The GSBGM Working Paper Series

WORKING PAPER 5/95

Pollution Management through levies and subsidies

J.B. Krawczyk and G. Zaccour

ISSN 0-114-7420
ISBN 0-475-11486-8

The Graduate School of Business and Government Management Working Paper Series 5/95 March 1995.
J.B. Krawczyk and G. Zaccour* 'Pollution management through levies and subsidies'

Enquiries concerning this paper direct to the first author
General enquiries concerning GSBGM publications to:
Monica Cartner
Research Co-ordinator
The Graduate School of Business and Government Management
The Victoria University of Wellington
PO Box 600
Wellington
New Zealand

Telephone: 64-4-495 5085
Facsimile: 64-4-496 5435
E-mail: Monica.Cartner@vuw.ac.nz

* Jacek Krawczyk
Econometrics Group
Faculty of Commerce and Administration
Victoria University of Wellington
G. Zaccour
Ecole des Hautes Etudes Commerciales Montreal
5255 avenue Decelles
Montreal
Canada H3T

Printed by The Victoria University of Wellington Printers.

POLLUTION MANAGEMENT THROUGH LEVIES AND SUBSIDIES

J.B. KRAWCZYK* and G. ZACCOUR**

*Faculty of Commerce & Administration, Victoria University of Wellington, PO Box 600, Wellington New Zealand. Email:Jacek.Krawczyk@vuw.ac.nz

**École des Hautes Études Commerciales, Montréal. 5255 avenue Decelles, Montréal, Canada H3T 1V6. Email: Georges.Zaccour@hec.ca

Abstract. This paper is concerned with the problem of the management of pollution by a local government which aims at the achievement of certain environmental standards within a relatively short time horizon. It is assumed that this government disposes of financial means which might be spent on subsidies to encourage the polluting agents to build their abatement facilities, and also possesses a legislative power to impose environmental levies on emission for the non compliance to the standards.

Key Words. Pollution, Stackelberg equilibrium, Environmental levy.

1. INTRODUCTION

This paper[1] is concerned with the problem of the management of pollution by a local government which aims at the achievement of certain environmental standards within a relatively short time horizon. It is assumed that the government uses financial means which might be spent on subsidies to encourage the polluting agents to build their abatement facilities. It also possesses a legislative power to impose environmental levies on emission for the non compliance to the legislated standards.

The idea of making a polluter pay for causing environmental damage has already been explored in general, *cf* Tietenberg (1990), as well as in some details: *e.g.* for the static set up see Sergerson (1988), for non point-source pollution Xepapedas (1992), for point-source pollution Krawczyk (1995), for the global environmental management van der Ploeg & de Zeeuw (1992), Haurie & Zaccour (1993) and Martin *et al.* (1993) *etc.* However, the idea of the local government facing a range of options: to tax, subsidise or to do both appears to be new in the environmental context.

This paper, together with a few "dynamic game" papers (like the cited above Haurie & Zaccour (1993) and Krawczyk (1995)), can be seen as one which establishes a base for the legislation, according to which the polluters would be taxed depending on how much they *pollute*, rather than *emit* as is in the case of the emission permits approach. Moreover, this paper is different from most of the above cited papers, in that it addresses explicitly the *transition* problem from a current "polluted" environmental state to a "desired" environmental state. The model which we will use to study the local government options is a version of the leader-follower set-up, for which an open loop Stackelberg equilibrium will be sought (see Başar & Olsder (1982), Başar (1989)). Another novelty of the paper consists of using the *maximum principle with parameters* for the solution of the leader's problem.

The paper is organised as follows. The physical situation which we model in this paper is presented in Section 2. The hierarchical optimisation problem which models the "game" between the local government and the polluting agents is described in Section 3. In Section 4, the solution to the game is presented. A simple illustrative example is provided in Section 5. The paper ends with concluding remarks.

[1] Presented at the IFAC/IFORS/SEDC Symposium on National & Regional Economies, Gold Coast 1995.

