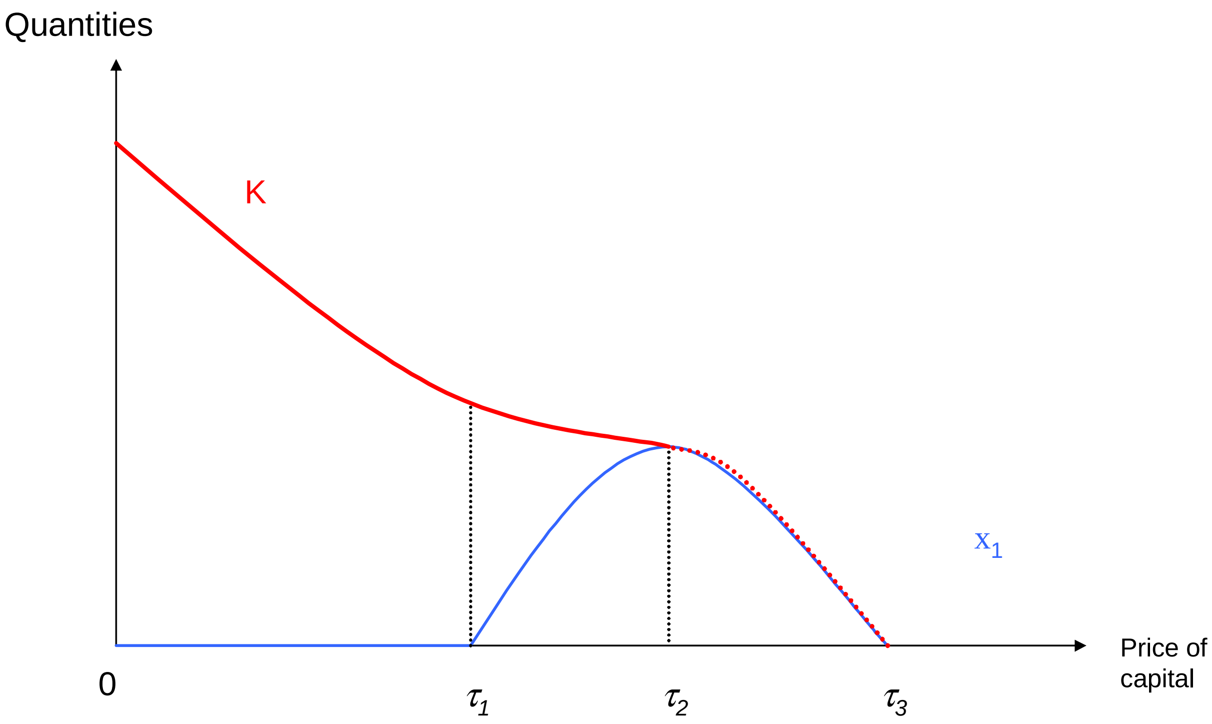

Figure 1: Optimal paths of exante variables

(iii) *the relationship between τ and the expected level of curative irrigation ($\mathsf{E}(x_2)$) is ambiguous, which implies that variation of the expected total amount of irrigation ($x_1 + \mathsf{E}(x_2)$)is also ambiguous.*

As expected, the level of investment in irrigation capacity decreases when the cost of capital increases. Concerning the level of preventive irrigation x_1, we analyze successively the different phases. There are several effects at work. First of all, when the cost of capital increases, the farmer has more and more incentives to use the irrigation capacity, so that the ratio x_1/K increases. This *capital effect* leads to have the highest preventive irrigation level. However, recall that the preventive irrigation level is only an imperfect substitute to the curative irrigation level. This *substitution effect* implies that the marginal productivity of x_1 is lesser than the one of x_2, thus ceteris paribus, it is optimal for the farmer to irrigate in period 2 given that the variable costs of irrigation levels are the same. Whatever the cost of capital τ, the farmer has to trade-off between both effects. When the cost of capital is low, the substitution effect overcomes totally the capital effect. Thus, in the first phase, there is no preventive irrigation ($x_1/K = 0$). For a sufficiently high level of cost, we get the opposite result that is to say, the capital effect overcomes totally the substitution effect ($x_1/K = 1$ in the third phase). For intermediate values of τ, an interior solution for x_1 is obtained. As the ratio x_1/K monotonically increases with τ, the preventive irrigation level x_1 is increasing over the second phase.

In order to get further results, we solve our model in the particular case of a logistic production function f, with the following form:

$$f(x_1, x_2, \varepsilon) = r(\alpha x_1 + x_2 + \varepsilon)(1 - \frac{\alpha x_1 + x_2 + \varepsilon}{a})$$

This specification satisfies our assumptions, in particular the level of production is decreasing if the amount of water supplied to the plant is too large.

Proposition 2 *When the production function f is a logistic we have an additional result, whenever the preventive irrigation level x_1 is interior ($0 < x_1 < K$) the total expected water use ($x_1 + \mathsf{E}(x_2)$) increases with the cost τ of capital. Otherwise this amount is decreasing.*

In the plausible case of a logistic production function, we get a counterintuitive result. Indeed, the total expected water use increases with the capital price for intermediate values of τ. Consequently, as it may be difficult and costly for sure to ascertain if the preventive irrigation level is interior, raising the cost of capital in order to decrease the water use may have unexpected effects.

3.2 The impact of water price

In this section, we provide the comparative statics of the optimal farmer's behavior with respect to the per acre irrigation price c. In fact, raising the water price in order to reduce the water use in irrigation is certainly the policy that the economist would first advocate. Unfortunately, this instrument fails to reach this goal as shown in the following proposition.

Proposition 3 *When the farmer is risk neutral (a fortiori when his utility is CARA) comparative statics with respect to the water price reveals that the impact of a price variation on the farmer's decisions is generally ambiguous.*

Contrary to the cost of capital, the water price affects the marginal profitabilities of preventive and curative irrigation levels which complicates the comparative statics. This effect is added to the ones discussed in the section above.

4 Conclusion

We have tried in this paper to analyze two ways of regulating water use in irrigated agricultural production. For that purpose we consider a two periods model of cropping under rainfall uncertainty. A natural way to decrease the total amount of water use by farmer is to increase the price of water. In our standard neoclassical model we have shown that the impact of an increase of water price is generally ambiguous due to the complex relationships between the decisions may before the uncertainty is resolved and decisions made after. As preventive irrigation is only an imperfect substitute of curative irrigation the farmer gives priority to the latter one. But as capital is costly the farmer try to write off this investment along the two periods, and so he is induced to bring preventive irrigation. Whatever the policy chosen by the planner these trade-offs remains true. However, when looking at the capital taxation the marginal profitability of water use is independent of the cost of capital. In that case relationships are clearer than for a water price policy. Nevertheless, the relationship between the cost of capital and the total water use from an ex ante perspective can be non monotonic. Indeed it may happen that taxing capital leads to an increase of expected water use. Points highlighted in the paper entail that regulating water use could be problematic in practice if regulator wants to use price instrument. Quantity instruments such as quotas could provide a solution.

References

[1] Caswell, M. and D. Zilberman. "The Choices of Irrigation Technologies in California." *American Journal of Agricultural Economics* 67(May 1985):224-234.

[2] Chambers, R.G. and J. Quiggin. *Uncertainty, Production, Choice and Agency.* Cambridge, U.K.: Cambridge University Press, 2000.

[3] Feinerman, E., E. Kwan Choi and S.R. Johnson. "Uncertainty and Split Nitrogen Application in Corn Production." *American Journal of Agricultural Economics* 72(November 1990):975-984.

[4] Green, G., D. Sunding, D. Zilberman and D. Parker. "Explaining Irrigation Technology Choices: A Microparameter Approach", *American Journal of Agricultural Economics* 78(November 1996):1064-1072.

[5] Loehman, E. and C. Nelson. "Optimal Risk Management, Risk Aversion, and Production Function Properties." *Journal of Agricultural and Resource Economics* 17(December 1992):219-231.

[6] Ramaswami, B. "Production Risk and Optimal Input Decisions." *American Journal of Agricultural Economics* 74(November 1992):860-869.

[7] Roosen, J. and D.A. Hennessy. "Tests for the Role of Risk Aversion on Input Use." September 2001, W.P. n°$J - 18743$, Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa

Appendix

A Proof of proposition 1

We conduct this analysis by studying the impact on ex-ante decisions and then on the ex-post decision.

A.1 Optimal preventive irrigation and capital investment

As above, we will consider successively the three cases of note.