2. THE ECOLOGICAL ECONOMICS PROBLEM

The ecological-economic situation which we study in this paper, is as follows. There is a geographic region like a river basin with a few economic agents $i = 1, ...N$ whose productive activity $q_i(t)$ generates a by-product (emission)

$$e_i(t) = f_i(q_i(t), K_i(t)) \tag{1}$$

where $K_i(t)$ is the abatement capital and t is the (continuous) time. We assume that $f_i(\cdot, \cdot)$ is convex in either of its arguments with

$$\frac{\partial f_i}{\partial q_i} \geq 0, \quad \frac{\partial f_i}{\partial K_i} \leq 0.$$

The agents are assumed to not observe the cumulative effects of their emissions on the state of the environment. However, the agents are levied $\tau v_i(e_i(t))$, $\tau \geq 0$ by the local government for each unit of the emitted pollutant $e_i(t)$, where $v_i(\cdot)$ is a function which allows for the pollutant's diffusion, decay and transportation from the source down to a critical area at which the government wants to enforce a standard. This function is known to each agent and to the government, and can be a solution to the pollutant's transportation equation, *cf* Krawczyk (1995).

The agents also face an environmental lobby which can mobilise the public to boycott the i-th agent's production should he[2] operate without an adequate level of $K_i(t)$. Moreover, the agents expect a subsidy $\phi I_i(t)$, $\phi \in [0, 1]$ from the government for their abatement capital expansion $I_i(t)$. It is this paper's task to study whether the government programmes τ, ϕ, and the lobby pressure, can induce the agents to invest in their active abatement capacities so that the pollution level is within tolerable limits.

Let $S(t)$ denote the pollutant's concentration in time $t \in [0, T]$ at an environmentally critical place (a river section, say) and $\bar{S}$ is a desired standard in the finite time T. Suppose that the local government together with (or because of) the environmental lobby launches a campaign that pollution has to come down from $S(0)$ to $S(T)$ as close as possible to $\bar{S}$. In practical terms, the government announces that, for a period $[0, T]$, the tax level will be τ and the subsidy programme ϕ. The lobbyists are also campaigning against the emission. For the agents, this could mean that they have to install, use and keep after T, a discernible amount of the abatement capital (the more capital the less "hassle" from the environmentalists). Otherwise, the agents will face their products' boycott.

[2] With no prejudice against either sex we will refer to a sexless agent as *he*, and as *they* to the local government.

Under the above circumstances, the i-th agent's pay-off function can be modelled as follows:

$$\pi_i = e^{-\rho T} M(K_i(T)) + \int_0^T e^{-\rho t}[p_i q_i(t) - g_i(q_i(t), e_i(t)) - (1-\phi) h_i(I_i(t), K_i(t)) - \tau v_i(e_i(t))] dt \quad (2)$$

where $M(K_i(T))$ represents the future gains of the installed abatement capital and could be negative if $K_i(T)$ was below the environmentalists' expectations. Function $g_i(\cdot,\cdot)$ is the production cost. Its dependence on e_i allows for the fact that although the i-th agent does not realise the cumulative effects of his emission, he may be interested in the clean production in his own interest, if *e.g.* his water intake is below his effluent pipes. Function $h_i(\cdot,\cdot)$ is the investment cost, p_i is an exogenous price and ρ is the discount rate. We assume that

$$\frac{\partial h_i}{\partial I_i} \geq 0, \ \frac{\partial h_i}{\partial K_i} \geq 0, \ \frac{\partial^2 h_i}{\partial I_i^2} \geq 0, \ \frac{\partial^2 h_i}{\partial K_i^2} \geq 0, \ \frac{\partial^2 h_i}{\partial I_i \partial K_i} \geq 0;$$

$$\frac{\partial g_i}{\partial q_i} \geq 0, \ \frac{\partial g_i}{\partial e_i} \geq 0, \ \frac{\partial^2 g_i}{\partial q_i^2} \geq 0, \ \frac{\partial^2 g_i}{\partial e_i^2} \leq 0, \ \frac{\partial^2 g_i}{\partial q_i \partial e_i} \geq 0;$$

and that the installed abatement capacity changes according to the following equation of motion:

$$\left.\begin{array}{lcl} \dot{K}_i(t) & = & -\mu_i K_i(t) + I_i(t), \\ K_i(0) & & \text{given} \end{array}\right\} \quad (3)$$

where μ_i is the abatement capital depreciation rate. The investment cost h_i is convex and increases in both I_i and K_i. We also assume that its mixed second order partial derivative is non negative, which allows us to capture the fact that the incremental investment is costly. Similar qualitative behaviour is assumed about the function $g_i(q_i, e_i)$.

The government may have at their disposal a third "programme" (*i.e.* one more beside those of $\tau \in \mathcal{R}^1_+$ and $\phi \in [0,1]$) namely, the cleaning effort $c \in \mathcal{R}^1_+$ which will have to be exercised, if the instruments τ and ϕ have failed to induce the agents to diminish their emissions. The pollution $S(t)$, in some critical area (a section of the river below the "last" agent, say) can be modelled as a result of the transportation and accumulation of emission, as in the following equation:

$$\left.\begin{array}{l} \dot{S}(t) = -(\delta + c)S(t) + \sum_{i=1}^N v_i(e_i(t)), \\ S(0) \quad \text{given} \end{array}\right\} \quad (4)$$

where δ is the natural cleaning rate.

3. THE GAME MODEL

3.1. *The follower's problem*

Given the government programmes: the subsidy rate ϕ and the tax rate τ, each producer (*follower*) is supposed to solve the following problem:

$$\max_{q_i(t), I_i(t)} (2) \quad (5)$$

subject to (1), (3), with the other parameters being fixed. Note that the producers are *not* coupled either through the market, because they are presumably small; or, through the environment, as due to their "myopia" they do not realise the cumulative effects of their production by-product $e_i(t)$ on the surrounding world.

3.2. *The leader's problem*

The local government aims to stabilise the critical pollutant's concentration (4) around the level $\bar{S}$, which is socially and politically acceptable. The government is therefore choosing programmes ϕ, τ and c so that, at time T, $S(T)$ reaches $\bar{S}$ while a financial balance is observed. This task can be modelled in the following way:

$$\left.\begin{array}{l} \text{Find } (\phi, \tau, c) \in [0,1] \times \mathcal{R}^1_+ \times \mathcal{R}^1_+ \\ \text{such that} \\ S(T) = \bar{S} \end{array}\right\} \quad (6)$$

subject to (4) and

$$\left.\begin{array}{lcl} \dot{y}(t) & = & \sum_{i=1}^N [\tau v_i(e_i(t)) \\ & & -\phi h_i(I_i(t), K_i(t))] - l(c), \\ y(0) & = & \underline{y}, \ y(T) = \bar{y} \end{array}\right\} \quad (7)$$

where $l(\cdot)$ is the convex cost cleaning function, $\underline{y}$ is an initial budget of the local government and $\bar{y}$ is the budget end-point condition[3].

3.3. *A Stackelberg game*

The government, in order to chose, for the time horizon $[0,T]$, the right values of $(\phi, \tau, c) \in [0,1] \times \mathcal{R}^1_+ \times \mathcal{R}^1_+$, has to allow for the followers' reaction to the instruments ϕ and τ. The leader is therefore looking for a solution to

$$\left.\begin{array}{lll} (6) & \text{subject to} & (4), (7) \\ \text{and} & & (5), (1), (3). \end{array}\right\} \quad (8)$$

A solution to (8) defines an open loop Stackelberg equilibrium (OLSE) for the game played between a local authority (*leader*) and polluters (*followers*).

[3] Various policy options may be investigated: $\bar{y} = \underline{y} e^{\rho t}$, $\bar{y} = 0$, *etc.*

This solution concept (OLSE) is renown for the time inconsistency of the leader solution see Basar and Olsder (1982), Basar (1989). However, for the situation at hand, this solution concept seems relevant. The local government, once having declared (and probably legislated) the pollution abatement programmes for a "short" time horizon T, shall not risk their reputation by changing the programmes before T has lapsed. Consequently, the government will stick to the announced ϕ and τ.

4. THE SOLUTION

4.1. *The reaction function*

Introduce the *current* adjoint state variable $\lambda_i(t)$ for each follower. The i-th follower's *current-value* Hamiltonian is

$$\begin{aligned} H_i &= p_i q_i(t) - g_i(q_i, f_i(q_i, K_i)) \\ &- (1-\phi)h_i(I_i, K_i) - \tau v_i(f_i(q_i, K_i)) \\ &+ \lambda_i(t)(-\mu_i K_i + I_i). \end{aligned} \tag{9}$$