Case 1: No preventive irrigation ($x_1^* = 0$)

Then $\lambda = 0$ and $\pi \equiv \pi(0, x_2^*, K; \varepsilon, c, \tau)$

Comparative static: $K^*(\tau)$. Totally differentiating equation (3), we obtain:

$$\frac{dK}{d\tau} = \frac{\frac{\partial \pi}{\partial \tau}\mathsf{E}\left[\rho(\pi)u'(\pi)(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K})\right] - \frac{\partial^2 \pi}{\partial K \partial \tau}\mathsf{E}\left[u'(\pi)\right]}{\mathsf{E}\left[u'(\pi)(\frac{\partial^2 \pi}{\partial x_2^2}\mathsf{I}_{x_2^*=K} + \frac{\partial^2 \pi}{\partial K^2})\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K})^2\right]} \tag{4}$$

the denominator is always negative.

Then if $\rho(\pi)$ is a constant, (4) becomes:

$$\frac{dK}{d\tau} = \frac{\rho\frac{\partial \pi}{\partial \tau}\mathsf{E}\left[u'(\pi)(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K})\right] - \frac{\partial^2 \pi}{\partial K \partial \tau}\mathsf{E}\left[u'(\pi)\right]}{\mathsf{E}\left[u'(\pi)(\frac{\partial^2 \pi}{\partial x_2^2}\mathsf{I}_{x_2^*=K} + \frac{\partial^2 \pi}{\partial K^2})\right] - \rho\mathsf{E}\left[u'(\pi)(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K})^2\right]}$$

using (3) we get

$$\frac{dK}{d\tau} = \frac{-\frac{\partial^2 \pi}{\partial K \partial \tau}\mathsf{E}\left[u'(\pi)\right]}{\mathsf{E}\left[u'(\pi)(\frac{\partial^2 \pi}{\partial x_2^2}\mathsf{I}_{x_2^*=K} + \frac{\partial^2 \pi}{\partial K^2})\right] - \rho\mathsf{E}\left[u'(\pi)(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K})^2\right]} < 0.$$

Case 2: Unconstrained preventive irrigation ($x_1^* \in (0, K)$)

Then $\lambda = 0$ and $\pi \equiv \pi(x_1, x_2^*, K; \varepsilon, c, \tau)$

Comparative static: $x_1^*(\tau)$, $K^*(\tau)$. Totally differentiating the system (2) (3), we obtain:

$$\begin{aligned}
y_1 \frac{dx_1}{d\tau} + y_2 \frac{dK}{d\tau} &= y_3 \\
y_4 \frac{dx_1}{d\tau} + y_5 \frac{dK}{d\tau} &= y_6
\end{aligned}$$

where

$$y_1 = \mathsf{E}\left[u'(\pi)\left(\frac{\partial^2 \pi}{\partial x_1^2} + \frac{\partial^2 \pi}{\partial x_1 \partial x_2}\frac{dx_2^*}{dx_1}\right)\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)\left(\frac{\partial \pi}{\partial x_1}\right)^2\right]$$

$$y_2 = \mathsf{E}\left[u'(\pi)\frac{\partial^2 \pi}{\partial x_1 \partial x_2}\frac{dx_2^*}{dK}\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)\frac{\partial \pi}{\partial x_1}\left(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K}\right)\right]$$

$$y_3 = \frac{\partial \pi}{\partial \tau}\mathsf{E}\left[\rho(\pi)u'(\pi)\frac{\partial \pi}{\partial x_1}\right]$$

$$y_4 = \mathsf{E}\left[u'(\pi)\frac{\partial^2 \pi}{\partial x_1 \partial x_2}\mathsf{I}_{x_2^*=K}\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)\frac{\partial \pi}{\partial x_1}\left(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K}\right)\right]$$

$$y_5 = \mathsf{E}\left[u'(\pi)\left(\frac{\partial^2 \pi}{\partial x_2^2}\mathsf{I}_{x_2^*=K} + \frac{\partial^2 \pi}{\partial K^2}\right)\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)\left(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K}\right)^2\right]$$

$$y_6 = \frac{\partial \pi}{\partial \tau}\mathsf{E}\left[\rho(\pi)u'(\pi)\left(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K}\right)\right] - \frac{\partial^2 \pi}{\partial K \partial \tau}\mathsf{E}\left[u'(\pi)\right]$$

This system of two equation has unique and real solution in $\frac{dx_1}{d\tau}$ and $\frac{dK}{d\tau}$ if and only if $y_1 < 0$ and $y_1 y_5 - y_2^2 > 0$, which is true under our assumptions. Moreover $y_4 = y_2$ because $\frac{dx_2^*}{dK}$ is equal to zero when $x_2^* < K$ and to one when $x_2^* = K$.

$$\frac{dx_1}{d\tau} = \frac{y_3 y_5 - y_6 y_2}{y_1 y_5 - y_2^2} \tag{5}$$

$$\frac{dK}{d\tau} = \frac{y_1 y_6 - y_2 y_3}{y_1 y_5 - y_2^2} \tag{6}$$

Then if $\rho(\pi)$ is a constant, (5) and (6) become:

$$\frac{dx_1}{d\tau} = -\frac{y_6 y_2}{y_1 y_5 - y_2^2} > 0$$

$$\frac{dK}{d\tau} = \frac{y_1 y_6}{y_1 y_5 - y_2^2} < 0$$

because $y_2 < 0$, $y_3 = 0$ and $y_6 > 0$.

Case 3: Constrained preventive irrigation ($x_1^* = K$)

Then $\lambda > 0$ and $\pi \equiv \pi(K, x_2^*, K; \varepsilon, c, \tau)$ so the system (2) (3) implies that K is solution of the following equation:

$$\mathsf{E}\left[u'(\pi)\left(\frac{\partial\pi}{\partial x_1} + \frac{\partial\pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial\pi}{\partial K}\right)\right] = 0. \tag{7}$$

Comparative static: $K^*(\tau)$. Totally differentiating the above equation we obtain:

$$\frac{dK}{d\tau} = \frac{\frac{\partial\pi}{\partial\tau}\mathsf{E}\left[\rho(\pi)u'(\pi)(\frac{\partial\pi}{\partial x_1} + \frac{\partial\pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial\pi}{\partial K})\right] - \frac{\partial^2\pi}{\partial K\partial\tau}\mathsf{E}[u'(\pi)]}{\mathsf{E}\left[u'(\pi)(\frac{\partial^2\pi}{\partial x_1^2} + \frac{\partial^2\pi}{\partial x_1\partial x_2}\frac{dx_2^*}{dK} + \frac{\partial^2\pi}{\partial K^2} + (\frac{\partial^2\pi}{\partial x_1\partial x_2} + \frac{\partial^2\pi}{\partial x_1^2})\mathsf{I}_{x_2^*=K})\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)(\frac{\partial\pi}{\partial x_1} + \frac{\partial\pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial\pi}{\partial K})^2\right]}$$

the denominator is always negative.

Then if $\rho(\pi)$ is a constant, (4) becomes:

$$\frac{dK}{d\tau} = \frac{\rho\frac{\partial\pi}{\partial\tau}\mathsf{E}\left[u'(\pi)(\frac{\partial\pi}{\partial x_1} + \frac{\partial\pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial\pi}{\partial K})\right] - \frac{\partial^2\pi}{\partial K\partial\tau}\mathsf{E}[u'(\pi)]}{\mathsf{E}\left[u'(\pi)(\frac{\partial^2\pi}{\partial x_1^2} + \frac{\partial^2\pi}{\partial x_1\partial x_2}\frac{dx_2^*}{dK} + \frac{\partial^2\pi}{\partial K^2} + (\frac{\partial^2\pi}{\partial x_1\partial x_2} + \frac{\partial^2\pi}{\partial x_1^2})\mathsf{I}_{x_2^*=K})\right] - \rho\mathsf{E}\left[u'(\pi)(\frac{\partial\pi}{\partial x_1} + \frac{\partial\pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial\pi}{\partial K})^2\right]}$$

using (7) we get

$$\frac{dK}{d\tau} = \frac{-\frac{\partial^2\pi}{\partial K\partial\tau}\mathsf{E}[u'(\pi)]}{\mathsf{E}\left[u'(\pi)(\frac{\partial^2\pi}{\partial x_1^2} + \frac{\partial^2\pi}{\partial x_1\partial x_2}\frac{dx_2^*}{dK} + \frac{\partial^2\pi}{\partial K^2} + (\frac{\partial^2\pi}{\partial x_1\partial x_2} + \frac{\partial^2\pi}{\partial x_1^2})\mathsf{I}_{x_2^*=K})\right] - \rho\mathsf{E}\left[u'(\pi)(\frac{\partial\pi}{\partial x_1} + \frac{\partial\pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial\pi}{\partial K})^2\right]} < 0.$$

A.2 Optimal curative irrigation paths

Let us define τ_1 the level of τ such as, with $\pi \equiv \pi(0, x_2^*, K; \varepsilon, c, \tau_1)$:

$$\mathsf{E}\left[u'(\pi)\frac{\partial\pi}{\partial x_1}\right] = 0$$

$$\mathsf{E}\left[u'(\pi)\left(\frac{\partial \pi}{\partial K}+\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K}\right)\right]=0$$

by assumption there is an unique pair (K_1, τ_1) solution of this system. Over $[0, \tau_1)$ there is no preventive irrigation.

Let us define τ_2 the level of τ such as, with $\pi \equiv \pi(K, x_2^*, K; \varepsilon, c, \tau_2)$:

$$\mathsf{E}\left[u'(\pi)\frac{\partial \pi}{\partial x_1}\right]=0$$

$$\mathsf{E}\left[u'(\pi)\left(\frac{\partial \pi}{\partial K}+\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K}\right)\right]=0$$

by assumption there is an unique pair (K_2, τ_2) solution of this system. Over $[\tau_1, \tau_2]$ the preventive irrigation is not constrained.

Let us define τ_3 the level of τ such as, with $\pi \equiv \pi(0, 0, 0; \varepsilon, c, \tau_3)$:

$$\mathsf{E}\left[u'(\pi)\left(\frac{\partial \pi}{\partial x_1}+\frac{\partial \pi}{\partial K}+\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K}\right)\right]=0$$

by assumption there is an unique and finite τ_3 solution of this equation. Over $(\tau_2, \tau_3]$ the preventive irrigation is constrained by the level of capital.

Let us analyze the relationship between the curative irrigation level and the cost of capital over these three intervals.

- x_2^* over $[0, \tau_1)$

First of all note that $\frac{\partial \pi}{\partial x_2}$ is in our model independent of K and τ. When $x_2^* = 0$ then

$$\frac{\partial \pi(0, 0, K; \varepsilon, c, \tau)}{\partial x_2} < 0$$

which implies that

$$\frac{dx_2^*}{d\tau} = 0$$

because

$$\frac{d}{d\tau}\frac{\partial \pi(0, 0, K; \varepsilon, c, \tau)}{\partial x_2} = 0.$$

When $x_2^* = [0, K)$ then x_2^* is given by:

$$\frac{\partial \pi(0, x_2^*, K; \varepsilon, c, \tau)}{\partial x_2} = 0$$

so

$$\frac{dx_2^*}{d\tau} = 0.$$

Finally when $x_2^* = K$ then

$$\frac{\partial \pi(0, K, K; \varepsilon, c, \tau)}{\partial x_2} > 0$$

which implies that

$$\frac{dx_2^*}{d\tau} = \frac{dK}{d\tau}$$

because

$$\frac{d}{d\tau} \frac{\partial \pi(0, 0, K; \varepsilon, c, \tau)}{\partial x_2} > 0.$$

- x_2^* over $[\tau_1, \tau_2]$

First of all note that $\frac{\partial \pi}{\partial x_2}$ is in our model independent of K and τ and $\frac{dx_1}{d\tau}$ is positive over $[\tau_1, \tau_2]$, when $x_2^* = 0$ then

$$\frac{\partial \pi(x_1, 0, K; \varepsilon, c, \tau)}{\partial x_2} < 0$$

which implies that

$$\frac{dx_2^*}{d\tau} = 0$$

because

$$\frac{d}{d\tau} \frac{\partial \pi(x_1, 0, K; \varepsilon, c, \tau)}{\partial x_2} < 0.$$

When $x_2^* = [0, K)$ then x_2^* is given by:

$$\frac{\partial \pi(x_1, x_2^*, K; \varepsilon, c, \tau)}{\partial x_2} = 0$$

so

$$\frac{dx_2^*}{d\tau} = -\frac{\dfrac{\partial^2 \pi}{\partial x_1 \partial x_2}}{\dfrac{\partial^2 \pi}{\partial x_2^2}} \frac{dx_1}{d\tau} < 0.$$

Finally when $x_2^* = K$ then

$$\frac{\partial \pi(x_1, K, K; \varepsilon, c, \tau)}{\partial x_2} > 0$$

which implies that

$$\frac{dx_2^*}{d\tau} \leqslant \frac{dK}{d\tau}$$

because

$$\frac{d}{d\tau} \frac{\partial \pi(x_1, K, K; \varepsilon, c, \tau)}{\partial x_2} \lesseqgtr 0.$$

- x_2^* over $(\tau_2, \tau_3]$

First of all note that $\frac{\partial \pi}{\partial x_2}$ is in our model independent of K and τ and $\frac{dx_1}{d\tau}$ is equal to $\frac{dK}{d\tau}$ over $(\tau_1, \tau_2]$, when $x_2^* = 0$ then

$$\frac{\partial \pi(K, 0, K; \varepsilon, c, \tau)}{\partial x_2} < 0$$

which implies that

$$\frac{dx_2^*}{d\tau} = 0$$

because

$$\frac{d}{d\tau} \frac{\partial \pi(K, 0, K; \varepsilon, c, \tau)}{\partial x_2} < 0.$$

When $x_2^* = [0, K)$ then x_2^* is given by:

$$\frac{\partial \pi(K, x_2^*, K; \varepsilon, c, \tau)}{\partial x_2} = 0$$

so

$$\frac{dx_2^*}{d\tau} = -\frac{\dfrac{\partial^2 \pi}{\partial x_1 \partial x_2}}{\dfrac{\partial^2 \pi}{\partial x_2^2}} \frac{dK}{d\tau} > 0.$$

Finally when $x_2^* = K$ then

$$\frac{\partial \pi(K, K, K; \varepsilon, c, \tau)}{\partial x_2} > 0$$

which implies that

$$\frac{dx_2^*}{d\tau} = \frac{dK}{d\tau}$$

because

$$\frac{d}{d\tau}\frac{\partial \pi(K, K, K; \varepsilon, c, \tau)}{\partial x_2} > 0.$$

B Proof of proposition 2

We show that:

Case 1: No preventive irrigation ($x_1^* = 0$), we have so:

$$\frac{d\mathsf{E}(x_2)}{d\tau} = \int_0^{\varepsilon_1} \frac{dK}{d\tau} dG(\varepsilon) < 0$$

Case 2: Unconstrained preventive irrigation ($x_1^* \in (0, K)$), we have so:

$$\begin{aligned} \frac{d(x_1 + \mathsf{E}(x_2))}{d\tau} &= \int_0^{\varepsilon_1} \frac{dK}{d\tau} dG(\varepsilon) - \alpha \int_{\varepsilon_1}^{\varepsilon_2} \frac{dx_1}{d\tau} dG(\varepsilon) + \int_0^{\overline{\varepsilon}} \frac{dx_1}{d\tau} dG(\varepsilon) \\ &= \int_0^{\varepsilon_1} \left(\frac{dK}{d\tau} + \frac{dx_1}{d\tau}\right) dG(\varepsilon) + (1 - \alpha) \int_{\varepsilon_1}^{\varepsilon_2} \frac{dx_1}{d\tau} dG(\varepsilon) + \int_{\varepsilon_2}^{\overline{\varepsilon}} \frac{dx_1}{d\tau} dG(\varepsilon) \end{aligned}$$

the last two terms are positive. It remains to show that the first one is also positive. Indeed

$$\frac{dK}{d\tau} + \frac{dx_1}{d\tau} = \frac{y_6(y_1 - y_2)}{y_1 y_5 - y_2^2}$$

and $y_1 - y_2$ is positive over $[0, \varepsilon_1)$ because:

$$y_1 - y_2 = \int_0^{\overline{\varepsilon}} u'(\pi) \left(\frac{\partial^2 \pi}{\partial x_1^2} + \frac{\partial^2 \pi}{\partial x_1 \partial x_2}\left(\frac{dx_2^*}{dx_1} - \frac{dx_2^*}{dK}\right) - \rho \frac{\alpha - 1}{\alpha}\left(\frac{\partial \pi}{\partial x_1}\right)^2\right) dG(\varepsilon)$$

$$\begin{aligned}
&\int_0^{\varepsilon_1}(y_1-y_2)dG(\varepsilon)\\
= &\int_0^{\bar{\varepsilon}}\int_0^{\varepsilon_1} u'(\pi)\left(\frac{\partial^2\pi}{\partial x_1^2}+\frac{\partial^2\pi}{\partial x_1\partial x_2}(\frac{dx_2^*}{dx_1}-\frac{dx_2^*}{dK})-\rho\frac{\alpha-1}{\alpha}(\frac{\partial\pi}{\partial x_1})^2\right)dG(\varepsilon)dG(\varepsilon)\\
= &\int_0^{\bar{\varepsilon}}\int_0^{\varepsilon_1} u'(\pi)\left(\frac{\partial^2\pi}{\partial x_1^2}-\frac{\partial^2\pi}{\partial x_1\partial x_2}-\rho\frac{\alpha-1}{\alpha}(\frac{\partial\pi}{\partial x_1})^2\right)dG(\varepsilon)dG(\varepsilon)\\
= &\int_0^{\bar{\varepsilon}}\int_0^{\varepsilon_1} u'(\pi)\left(\frac{\partial^2\pi}{\partial x_1\partial x_2}(\alpha-1)-\rho\frac{\alpha-1}{\alpha}(\frac{\partial\pi}{\partial x_1})^2\right)dG(\varepsilon)dG(\varepsilon)>0
\end{aligned}$$

so

$$\frac{d(x_1+\mathsf{E}(x_2))}{d\tau}>0$$

Case 3: Constrained preventive irrigation ($x_1^*=K$), we have so:

$$\begin{aligned}
\frac{d(K+\mathsf{E}(x_2))}{d\tau} &= \int_0^{\varepsilon_1}\frac{dK}{d\tau}dG(\varepsilon)-\alpha\int_{\varepsilon_1}^{\varepsilon_2}\frac{dK}{d\tau}dG(\varepsilon)+\int_0^{\bar{\varepsilon}}\frac{dK}{d\tau}dG(\varepsilon)\\
&= \frac{dK}{d\tau}((1+\alpha)G(\varepsilon_1)-\alpha G(\varepsilon_2)+1)<0.
\end{aligned}$$