Assuming an interior solution, the necessary conditions for the optimal reaction of the i-th follower to τ, ϕ, c are:

$$\frac{\partial H_i}{\partial q_i} = 0 \implies p_i - \frac{\partial g_i}{\partial q_i} - \tau \frac{\partial v_i}{\partial f_i}\frac{\partial f_i}{\partial q_i} = 0 \tag{10}$$

$$\frac{\partial H_i}{\partial I_i} = 0 \implies \lambda_i = (1-\phi)\frac{\partial h_i}{\partial I_i} \tag{11}$$

The canonical system of equations is given by (4) and

$$\begin{aligned} \dot{\lambda}_i(t) &= (\rho + \mu_i) + \frac{\partial g_i}{\partial f_i}\frac{\partial f_i}{\partial K_i} + (1-\phi)\frac{\partial h_i}{\partial K_i} \\ &+ \tau \frac{\partial v_i}{\partial f_i}\frac{\partial f_i}{\partial K_i} \end{aligned} \tag{12}$$

where all q_is and I_is are supposed to satisfy (10) and (11). The end point condition for $\lambda(T)$ is

$$\lambda_i(T) = e^{-\rho T}\frac{dM_i(K_i(T))}{d(K_i(T))} \tag{13}$$

and has been obtained through the transversality condition.

The above equations determine the i-th follower's reaction function to the leader's programmes, and can be attributed the following economic interpretations.

1. Equation (4) is the i-th follower's dynamic constraint.
2. Equation (10) shows that the marginal revenue equals the marginal cost. The latter is the sum of the marginal production cost and the marginal emission cost.
3. Equation (11) says that the investment is chosen so that its net marginal cost equals the abatement shadow price.
4. Equation (12) describes how the abatement capital shadow price evolves; it also determines the portfolio balance.

Obtaining the optimal reactions I_i, K_i and q_i as explicit functions of ϕ and τ requires the solution of the two-point boundary value problem (4), (12-13). This will be done for a a collection of simple functions g_i, h_i *etc.* in Section 5.

4.2. *The leader's optimisation*

The leader solves (6), (4), (7) allowing for the followers' reactions (10)-(13).

Under the assumption that there exist unique $\hat{I}_i$, and $\hat{q}_i$, which solve the follower's problem, the leader's Hamiltonian will be composed of one basic term[4] representing the leader's dynamics, which comprise the pollution dynamics (4) and the financial balance dynamics (7). Hence the leader's *current-value* Hamiltonian is

$$H = \Theta\left[-(\delta + c)S + \sum_{i=1}^{N} v_i(e_i)\right] + \Psi\left\{\sum_{i=1}^{N}[\tau v_i(e_i) - \phi h_i(I_i(t), K_i(t))] - l(c)\right\} \tag{14}$$

where the multipliers Θ, Ψ depend on $t \in [0, T]$, and are the leader's adjoint state variables.

The government's optimisation problem is ***particular*** in that their controls are constant, and ***degenerated*** in that there are no time dependent controls at all. This requires us to use the "special" maximum principle formulation for the ***optimal processes with parameters***, *cf* Pontryagin *et al.* (1962), Theorem 17. The necessary conditions for the optimal $\hat{c}, \hat{\phi}, \hat{\tau}$ are the "usual" ones:

$$\dot{\Theta} = -\frac{\partial H}{\partial S} = (\delta + c)\Theta \tag{15}$$

$$\dot{\Psi} = -\frac{\partial H}{\partial y} = 0 \tag{16}$$

and the "special" ones:

$$\Theta(T)\int_0^T \frac{\partial \dot{S}}{\partial c}dt + \Psi(T)\int_0^T \frac{\partial \dot{y}}{\partial c}dt = 0 \tag{17}$$

$$\Theta(T)\int_0^T \frac{\partial \dot{S}}{\partial \phi}dt + \Psi(T)\int_0^T \frac{\partial \dot{y}}{\partial \phi}dt = 0 \tag{18}$$

[4] It would have a second term: the instantaneous leader's cost, if the performance index (6) contained an integral of this cost. If the follower's problem did not have an explicit unique solution, the followers' adjoint state dynamics (12) would too have entered the leader's Hamiltonian.

$$\Theta(T)\int_0^T \frac{\partial \dot{S}}{\partial \tau}dt + \Psi(T)\int_0^T \frac{\partial \dot{y}}{\partial \tau}dt = 0. \qquad (19)$$

Notice that because the leader's state variables S, y and λ have the T-ends fixed, the corresponding adjoint state variables Θ and Ψ will have their T-ends free.