C Proof of proposition 3

Case 1: No preventive irrigation ($x_1^*=0$)

Then $\lambda=0$ and $\pi\equiv\pi(0,x_2^*,K;\varepsilon,c,\tau)$

Comparative static: $K^*(c)$. Totally differentiating equation (3), we obtain:

$$\frac{dK}{dc}=\frac{\mathsf{E}\left[\rho(\pi)u'(\pi)\frac{\partial\pi}{\partial c}(\frac{\partial\pi}{\partial x_2}\mathsf{I}_{x_2^*=K}+\frac{\partial\pi}{\partial K})\right]-\mathsf{E}\left[u'(\pi)\frac{\partial^2\pi}{\partial x_2\partial c}\mathsf{I}_{x_2^*=K}\right]}{\mathsf{E}\left[u'(\pi)(\frac{\partial^2\pi}{\partial x_2^2}\mathsf{I}_{x_2^*=K}+\frac{\partial^2\pi}{\partial K^2})\right]-\mathsf{E}\left[\rho(\pi)u'(\pi)(\frac{\partial\pi}{\partial x_2}\mathsf{I}_{x_2^*=K}+\frac{\partial\pi}{\partial K})^2\right]} \qquad (8)$$

the denominator is always negative.

When $\rho(\pi)$ is a constant, so (8) becomes:

$$\frac{dK}{dc}=\frac{\rho\mathsf{E}\left[u'(\pi)\frac{\partial\pi}{\partial c}(\frac{\partial\pi}{\partial x_2}\mathsf{I}_{x_2^*=K}+\frac{\partial\pi}{\partial K})\right]-\mathsf{E}\left[u'(\pi)\frac{\partial^2\pi}{\partial x_2\partial c}\mathsf{I}_{x_2^*=K}\right]}{\mathsf{E}\left[u'(\pi)(\frac{\partial^2\pi}{\partial x_2^2}\mathsf{I}_{x_2^*=K}+\frac{\partial^2\pi}{\partial K^2})\right]-\rho\mathsf{E}\left[u'(\pi)(\frac{\partial\pi}{\partial x_2}\mathsf{I}_{x_2^*=K}+\frac{\partial\pi}{\partial K})^2\right]}\lesseqgtr 0$$

and so if the farmer is risk neutral ($\rho=0$) $\frac{dK}{dc}<0$.

Case 2: Unconstrained preventive irrigation ($x_1^* \in (0, K)$)

Then $\lambda = 0$ and $\pi \equiv \pi(x_1, x_2^*, K; \varepsilon, c, \tau)$

Comparative static: $x_1^*(c)$, $K^*(c)$. Totally differentiating the system (2) (3), we obtain:

$$\begin{aligned} z_1 \frac{dx_1}{dc} + z_2 \frac{dK}{dc} &= z_3 \\ z_4 \frac{dx_1}{dc} + z_5 \frac{dK}{dc} &= z_6 \end{aligned}$$

where

$$z_1 = \mathsf{E}\left[u'(\pi)(\frac{\partial^2 \pi}{\partial x_1^2} + \frac{\partial^2 \pi}{\partial x_1 \partial x_2}\frac{dx_2^*}{dx_1})\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)(\frac{\partial \pi}{\partial x_1})^2\right]$$

$$z_2 = \mathsf{E}\left[u'(\pi)\frac{\partial^2 \pi}{\partial x_1 \partial x_2}\frac{dx_2^*}{dK}\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)\frac{\partial \pi}{\partial x_1}(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K})\right]$$

$$z_3 = \mathsf{E}\left[\rho(\pi)u'(\pi)\frac{\partial \pi}{\partial c}\frac{\partial \pi}{\partial x_1}\right] - \mathsf{E}\left[u'(\pi)\frac{\partial^2 \pi}{\partial x_1 \partial c}\right]$$

$$z_4 = \mathsf{E}\left[u'(\pi)\frac{\partial^2 \pi}{\partial x_1 \partial x_2}\mathsf{I}_{x_2^*=K}\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)\frac{\partial \pi}{\partial x_1}(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K})\right]$$

$$z_5 = \mathsf{E}\left[u'(\pi)(\frac{\partial^2 \pi}{\partial x_2^2}\mathsf{I}_{x_2^*=K} + \frac{\partial^2 \pi}{\partial K^2})\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K})^2\right]$$

$$z_6 = \mathsf{E}\left[\rho(\pi)u'(\pi)\frac{\partial \pi}{\partial c}(\frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K})\right] - \mathsf{E}\left[u'(\pi)\frac{\partial^2 \pi}{\partial x_2 \partial c}\mathsf{I}_{x_2^*=K}\right]$$

This system of two equation has unique and real solution in $\frac{dx_1}{dc}$ and $\frac{dK}{dc}$ if and only if $z_1 < 0$ and $z_1 z_5 - z_2^2 > 0$, which is true under our assumptions. Moreover $z_5 < 0$ and $z_4 = z_2$ because $\frac{dx_2^*}{dK}$ is equal to zero when $x_2^* < K$ and to one when $x_2^* = K$.

$$\frac{dx_1}{dc} = \frac{z_3 z_5 - z_6 z_2}{z_1 z_5 - z_2^2} \tag{9}$$

$$\frac{dK}{dc} = \frac{z_1 z_6 - z_2 z_3}{z_1 z_5 - z_2^2} \tag{10}$$

When $\rho(\pi)$ is a constant, and so $z_2 < 0$. So (9) and (10) implies:

$$\frac{dx_1}{dc} \lesseqgtr 0$$

$$\frac{dK}{dc} \lesseqgtr 0.$$

Case 3: Constrained preventive irrigation ($x_1^* = K$)

Then $\lambda > 0$ and $\pi \equiv \pi(K, x_2^*, K; \varepsilon, c, \tau)$ so the system (2) (3) implies that K is solution of the following equation:

$$\mathsf{E}\left[u'(\pi)\left(\frac{\partial \pi}{\partial x_1} + \frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K}\right)\right] = 0. \tag{11}$$

Comparative static: $K^*(c)$. Totally differentiating the above equation we obtain:

$$\frac{dK}{dc} =$$

$$\frac{\mathsf{E}\left[\rho(\pi)u'(\pi)\frac{\partial \pi}{\partial c}\left(\frac{\partial \pi}{\partial x_1} + \frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K}\right)\right] - \mathsf{E}\left[u'(\pi)\left(\frac{\partial^2 \pi}{\partial x_1 \partial c} + \frac{\partial^2 \pi}{\partial x_2 \partial c}\mathsf{I}_{x_2^*=K}\right)\right]}{\mathsf{E}\left[u'(\pi)\left(\frac{\partial^2 \pi}{\partial x_1^2} + \frac{\partial^2 \pi}{\partial x_1 \partial x_2}\frac{dx_2^*}{dK} + \frac{\partial^2 \pi}{\partial K^2} + \left(\frac{\partial^2 \pi}{\partial x_1 \partial x_2} + \frac{\partial^2 \pi}{\partial x_1^2}\right)\mathsf{I}_{x_2^*=K}\right)\right] - \mathsf{E}\left[\rho(\pi)u'(\pi)\left(\frac{\partial \pi}{\partial x_1} + \frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K}\right)^2\right]}$$

the denominator is always negative.

When $\rho(\pi)$ is a constant, so (8) becomes:

$$\frac{dK}{dc} =$$

$$\frac{\rho\mathsf{E}\left[u'(\pi)\frac{\partial \pi}{\partial c}\left(\frac{\partial \pi}{\partial x_1} + \frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K}\right)\right] - \mathsf{E}\left[u'(\pi)\left(\frac{\partial^2 \pi}{\partial x_1 \partial c} + \frac{\partial^2 \pi}{\partial x_2 \partial c}\mathsf{I}_{x_2^*=K}\right)\right]}{\mathsf{E}\left[u'(\pi)\left(\frac{\partial^2 \pi}{\partial x_1^2} + \frac{\partial^2 \pi}{\partial x_1 \partial x_2}\frac{dx_2^*}{dK} + \frac{\partial^2 \pi}{\partial K^2} + \left(\frac{\partial^2 \pi}{\partial x_1 \partial x_2} + \frac{\partial^2 \pi}{\partial x_1^2}\right)\mathsf{I}_{x_2^*=K}\right)\right] - \rho\mathsf{E}\left[u'(\pi)\left(\frac{\partial \pi}{\partial x_1} + \frac{\partial \pi}{\partial x_2}\mathsf{I}_{x_2^*=K} + \frac{\partial \pi}{\partial K}\right)^2\right]}$$

so

$$\frac{dK}{dc} \lesseqgtr 0.$$

and so if the farmer is risk neutral ($\rho = 0$) $\frac{dK}{dc} < 0$.

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI
Fondazione Eni Enrico Mattei Working Papers Series
Our working papers are available on the Internet at the following addresses:
***Server WWW*: WWW.FEEM.IT**
***Anonymous FTP*: FTP.FEEM.IT**
http://papers.ssrn.com/abstract_id=XXXXXX

SUST	1.2001	*Inge MAYERES and Stef PROOST*: Should Diesel Cars in Europe be Discouraged?
SUST	2.2001	*Paola DORIA and Davide PETTENELLA*: The Decision Making Process in Defining and Protecting Critical Natural Capital
CLIM	3.2001	*Alberto PENCH*: Green Tax Reforms in a Computable General Equilibrium Model for Italy
CLIM	4.2001	*Maurizio BUSSOLO and Dino PINELLI*: Green Taxes: Environment, Employment and Growth
CLIM	5.2001	*Marco STAMPINI*: Tax Reforms and Environmental Policies for Italy
ETA	6.2001	*Walid OUESLATI*: Environmental Fiscal Policy in an Endogenous Growth Model with Human Capital
CLIM	7.2001	*Umberto CIORBA, Alessandro LANZA and Francesco PAULI:* Kyoto Commitment and Emission Trading: a European Union Perspective
MGMT	8.2001	*Brian SLACK* (xlv): Globalisation in Maritime Transportation: Competition, uncertainty and implications for port development strategy
VOL	9.2001	*Giulia PESARO:* Environmental Voluntary Agreements: A New Model of Co-operation Between Public and Economic Actors
VOL	10.2001	*Cathrine HAGEM*: Climate Policy, Asymmetric Information and Firm Survival
ETA	11.2001	*Sergio CURRARINI and Marco MARINI*: A Sequential Approach to the Characteristic Function and the Core in Games with Externalities
ETA	12.2001	*Gaetano BLOISE, Sergio CURRARINI and Nicholas KIKIDIS*: Inflation and Welfare in an OLG Economy with a Privately Provided Public Good
KNOW	13.2001	*Paolo SURICO:* Globalisation and Trade: A "New Economic Geography" Perspective
ETA	14.2001	*Valentina BOSETTI and Vincenzina MESSINA:* Quasi Option Value and Irreversible Choices
CLIM	15.2001	*Guy* ENGELEN (xlii): Desertification and Land Degradation in Mediterranean Areas: from Science to Integrated Policy Making
SUST	16.2001	*Julie Catherine SORS:* Measuring Progress Towards Sustainable Development in Venice: A Comparative Assessment of Methods and Approaches
SUST	17.2001	*Julie Catherine SORS:* Public Participation in Local Agenda 21: A Review of Traditional and Innovative Tools
CLIM	18.2001	*Johan ALBRECHT and Niko GOBBIN*: Schumpeter and the Rise of Modern Environmentalism
VOL	19.2001	*Rinaldo BRAU, Carlo CARRARO and Giulio GOLFETTO* (xliii): Participation Incentives and the Design of Voluntary Agreements
ETA	20.2001	*Paola ROTA*: Dynamic Labour Demand with Lumpy and Kinked Adjustment Costs
ETA	21.2001	*Paola ROTA*: Empirical Representation of Firms' Employment Decisions by an (S,s) Rule
ETA	22.2001	*Paola ROTA*: What Do We Gain by Being Discrete? An Introduction to the Econometrics of Discrete Decision Processes
PRIV	23.2001	*Stefano BOSI, Guillaume GIRMANS and Michel GUILLARD:* Optimal Privatisation Design and Financial Markets
KNOW	24.2001	*Giorgio BRUNELLO, Claudio LUPI, Patrizia ORDINE, and Maria Luisa PARISI*: Beyond National Institutions: Labour Taxes and Regional Unemployment in Italy
ETA	25.2001	*Klaus CONRAD:* Locational Competition under Environmental Regulation when Input Prices and Productivity Differ
PRIV	26.2001	*Bernardo BORTOLOTTI, Juliet D'SOUZA, Marcella FANTINI and William L. MEGGINSON:* Sources of Performance Improvement in Privatised Firms: A Clinical Study of the Global Telecommunications Industry
CLIM	27.2001	*Frédéric BROCHIER and Emiliano RAMIERI:* Climate Change Impacts on the Mediterranean Coastal Zones
ETA	28.2001	*Nunzio CAPPUCCIO and Michele MORETTO:* Comments on the Investment-Uncertainty Relationship in a Real Option Model
KNOW	29.2001	*Giorgio BRUNELLO*: Absolute Risk Aversion and the Returns to Education
CLIM	30.2001	*ZhongXiang ZHANG:* Meeting the Kyoto Targets: The Importance of Developing Country Participation
ETA	31.2001	*Jonathan D. KAPLAN, Richard E. HOWITT and Y. Hossein FARZIN*: An Information-Theoretical Analysis of Budget-Constrained Nonpoint Source Pollution Control
MGMT	32.2001	*Roberta SALOMONE and Giulia GALLUCCIO:* Environmental Issues and Financial Reporting Trends
Coalition Theory Network	33.2001	*Shlomo WEBER and Hans WIESMETH:* From Autarky to Free Trade: The Impact on Environment
ETA	34.2001	*Margarita GENIUS and Elisabetta STRAZZERA*: Model Selection and Tests for Non Nested Contingent Valuation Models: An Assessment of Methods