The leader's optimality conditions lend themselves for the general economic interpretation.

a. Equation (15) tells us that the abatement capital shadow price is an exponential function and that it depends on the cleaning programme c.
b. Equation (16) tell us that the shadow price of financial resources is constant.
c. Equations (17)-(18) set the leader's terminal shadow prices' values at levels for which the budget's changes, accumulated within the transition period, due to cleaning (subsidising, taxing — respectively), are "balanced" by the pollution changes caused be the same instrument.

5. NUMERICAL ILLUSTRATION

We will use the above obtained conditions to answer a question what should be the local government's subsidising and taxing programme, in a simple environmental-transition management-problem.

We suppose that the time horizon for the problem is short *e.g.*,

$T = 10$ quarters.

This makes valid an assertion, that the capital will not depreciate *i.e.*, $\mu = 0$. Moreover, we assume that the pollution self-cleaning process is minimal and that the local government does not dispose of their cleaning facility; hence $\delta = 0$ and $c = 0$. The emission abatement function is linear, so

$$v_i(f_i(q_i, K_i)) = (\beta_i - \alpha_i K_i)q_i \qquad (20)$$

$$\text{where} \quad 0 \le K_i \le \frac{\beta_i}{\alpha_i}. \qquad (21)$$

The cost functions, of production and investment, are given, respectively, as

$$g_i(q_i, \cdot) = a_i q_i \qquad (22)$$

$$h_i(I_i, \cdot) = \frac{b_i}{2} I_i^2. \qquad (23)$$

The producers are assumed to be myopic, hence $M(\cdot) = 0$; moreover the interest rate is zero[5].

We set up the following parameters' values, as in Table 1. We assume that the initial pollution

β_1	.2	α_1	.01
β_2	.25	α_2	.015
β_3	.3	α_3	.02
b_1	100	a_1	3
b_2	100	a_2	4
b_3	100	a_3	6
q_1	10	p_1	9
q_2	20	p_2	11
q_3	30	p_3	15

Table 1 Parameter values.

$S(0) = 100$ is to be curbed at the level of $\bar{S} = 200$. Notice that the target $\bar{S}$ is above the initial pollution level which is a reasonable requirement because of the no cleaning option.

A numerical optimisation procedure was executed and the optimal susbidisation rate was computed as

$\hat{\phi} = .8081$

and the optimal taxation rate as

$\hat{\tau} = 3.7954.$

Suppose that the local government did not want to implement any subsidising or taxing programme. We will now present the pollution level to which this *laissez faire* option would lead, and compare it with the government controlled situation. It is evident (see Figure 1) that the local government programme is efficient in that, after the ten unit (quarters, as said) transition period, the desired accumulated pollution level is attained.

It is interesting to see how the government's financial situation changes, once the programme $(\hat{\phi}, \hat{\tau})$, of optimal subsidising and taxing, has been implemented. It is shown in Figure 2 that the programme is practically self-financing: by the end of the transition period, the tax income balances the subsidy expenses.

From the producers' point of view, for the programme to be implementable it must not decrease the incomes dramatically. Table 2 can ensure the local government's decision makers, that while the agents' incomes for the *laissez faire* option *are* larger than when the producers' follow the government programme (*i.e.*, when they install the

[5] Notice that however radical the simplifications might look, they are not essential in that they lead to the *limit* results. The original leader's model satisfies the *joint continuity* conditions, see (Dutta *et al.*, 1994). Therefore, the solution to the leader's optmisation problem is *jointly* continuous in all of its parameters (ρ, δ *etc.*), see *ibidem*. Hence the results obtained for the simple model are indeed the limit results.

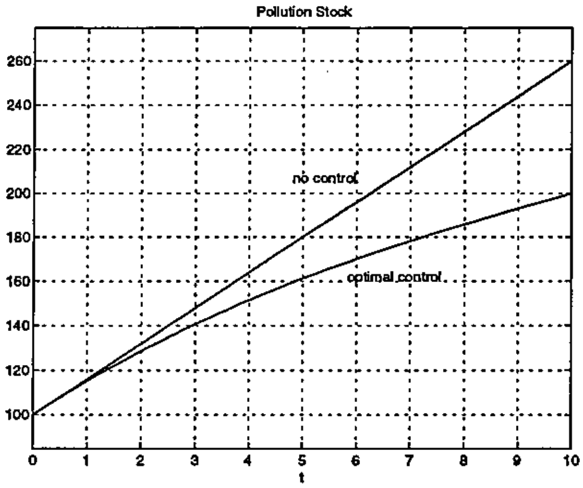

Fig. 1. Accumulated pollution profile.