NRM	35.2001	*Carlo GIUPPONI*: The Substitution of Hazardous Molecules in Production Processes: The Atrazine Case Study in Italian Agriculture
KNOW	36.2001	*Raffaele PACI and Francesco PIGLIARU*: Technological Diffusion, Spatial Spillovers and Regional Convergence in Europe
PRIV	37.2001	*Bernardo BORTOLOTTI:* Privatisation, Large Shareholders, and Sequential Auctions of Shares
CLIM	38.2001	*Barbara BUCHNER*: What Really Happened in The Hague? Report on the COP6, Part I, 13-25 November 2000, The Hague, The Netherlands
PRIV	39.2001	*Giacomo CALZOLARI and Carlo SCARPA*: Regulation at Home, Competition Abroad: A Theoretical Framework
KNOW	40.2001	*Giorgio BRUNELLO*: On the Complementarity between Education and Training in Europe
Coalition Theory Network	41.2001	*Alain DESDOIGTS and Fabien MOIZEAU* (xlvi): Multiple Politico-Economic Regimes, Inequality and Growth
Coalition Theory Network	42.2001	*Parkash CHANDER and Henry TULKENS* (xlvi): Limits to Climate Change
Coalition Theory Network	43.2001	*Michael FINUS and Bianca RUNDSHAGEN* (xlvi): Endogenous Coalition Formation in Global Pollution Control
Coalition Theory Network	44.2001	*Wietze LISE, Richard S.J. TOL and Bob van der ZWAAN* (xlvi): Negotiating Climate Change as a Social Situation
NRM	45.2001	*Mohamad R. KHAWLIE* (xlvii): The Impacts of Climate Change on Water Resources of Lebanon- Eastern Mediterranean
NRM	46.2001	*Mutasem EL-FADEL and E. BOU-ZEID* (xlvii): Climate Change and Water Resources in the Middle East: Vulnerability, Socio-Economic Impacts and Adaptation
NRM	47.2001	*Eva IGLESIAS, Alberto GARRIDO and Almudena GOMEZ* (xlvii): An Economic Drought Management Index to Evaluate Water Institutions' Performance Under Uncertainty and Climate Change
CLIM	48.2001	*Wietze LISE and Richard S.J. TOL* (xlvii): Impact of Climate on Tourist Demand
CLIM	49.2001	*Francesco BOSELLO, Barbara BUCHNER, Carlo CARRARO and Davide RAGGI*: Can Equity Enhance Efficiency? Lessons from the Kyoto Protocol
SUST	50.2001	*Roberto ROSON* (xlviii): Carbon Leakage in a Small Open Economy with Capital Mobility
SUST	51.2001	*Edwin WOERDMAN* (xlviii): Developing a European Carbon Trading Market: Will Permit Allocation Distort Competition and Lead to State Aid?
SUST	52.2001	*Richard N. COOPER* (xlviii): The Kyoto Protocol: A Flawed Concept
SUST	53.2001	*Kari KANGAS* (xlviii): Trade Liberalisation, Changing Forest Management and Roundwood Trade in Europe
SUST	54.2001	*Xueqin ZHU and Ekko VAN IERLAND* (xlviii)*:* Effects of the Enlargement of EU on Trade and the Environment
SUST	55.2001	*M. Ozgur KAYALICA and Sajal LAHIRI* (xlviii): Strategic Environmental Policies in the Presence of Foreign Direct Investment
SUST	56.2001	*Savas ALPAY* (xlviii): Can Environmental Regulations be Compatible with Higher International Competitiveness? Some New Theoretical Insights
SUST	57.2001	*Roldan MURADIAN, Martin O'CONNOR, Joan MARTINEZ-ALER* (xlviii): Embodied Pollution in Trade: Estimating the "Environmental Load Displacement" of Industrialised Countries
SUST	58.2001	*Matthew R. AUER and Rafael REUVENY* (xlviii): Foreign Aid and Direct Investment: Key Players in the Environmental Restoration of Central and Eastern Europe
SUST	59.2001	*Onno J. KUIK and Frans H. OOSTERHUIS* (xlviii): Lessons from the Southern Enlargement of the EU for the Environmental Dimensions of Eastern Enlargement, in particular for Poland
ETA	60.2001	*Carlo CARRARO, Alessandra POME and Domenico SINISCALCO* (xlix): Science vs. Profit in Research: Lessons from the Human Genome Project
CLIM	61.2001	*Efrem CASTELNUOVO, Michele MORETTO and Sergio VERGALLI:* Global Warming, Uncertainty and Endogenous Technical Change: Implications for Kyoto
PRIV	62.2001	*Gian Luigi ALBANO, Fabrizio GERMANO and Stefano LOVO:* On Some Collusive and Signaling Equilibria in Ascending Auctions for Multiple Objects
CLIM	63.2001	*Elbert DIJKGRAAF and Herman R.J. VOLLEBERGH:* A Note on Testing for Environmental Kuznets Curves with Panel Data
CLIM	64.2001	*Paolo BUONANNO, Carlo CARRARO and Marzio GALEOTTI*: Endogenous Induced Technical Change and the Costs of Kyoto
CLIM	65.2001	*Guido CAZZAVILLAN and Ignazio MUSU* (l): Transitional Dynamics and Uniqueness of the Balanced-Growth Path in a Simple Model of Endogenous Growth with an Environmental Asset
CLIM	66.2001	*Giovanni BAIOCCHI and Salvatore DI FALCO* (l): Investigating the Shape of the EKC: A Nonparametric Approach
CLIM	67.2001	*Marzio GALEOTTI, Alessandro LANZA and Francesco PAULI* (l): Desperately Seeking (Environmental) Kuznets: A New Look at the Evidence
CLIM	68.2001	*Alexey VIKHLYAEV* (xlviii): The Use of Trade Measures for Environmental Purposes – Globally and in the EU Context
NRM	69.2001	*Gary D. LIBECAP and Zeynep K. HANSEN* (li): U.S. Land Policy, Property Rights, and the Dust Bowl of the 1930s

NRM	70.2001	*Lee J. ALSTON, Gary D. LIBECAP and Bernardo MUELLER* (li): Land Reform Policies, The Sources of Violent Conflict and Implications for Deforestation in the Brazilian Amazon
CLIM	71.2001	*Claudia KEMFERT*: Economy-Energy-Climate Interaction – The Model WIAGEM -
SUST	72.2001	*Paulo A.L.D. NUNES and Yohanes E. RIYANTO*: Policy Instruments for Creating Markets for Bodiversity: Certification and Ecolabeling
SUST	73.2001	*Paulo A.L.D. NUNES and Erik SCHOKKAERT* (lii): Warm Glow and Embedding in Contingent Valuation
SUST	74.2001	*Paulo A.L.D. NUNES, Jeroen C.J.M. van den BERGH and Peter NIJKAMP* (lii): Ecological-Economic Analysis and Valuation of Biodiversity
VOL	75.2001	*Johan EYCKMANS and Henry TULKENS* (li): Simulating Coalitionally Stable Burden Sharing Agreements for the Climate Change Problem
PRIV	76.2001	*Axel GAUTIER and Florian HEIDER*: What Do Internal Capital Markets Do? Redistribution vs. Incentives
PRIV	77.2001	*Bernardo BORTOLOTTI, Marcella FANTINI and Domenico SINISCALCO*: Privatisation around the World: New Evidence from Panel Data
ETA	78.2001	*Toke S. AIDT and Jayasri DUTTA* (li): Transitional Politics. Emerging Incentive-based Instruments in Environmental Regulation
ETA	79.2001	*Alberto PETRUCCI*: Consumption Taxation and Endogenous Growth in a Model with New Generations
ETA	80.2001	*Pierre LASSERRE and Antoine SOUBEYRAN* (li): A Ricardian Model of the Tragedy of the Commons
ETA	81.2001	*Pierre COURTOIS, Jean Christophe PÉREAU and Tarik TAZDAÏT*: An Evolutionary Approach to the Climate Change Negotiation Game
NRM	82.2001	*Christophe BONTEMPS, Stéphane COUTURE and Pascal FAVARD:* Is the Irrigation Water Demand Really Convex?
NRM	83.2001	*Unai PASCUAL and Edward BARBIER*: A Model of Optimal Labour and Soil Use with Shifting Cultivation
CLIM	84.2001	*Jesper JENSEN and Martin Hvidt THELLE*: What are the Gains from a Multi-Gas Strategy?
CLIM	85.2001	*Maurizio MICHELINI* (liii): IPCC "Summary for Policymakers" in TAR. Do its results give a scientific support always adequate to the urgencies of Kyoto negotiations?
CLIM	86.2001	*Claudia KEMFERT* (liii): Economic Impact Assessment of Alternative Climate Policy Strategies
CLIM	87.2001	*Cesare DOSI and Michele MORETTO:* Global Warming and Financial Umbrellas
ETA	88.2001	*Elena BONTEMPI, Alessandra DEL BOCA, Alessandra FRANZOSI, Marzio GALEOTTI and Paola ROTA:* Capital Heterogeneity: Does it Matter? Fundamental Q and Investment on a Panel of Italian Firms
ETA	89.2001	*Efrem CASTELNUOVO and Paolo SURICO*: Model Uncertainty, Optimal Monetary Policy and the Preferences of the Fed
CLIM	90.2001	*Umberto CIORBA, Alessandro LANZA and Francesco PAULI*: Kyoto Protocol and Emission Trading: Does the US Make a Difference?
CLIM	91.2001	*ZhongXiang ZHANG and Lucas ASSUNCAO:* Domestic Climate Policies and the WTO
SUST	92.2001	*Anna ALBERINI, Alan KRUPNICK, Maureen CROPPER, Nathalie SIMON and Joseph COOK* (lii): The Willingness to Pay for Mortality Risk Reductions: A Comparison of the United States and Canada
SUST	93.2001	*Riccardo SCARPA, Guy D. GARROD and Kenneth G. WILLIS* (lii): Valuing Local Public Goods with Advanced Stated Preference Models: Traffic Calming Schemes in Northern England
CLIM	94.2001	*Ming CHEN and Larry KARP*: Environmental Indices for the Chinese Grain Sector
CLIM	95.2001	*Larry KARP and Jiangfeng ZHANG*: Controlling a Stock Pollutant with Endogenous Investment and Asymmetric Information
ETA	96.2001	*Michele MORETTO and Gianpaolo ROSSINI*: On the Opportunity Cost of Nontradable Stock Options
SUST	97.2001	*Elisabetta STRAZZERA, Margarita GENIUS, Riccardo SCARPA and George HUTCHINSON*: The Effect of Protest Votes on the Estimates of Willingness to Pay for Use Values of Recreational Sites
NRM	98.2001	*Frédéric BROCHIER, Carlo GIUPPONI and Alberto LONGO*: Integrated Coastal Zone Management in the Venice Area – Perspectives of Development for the Rural Island of Sant'Erasmo
NRM	99.2001	*Frédéric BROCHIER, Carlo GIUPPONI and Julie SORS*: Integrated Coastal Management in the Venice Area – Potentials of the Integrated Participatory Management Approach
NRM	100.2001	*Frédéric BROCHIER and Carlo GIUPPONI*: Integrated Coastal Zone Management in the Venice Area – A Methodological Framework
PRIV	101.2001	*Enrico C. PEROTTI and Luc LAEVEN*: Confidence Building in Emerging Stock Markets
CLIM	102.2001	*Barbara BUCHNER, Carlo CARRARO and Igor CERSOSIMO*: On the Consequences of the U.S. Withdrawal from the Kyoto/Bonn Protocol
SUST	103.2001	*Riccardo SCARPA, Adam DRUCKER, Simon ANDERSON, Nancy FERRAES-EHUAN, Veronica GOMEZ, Carlos R. RISOPATRON and Olga RUBIO-LEONEL*: Valuing Animal Genetic Resources in Peasant Economies: The Case of the Box Keken Creole Pig in Yucatan
SUST	104.2001	*R. SCARPA, P. KRISTJANSON, A. DRUCKER, M. RADENY, E.S.K. RUTO, and J.E.O. REGE:* Valuing Indigenous Cattle Breeds in Kenya: An Empirical Comparison of Stated and Revealed Preference Value Estimates
SUST	105.2001	*Clemens B.A. WOLLNY*: The Need to Conserve Farm Animal Genetic Resources Through Community-Based Management in Africa: Should Policy Makers be Concerned?
SUST	106.2001	*J.T. KARUGIA, O.A. MWAI, R. KAITHO, Adam G. DRUCKER, C.B.A. WOLLNY and J.E.O. REGE:* Economic Analysis of Crossbreeding Programmes in Sub-Saharan Africa: A Conceptual Framework and Kenyan Case Study
SUST	107.2001	*W. AYALEW, J.M. KING, E. BRUNS and B. RISCHKOWSKY*: Economic Evaluation of Smallholder Subsistence Livestock Production: Lessons from an Ethiopian Goat Development Program