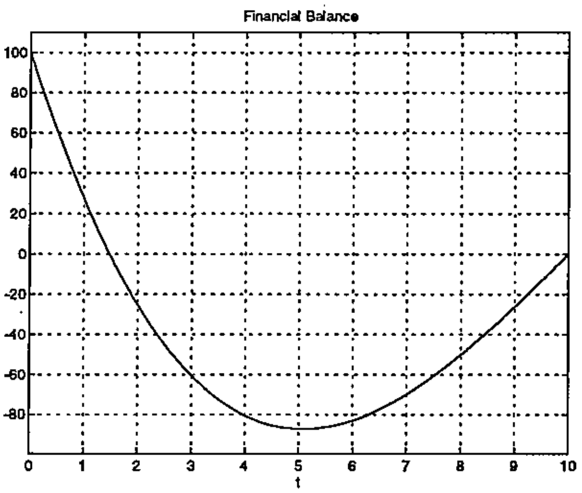

Fig. 2. Financial balance.

abatement capacities), the income gap is probably not prohibitive for the programme to be completed.

Figure 3 shows how the abatement capacities grow under the optimal subsidising and taxing programme; the top panel provides information on the abatement capital shadow prices.

6. CONCLUDING REMARKS

We have solved a transition problem of environmental management which was modelled as a leader-follower dynamic game. We have shown how an extended version of the maximum principle can be used for this purpose. The necessary conditions have provided two sets of general economic interpretations (1 - 4) and (a - c). We have also solved a numerical example and illustrated the fact that the proposed mathematical technique could help in a local government's decision making process.

Agent:	1	2	3
no controls	600	1400	2700
optimal controls	524	1210	2358

Table 2 Agents' incomes.

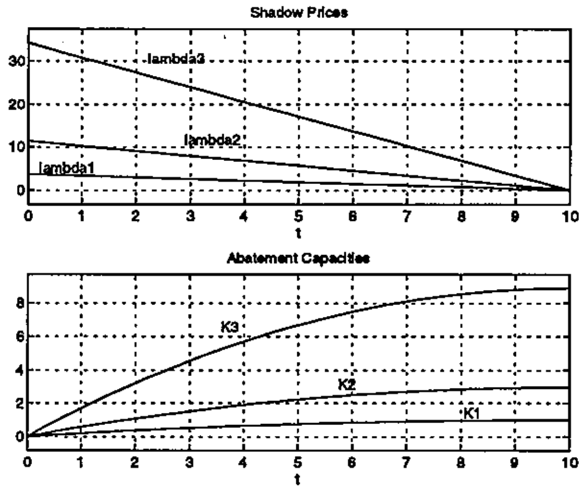

Fig. 3. Abatement capital growth.

7. REFERENCES

Başar T. & G. K. Olsder, **Dynamic Noncooperative Game Theory**, Academic Press, New York, 1982.

Başar T., "Time consistency and robustness of equilibria in non cooperative dynamic games" *in:* **Dynamic Policy Games in Economics,** *eds.:* Ploeg van der F. and A. J. de Zeeuw, North Holland, Amsterdam, 1989.

Dutta, P. K., M. K. Majumdar, R. K. Sundaram, "Parametric Continuity in Dynamic Programming Problems", *Journal of Economic Dynamics and Control*, **18**, pp 1069-1092, 1994.

Haurie A. and G. Zaccour, "Differential Games Models of Global Environmental Management", **Fondazione ENI Enrico Mattei,** Nota di Lavoro 46.93, 1993; also *Annals of Dynamic Games*, vol.2, 1995 (forthcoming).

Krawczyk, J.B., "Management of Effluent Discharges: A Dynamic Game Model", *Annals of Dynamic Games*, vol. 2, 1995 (forthcoming).

Martin, W.E., R.H. Patrick and B. Tolwinski, "A Dynamic Game of a Transboundary Pollutant with Asymmetric Players", *Journal of Environmental Economics and Management*, vol. 24, pp. 1-12, 1993.

Pontryagin, L. S., V. G. Boltyanskii, R. V. Gamkrelidze and E. F. Mishchenko, **The Mathematical Theory of Optimal Processes**, J. Wiley & Sons, New York *etc.*, 1965.

van der Ploeg & A. de Zeeuw, "International Aspects of Pollution Control", *Environmental and Resource Economics*, 2, 117-139, 1992.

Sergerson, K., "Uncertainty and Incentives for Non point Pollution Control", *Journal of Environmental Economics and Management*, 15, pp 87-98, 1988.

Tietenberg, T.H., "Economic Instruments for Environmental Regulation", *Oxford Review of Economic Policy*, vol. 6, no 1, pp 17-31, 1990.

Xepapedas, A.P., "Environmental Policy Design and Dynamic Non point-Source Pollution", *Journal of Environmental Economics and Management*, vol. 23, no 1, pp 22-39, 1992.

THE GSBGM WORKING PAPER SERIES

The main purpose of this series is to reach a wide audience quickly for feedback on recently completed or in progress research. All papers are reviewed before publication.

A full catalogue with abstracts and details of other publications is available, for enquires and to be included in our distribution list, write to:

Monica Cartner
Research Programmes Co-ordinator,
GSBGM, Victoria University of Wellington,
PO Box 600, Wellington, New Zealand
Tel: (04) 495 5085; Fax: (04) 712 200

Code in bold denotes order number, eg: WP 1/91

--- Group denotes the author's academic discipline Group (note this does not necessarily define the subject matter, as staff's interests may not be confined to the subjects they teach).

1990 - 1991 titles available on request.

WP 1/92 **Money and Finance Group**
Burnell, Stephen J. and David K. Sheppard `Upgrading New Zealand's competitive advantage: a critique and some proposals.' 1992 pp 26.

New Zealand Economic Papers Vol 26(1), 1992 pp101-125.

WP 2/92 **Quantitative Studies Group**
Poot, Jacques and Jacques J. Siegers `An economic analysis of fertility and female labour force participation in New Zealand.' 1992 pp 27.

New Zealand Economic Papers Vol. 26, No. 2, December 1992, pp. 219-248

WP 3/92 **Money and Finance Group**
Lally, Martin `Project valuation using state contingent claim prices.' 1992 pp 9.

WP 4/92 **Economics Group**
Kim, Kunhong, R.A. Buckle and V.B. Hall `Key features of New Zealand Business Cycles.'

The Economic Record, Vol. 70, No 208, March 1994, pp56-72

WP 5/92 **Management Group**
McLennan, Roy `The OD Focus Group: A versatile tool for planned change.'

WP 6/92 **Information Systems Group**
Jackson, Ivan F. `Customer-oriented strategic information systems.'

`A customer-oriented IS model: from factory to "Information Factory".' In Proceedings of the Third Australian Conference on Information Systems. Woollongong, Australia. 1992 pp 406-420.

WP 7/92 **Quantitative Studies Group**
Krawczyk, Jacek B. and Boleslaw Tolwinski `A cooperative solution for the three-nation problem of exploitation of the southern blue tuna.'

> `A cooperative solution for a three-agent southern bluefin tuna management problem' In *System Modelling and Optimisation, Lecture Notes in Control and Information Sciences. No. 180.* P. Kahl, ed. Springer Verlag, 1992. pp 747-756.

WP 8/92 **Marketing Group**
Thirkell, Peter and David Stewart `A description of the advertising and direct marketing decision processes of New Zealand marketing managers.'

WP 9/92 **Quantitative Studies Group**
Jorgensen, H.P. and J.B. Krawczyk `Application of optimal control to the determination of an environmental levy.'

WP 10/92 **Economics Group**
Kim, Kunhong `A stochastic overlapping generations real business cycle model of a small open economy'

WP 11/92 **Quantitative Studies Group**
Wu, Ping X. `Testing fractionally integrated time series.'

WP 12/92 **Quantitative Studies Group**
Wu, Ping X. `A test for fractionally integrated time series.'

WP 13/92 **Quantitative Studies Group**
Nijkamp, Peter and Jacques Poot `Endogenous technological change, innovation diffusion and transitional dynamics in a nonlinear growth model.'

WP 14/92 **Management Group**
Cavana, R.Y. `Railway system in New Zealand: Case study in strategic change.'