SUST	108.2001	*Gianni CICIA, Elisabetta D'ERCOLE and Davide MARINO*: Valuing Farm Animal Genetic Resources by Means of Contingent Valuation and a Bio-Economic Model: The Case of the Pentro Horse
SUST	109.2001	*Clem TISDELL*: Socioeconomic Causes of Loss of Animal Genetic Diversity: Analysis and Assessment
SUST	110.2001	*M.A. JABBAR and M.L. DIEDHOU*: Does Breed Matter to Cattle Farmers and Buyers? Evidence from West Africa
SUST	1.2002	*K. TANO, M.D. FAMINOW, M. KAMUANGA and B. SWALLOW*: Using Conjoint Analysis to Estimate Farmers' Preferences for Cattle Traits in West Africa
ETA	2.2002	*Efrem CASTELNUOVO and Paolo SURICO*: What Does Monetary Policy Reveal about Central Bank's Preferences?
WAT	3.2002	*Duncan KNOWLER and Edward BARBIER*: The Economics of a "Mixed Blessing" Effect: A Case Study of the Black Sea
CLIM	4.2002	*Andreas LÖSCHEL*: Technological Change in Economic Models of Environmental Policy: A Survey
VOL	5.2002	*Carlo CARRARO and Carmen MARCHIORI*: Stable Coalitions
CLIM	6.2002	*Marzio GALEOTTI, Alessandro LANZA and Matteo MANERA*: Rockets and Feathers Revisited: An International Comparison on European Gasoline Markets
ETA	7.2002	*Effrosyni DIAMANTOUDI and Eftichios S. SARTZETAKIS*: Stable International Environmental Agreements: An Analytical Approach
KNOW	8.2002	*Alain DESDOIGTS*: Neoclassical Convergence Versus Technological Catch-up: A Contribution for Reaching a Consensus
NRM	9.2002	*Giuseppe DI VITA:* Renewable Resources and Waste Recycling
KNOW	10.2002	*Giorgio BRUNELLO*: Is Training More Frequent when Wage Compression is Higher? Evidence from 11 European Countries
ETA	11.2002	*Mordecai KURZ, Hehui JIN and Maurizio MOTOLESE*: Endogenous Fluctuations and the Role of Monetary Policy
KNOW	12.2002	*Reyer GERLAGH and Marjan W. HOFKES:* Escaping Lock-in: The Scope for a Transition towards Sustainable Growth?
NRM	13.2002	*Michele MORETTO and Paolo ROSATO*: The Use of Common Property Resources: A Dynamic Model
CLIM	14.2002	*Philippe QUIRION*: Macroeconomic Effects of an Energy Saving Policy in the Public Sector
CLIM	15.2002	*Roberto ROSON*: Dynamic and Distributional Effects of Environmental Revenue Recycling Schemes: Simulations with a General Equilibrium Model of the Italian Economy
CLIM	16.2002	*Francesco RICCI* (l): Environmental Policy Growth when Inputs are Differentiated in Pollution Intensity
ETA	17.2002	*Alberto PETRUCCI*: Devaluation (Levels versus Rates) and Balance of Payments in a Cash-in-Advance Economy
Coalition Theory Network	18.2002	*László Á. KÓCZY* (liv*):* The Core in the Presence of Externalities
Coalition Theory Network	19.2002	*Steven J. BRAMS, Michael A. JONES and D. Marc KILGOUR* (liv): Single-Peakedness and Disconnected Coalitions
Coalition Theory Network	20.2002	*Guillaume HAERINGER* (liv): On the Stability of Cooperation Structures
NRM	21.2002	*Fausto CAVALLARO and Luigi CIRAOLO:* Economic and Environmental Sustainability: A Dynamic Approach in Insular Systems
CLIM	22.2002	*Barbara BUCHNER, Carlo CARRARO, Igor CERSOSIMO and Carmen MARCHIORI*: Back to Kyoto? US Participation and the Linkage between R&D and Climate Cooperation
CLIM	23.2002	*Andreas LÖSCHEL and ZhongXIANG ZHANG:* The Economic and Environmental Implications of the US Repudiation of the Kyoto Protocol and the Subsequent Deals in Bonn and Marrakech
ETA	24.2002	*Marzio GALEOTTI, Louis J. MACCINI and Fabio SCHIANTARELLI*: Inventories, Employment and Hours
CLIM	25.2002	*Hannes EGLI:* Are Cross-Country Studies of the Environmental Kuznets Curve Misleading? New Evidence from Time Series Data for Germany
ETA	26.2002	*Adam B. JAFFE, Richard G. NEWELL and Robert N. STAVINS*: Environmental Policy and Technological Change
SUST	27.2002	*Joseph C. COOPER and Giovanni SIGNORELLO*: Farmer Premiums for the Voluntary Adoption of Conservation Plans
SUST	28.2002	*The ANSEA Network*: Towards An Analytical Strategic Environmental Assessment
KNOW	29.2002	*Paolo SURICO*: Geographic Concentration and Increasing Returns: a Survey of Evidence
ETA	30.2002	*Robert N. STAVINS:* Lessons from the American Experiment with Market-Based Environmental Policies
NRM	31.2002	*Carlo GIUPPONI and Paolo ROSATO:* Multi-Criteria Analysis and Decision-Support for Water Management at the Catchment Scale: An Application to Diffuse Pollution Control in the Venice Lagoon
NRM	32.2002	*Robert N. STAVINS*: National Environmental Policy During the Clinton Years
KNOW	33.2002	*A. SOUBEYRAN and H. STAHN* : Do Investments in Specialized Knowledge Lead to Composite Good Industries?
KNOW	34.2002	*G. BRUNELLO, M.L. PARISI and Daniela SONEDDA:* Labor Taxes, Wage Setting and the Relative Wage Effect
CLIM	35.2002	*C. BOEMARE and P. QUIRION* (lv): Implementing Greenhouse Gas Trading in Europe: Lessons from Economic Theory and International Experiences