WP 1/93 **Economics Group**
Bertram, I.G. `Economy-wide effects of a major increase in the wholesale price of electricity: New results from the JOANNA Model.'

WP 2/93 **Economics Group**
Michael Williams and Geert Reuten `The political-economic transformations in central and eastern Europe: A tragic neglect of civil society.'

WP 3/93 **Information Systems Group**
Pak Yoong `Computer-Supported Environmental Scanning: A case study.'

WP 4/93 **Management Group**
Everett Jr., Adam E., Lawrence M. Corbett and Boo Ho Rho `A comparison of Quality Improvement Practices in Korea, New Zealand and the United States of America.'

WP 5/93 **Management Group**
Campbell-Hunt, Colin, David Harper and Bob Hamilton `National renewal and strategic change - First lessons from an early-mover in deregulation.'

WP 6/93 **Management Group**
Cavana, R.Y. `Coastal shipping policy in New Zealand: economy wide implications.'

> *Also in:* Maritime Policy and Management 1994, Vol 21, No 2, 161-172.

WP/793 **Economic History Group**
Mulcare, Tim `Gross Capital Formation and Improved Estimates of Real Gross and Net Capital Stocks to 1990 for the New Zealand Non-Market Production Sector.'

WP 8/93 **Management Group**
Knight, Russell M. and Gilbertson, David W. `Criteria used by venture capitalists: a cross country analysis.'

WP 1/94 **Economics Group**
Nana, G. Hall, V.B. and Philpott, B.P. `Trans-Tasman CGE modelling: Some illustrative results from the Joani model.'

WP 2/94 **Econometrics Group**
Krawczyk, Jacek B. 'Management of effluent discharges: A dynamic game model.'

Annals of Dynamic Games Vol 2, 1994

WP 3/94 **Public Policy Group**
Boston, Jonathon 'The future of cabinet government in New Zealand: The implications of MMP for the formation, organization and operations of the cabinet.'

WP 4/94 **Economics Group**
Kim, Kunhong and Yongyil Choi 'Business cycles in Korea: Is there a stylised feature?'

WP 5/94 **Accountancy Group**
Dunmore, Paul . 'The cross-sectional distributions of financial ratios: theory, evidence, and implications.'

WP 6/94 **Economics Group**
Kunhong Kim, R.A. Buckle and V.B. Hall 'Dating New Zealand Business Cycles.'

WP 7/94 **Management Group**
Brocklesby, John 'Strategic cultural interventions in systems science - Examining the prospects for the further development of methodological complementarism.'

WP 8/94 **Economics Group**
Goodson, Matthew C. 'Irreversible investment, uncertainty and hysteresis: A New Zealand Investigation.'

WP 9/94 **Economics Group**
Boles de Boer, David and Lewis Evans 'Government department to public corporation in a deregulated economy: The economic efficiency of New Zealand telecommunications.

WP 10/94 **Economics Group**
Cassino, Vincenzo 'A study of the distributions underlying business survey reponses in New Zealand.

WP 11/94 **Public Policy Group**
Stephens, Bob 'The impact of housing expenditure on the incidence and severity of poverty in New Zealand.'

WP 12/94 **Public Policy Group**
Stephens, Bob 'The incidence and severity of poverty in New Zealand, 1990 - 1991.'

WP 13/94 **Economic History Group**

Boyce, Gordon 'Contracting capability: A distillate of co-operative principles from business history to guide present day restructuring.

WP 14/94 **Econometrics Group**

Haurie, Alain, and Jacek B. Krawczyk 'A game theoretic model for river basin environmental management of identifiable source pollution.'

WP 1/95 **Management Group**

Gilbertson, D.K., Wright, H., Yska, G, Gilbertson, D.W. and 1994 Students of MGMT 306 'Kiwi entrepreneurs: A study.'

WP 2/95 **Management Group**

Cavana, R. 'Policy issues related to coastal and international shipping in New Zealand'

WP 3/95 **Information Systems Group**

Bonner, Marcus 'On seeing information systems as bridges'

WP 4/95 **Management Group**

Cavana, Bob, Rob Crozier, Barrie Davis and Perumal Pillai 'A survey of academic staff attitudes towards the system of academic titles used in New Zealand universities'

WP 5/95 **Econometrics Group**

Krawczyk, J.B. and G. Zaccour 'Pollution management through levies and subsidies'