CLIM	36.2002	*T.TIETENBERG* (lv): The Tradable Permits Approach to Protecting the Commons: What Have We Learned?
CLIM	37.2002	*K. REHDANZ and R.J.S. TOL* (lv): On National and International Trade in Greenhouse Gas Emission Permits
CLIM	38.2002	*C. FISCHER* (lv): Multinational Taxation and International Emissions Trading
SUST	39.2002	*G. SIGNORELLO and G. PAPPALARDO:* Farm Animal Biodiversity Conservation Activities in Europe under the Framework of Agenda 2000
NRM	40.2002	*S .M. CAVANAGH, W. M. HANEMANN and R. N. STAVINS:* Muffled Price Signals: Household Water Demand under Increasing-Block Prices
NRM	41.2002	*A. J. PLANTINGA, R. N. LUBOWSKI and R. N. STAVINS:* The Effects of Potential Land Development on Agricultural Land Prices
CLIM	42.2002	*C. OHL* (lvi): Inducing Environmental Co-operation by the Design of Emission Permits
CLIM	43.2002	*J. EYCKMANS, D. VAN REGEMORTER and V. VAN STEENBERGHE* (lvi): Is Kyoto Fatally Flawed? An Analysis with MacGEM
CLIM	44.2002	*A. ANTOCI and S. BORGHESI* (lvi): Working Too Much in a Polluted World: A North-South Evolutionary Model
ETA	45.2002	*P. G. FREDRIKSSON, Johan A. LIST and Daniel MILLIMET* (lvi): Chasing the Smokestack: Strategic Policymaking with Multiple Instruments
ETA	46.2002	*Z. YU* (lvi): A Theory of Strategic Vertical DFI and the Missing Pollution-Haven Effect
SUST	47.2002	*Y. H. FARZIN*: Can an Exhaustible Resource Economy Be Sustainable?
SUST	48.2002	*Y. H. FARZIN*: Sustainability and Hamiltonian Value
KNOW	49.2002	*C. PIGA and M. VIVARELLI*: Cooperation in R&D and Sample Selection
Coalition Theory Network	50.2002	*M. SERTEL and A. SLINKO* (liv): Ranking Committees, Words or Multisets
Coalition Theory Network	51.2002	*Sergio CURRARINI* (liv): Stable Organizations with Externalities
ETA	52.2002	*Robert N. STAVINS*: Experience with Market-Based Policy Instruments
ETA	53.2002	*C.C. JAEGER, M. LEIMBACH, C. CARRARO, K. HASSELMANN, J.C. HOURCADE, A. KEELER and R. KLEIN* (liii): Integrated Assessment Modeling: Modules for Cooperation
CLIM	54.2002	*Scott BARRETT* (liii)*:* Towards a Better Climate Treaty
ETA	55.2002	*Richard G. NEWELL and Robert N. STAVINS*: Cost Heterogeneity and the Potential Savings from Market-Based Policies
SUST	56.2002	*Paolo ROSATO and Edi DEFRANCESCO*: Individual Travel Cost Method and Flow Fixed Costs
SUST	57.2002	*Vladimir KOTOV and Elena NIKITINA* (lvii): Reorganisation of Environmental Policy in Russia: The Decade of Success and Failures in Implementation of Perspective Quests
SUST	58.2002	*Vladimir KOTOV* (lvii): Policy in Transition: New Framework for Russia's Climate Policy
SUST	59.2002	*Fanny MISSFELDT and Arturo VILLAVICENCO* (lvii): How Can Economies in Transition Pursue Emissions Trading or Joint Implementation?
VOL	60.2002	*Giovanni DI BARTOLOMEO, Jacob ENGWERDA, Joseph PLASMANS and Bas VAN AARLE:* Staying Together or Breaking Apart: Policy-Makers' Endogenous Coalitions Formation in the European Economic and Monetary Union
ETA	61.2002	*Robert N. STAVINS, Alexander F.WAGNER and Gernot WAGNER*: Interpreting Sustainability in Economic Terms: Dynamic Efficiency Plus Intergenerational Equity
PRIV	62.2002	*Carlo CAPUANO*: Demand Growth, Entry and Collusion Sustainability
PRIV	63.2002	*Federico MUNARI and Raffaele ORIANI*: Privatization and R&D Performance: An Empirical Analysis Based on Tobin's Q
PRIV	64.2002	*Federico MUNARI and Maurizio SOBRERO*: The Effects of Privatization on R&D Investments and Patent Productivity
SUST	65.2002	*Orley ASHENFELTER and Michael GREENSTONE*: Using Mandated Speed Limits to Measure the Value of a Statistical Life
ETA	66.2002	*Paolo SURICO:* US Monetary Policy Rules: the Case for Asymmetric Preferences
PRIV	67.2002	*Rinaldo BRAU and Massimo FLORIO*: Privatisations as Price Reforms: Evaluating Consumers' Welfare Changes in the U.K.
CLIM	68.2002	*Barbara K. BUCHNER and Roberto ROSON*: Conflicting Perspectives in Trade and Environmental Negotiations
CLIM	69.2002	*Philippe QUIRION*: Complying with the Kyoto Protocol under Uncertainty: Taxes or Tradable Permits?
SUST	70.2002	*Anna ALBERINI, Patrizia RIGANTI and Alberto LONGO*: Can People Value the Aesthetic and Use Services of Urban Sites? Evidence from a Survey of Belfast Residents
SUST	71.2002	*Marco PERCOCO:* Discounting Environmental Effects in Project Appraisal
NRM	72.2002	*Philippe BONTEMS and Pascal FAVARD*: Input Use and Capacity Constraint under Uncertainty: The Case of Irrigation

(xlii) This paper was presented at the International Workshop on "Climate Change and Mediterranean Coastal Systems: Regional Scenarios and Vulnerability Assessment" organised by the Fondazione Eni Enrico Mattei in co-operation with the Istituto Veneto di Scienze, Lettere ed Arti, Venice, December 9-10, 1999.

(xliii)This paper was presented at the International Workshop on “Voluntary Approaches, Competition and Competitiveness” organised by the Fondazione Eni Enrico Mattei within the research activities of the CAVA Network, Milan, May 25-26,2000.

(xliv) This paper was presented at the International Workshop on “Green National Accounting in Europe: Comparison of Methods and Experiences” organised by the Fondazione Eni Enrico Mattei within the Concerted Action of Environmental Valuation in Europe (EVE), Milan, March 4-7, 2000

(xlv) This paper was presented at the International Workshop on “New Ports and Urban and Regional Development. The Dynamics of Sustainability” organised by the Fondazione Eni Enrico Mattei, Venice, May 5-6, 2000.

(xlvi) This paper was presented at the Sixth Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CORE, Université Catholique de Louvain, Louvain-la-Neuve, Belgium, January 26-27, 2001

(xlvii) This paper was presented at the RICAMARE Workshop “Socioeconomic Assessments of Climate Change in the Mediterranean: Impact, Adaptation and Mitigation Co-benefits”, organised by the Fondazione Eni Enrico Mattei, Milan, February 9-10, 2001

(xlviii) This paper was presented at the International Workshop “Trade and the Environment in the Perspective of the EU Enlargement ”, organised by the Fondazione Eni Enrico Mattei, Milan, May 17-18, 2001

(xlix) This paper was presented at the International Conference “Knowledge as an Economic Good”, organised by Fondazione Eni Enrico Mattei and The Beijer International Institute of Environmental Economics, Palermo, April 20-21, 2001

(l) This paper was presented at the Workshop “Growth, Environmental Policies and Sustainability” organised by the Fondazione Eni Enrico Mattei, Venice, June 1, 2001

(li) This paper was presented at the Fourth Toulouse Conference on Environment and Resource Economics on “Property Rights, Institutions and Management of Environmental and Natural Resources”, organised by Fondazione Eni Enrico Mattei, IDEI and INRA and sponsored by MATE, Toulouse, May 3-4, 2001

(lii) This paper was presented at the International Conference on “Economic Valuation of Environmental Goods”, organised by Fondazione Eni Enrico Mattei in cooperation with CORILA, Venice, May 11, 2001

(liii) This paper was circulated at the International Conference on “Climate Policy – Do We Need a New Approach?”, jointly organised by Fondazione Eni Enrico Mattei, Stanford University and Venice International University, Isola di San Servolo, Venice, September 6-8, 2001

(liv) This paper was presented at the Seventh Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CORE, Université Catholique de Louvain, Venice, Italy, January 11-12, 2002

(lv) This paper was presented at the First Workshop of the Concerted Action on Tradable Emission Permits (CATEP) organised by the Fondazione Eni Enrico Mattei, Venice, Italy, December 3-4, 2001

(lvi) This paper was presented at the ESF EURESCO Conference on Environmental Policy in a Global Economy “The International Dimension of Environmental Policy”, organised with the collaboration of the Fondazione Eni Enrico Mattei , Acquafredda di Maratea, October 6-11, 2001

(lvii) This paper was presented at the First Workshop of “CFEWE – Carbon Flows between Eastern and Western Europe”, organised by the Fondazione Eni Enrico Mattei and Zentrum fur Europaische Integrationsforschung (ZEI), Milan, July 5-6, 2001

2002 SERIES

CLIM	*Climate Change Modelling and Policy* (Editor: Marzio Galeotti)
NRM	*Natural Resources Management* (Editor: Carlo Giupponi)
SUST	*Sustainability Indicators and Environmental Evaluation* (Editor: Carlo Carraro)
KNOW	*Knowledge, Technology, Human Capital* (Editor: Dino Pinelli)
PRIV	*Privatisation, Regulation, Antitrust* (Editor: Bernardo Bortolotti)
MGMT	*Corporate Sustainable Management* (Editor: Andrea Marsanich)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)