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Economic Evaluation of Water Purification Policy in The Closed Water Area with Dynamic Spatial Computable General Equilibrium Model

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Abstract

Recently, the eutrophication in the closed water area is a serious problem. In such closed water area, the water purification policy is necessary to not only remove storage pollutants but also regulate inflow pollutants. However, there are some conflicts of interests among regions or economic agents, because the water pollutants load exhausted by the agents in the upstream region exerts damage on the agents in the downstream region. Therefore, if we should check the feasibility of the water purification policy, we have to apply the comprehensive evaluation which is able to analyze the cost allocation among regions or agents.

In this paper, we firstly built a dynamic spatial computable general equilibrium (DSCGE) model based on the general equilibrium theory to evaluate the water purification policy. Next, we showed the relationship of benefits and costs on economic agents in each region by making the benefit incidence table. Finally, we measured benefits and costs depended on the water purification policy in Ise bay area.

1. Introduction

Recently, the eutrophication in the closed water area, such as the developed bay area, the inland sea or the lake, is a serious problem, because the inflow quantity of nitrogen and phosphorus are increasing, in addition to the closed water area has the topographical characteristic which the water pollutants little diffuses. In such closed water area, the water purification policy is necessary to not only remove storage pollutants but also regulate inflow pollutants. However, these are some conflicts of interests among regions or economic agents, because the water pollutants exhausted by the agents (for example household, industry and farmer) in the upstream region exerts damage on the agents (for example household, fishing industry and leisure firm) in the downstream region. Therefore, if we should check the feasibility of the water purification policy, we have to apply the comprehensive evaluation which is able to analyze the cost allocation among regions or economic agents.

In this paper, we firstly built a DSCGE model based on the general equilibrium theory to evaluate the water purification policy. The model is focused on the agent's behavior with exhausting water pollutants load, is able to analyze the characteristic that the water pollutants accumulate in closed water area, and clearly catches the agent's behavior with decreasing the water pollutants load. Next, we showed the relationship of benefits and costs on economic agents in each region by making the benefit incidence table. Finally, we measured benefits and costs depended on the water purification policy in Ise bay area.

2. Model

2.1 Assumption

The model in this paper is described with the following major assumptions.

1) There are a upstream region (region 1), a downstream region (region 2) in an economy.
2) There exists a representative household, a representative industry, a representative farmer and a representative firm produced the water purified good (W-firm) in region 1. Their behavior influence on the water quality in the closed water area.
3) There exists a representative household, a representative fishing industry and a

representative firm produced the recreational good (R-firm) in region 2. Their behavior are influenced on the water quality in the closed water area.

4) There exists a government who decreases the water pollutants load exhausted by household and purifies the water in closed water area in each region. The industry and farmer in region 1 decrease the water pollutants load exhausted by themselves.
5) Their location choice behavior are not considered.

2.2 Household in each region

Behavior formulation as a bi-level programming

Upper level : A representative household behaves as utility maximization.

Lower level : A representative household produces the recreational service (R-service) by oneself as cost minimization.

$$V^i = \max_{x_j^i, s^i, u_R^i, x_h^{Wi}} \int_0^\infty U^i\left(x_j^i(t), s^i(t), u_R^i(t), x_h^{Wi}(t), S^i(t)\right)\exp(-\rho t)dt \tag{1a}$$

$$s.t.\quad \dot{K}(t) = \left[w(t)\Omega_i - \tau^i(t)\right] + (r - \gamma_K)K_i(t) - \left[\sum_j (1+e_j)p_j(t)x_j^i(t) + w^i(t)s^i(t) + c_R^i(t)u_R^i(t) + p_h^{Wi}(t)x_h^{Wi}(t)\right] \tag{1b}$$

$$\Omega_i = L_i + s^i + t_R^i \tag{1c}$$

$$c_R^i(t)\cdot u(t)_R^i = \min_{x_R^i, t_R^i}\left(1+e^R\right)p_R(t)x_R^i(t) + w(t)t_R^i(t) \tag{2a}$$

$$s.t.\quad u_R^i(t) = \eta_R^i \cdot x_R^i(t)^{\alpha_i^R} \cdot t_R^i(t)^{\alpha_i^t} \tag{2b}$$

where i : a label of region, x_j : the consumption of industrial good supplied by industry, s : the leisure time, u_R : the production of R-service, x_h^{Wi} : the water pollutants load exhausted by household, S^i : the water quality in closed water area, w^i : the wage rate in region *i*, e_j : the consumption tax, ρ : the subjective discount rate, p_j : the price of industrial good, p_h^{Wi} : the fee for exhausting the water pollutants load, Ω : the total available time, K : the capital stock, r : the interest rate, γ_K : the capital wastage rate, τ : the lump sum tax, $\dot{K}$: the increase of the capital stock, x_R : the consumption of the recreational good (R-good) supplied by R-firm, t_R : the recreational time, p_R : the price of R-good, c_R : the price of R-service, η_R, α^R, α^t : parameter.

2.3 Industry in region 1

Behavior formulation as a 3-level programming

Upper level : A representative industry behaves as profit maximization.

Middle level : A representative industry produces the industrial good as cost minimization.

Lower level : A representative industry input the composite production factor as cost minimization.

$$\pi_M(t) = \max_{Y_M} p_M(t) Y_M(t) - C_M(t) \tag{3a}$$

$$s.t. \quad C_M(t) = \left[a_M^0 \cdot c_M(t) + a_M^{x^W} p_M^W(t)\right] Y_M(t) \tag{3b}$$

$$C_M(t) = \min_{PC_M, x_M^W} \left[c_M(t) PC_M(t) + \sum_l \delta_M^l(t) \cdot (q_M(t) - Q_M(t)) x_M^W(t)\right] \tag{4a}$$

$$s.t. \quad Y_M(t) = \min\left[\frac{PC_M(t)}{a_M^0}, \frac{x_M^W(t)}{a_M^{x^W}}\right] \tag{4b}$$

$$c_M(t) = \min_{L_M, K_M} \left[w^1(t) L_M(t) + r(t) K_M(t)\right] \tag{5a}$$

$$s.t. \quad PC_M(t) = \eta_M L_M^{\alpha_M^L}(t) K_M^{\alpha_M^K}(t) = 1 \tag{5b}$$

where PC_M : the input of composite production factor, x_M^W : the input of water, Y_M : the production of industrial good, c_M : the price of composite production factor, q_M : the water pollutants load exhausted by industry, Q_M : the standard of the water pollutants load exhausted by industry, δ_M^l : the skill for decreasing the water pollutants load, a_M^o : the input rate of composite production factor to production, $a_M^{x^W}$: the input rate of water, C_M : the production cost of industrial good, L_M : the labor input, K_M : the input capital, η_M , α_M^L, α_M^K : parameter ($\alpha_M^L + \alpha_M^K = 1$), c_M : the per unit input cost of composite production factor.

2.4 Farmer in region 1

Behavior of a representative farmer formulates as the same behavior as a representative industry.

A label M of the industry is only changed to a label A of the farmer.

Therefore, We omit the formulations here.

2.5 W-firm in region 1

Behavior formulation as a bi-level programming

Upper level : W-firm behaves as profit maximization.

Lower level : W-firm produces the water purified good as cost minimization.

$$\pi_d(t)=\max_{Y_d} p_d(t)Y_d(t)-C_d(t) \tag{6a}$$

$$s.t.\quad c_d(t)=\frac{1}{\eta_d}\left[w^1(t)\cdot\left[\frac{\alpha_d^L\cdot r(t)}{\alpha_d^K\cdot w^1(t)}\right]^{\alpha_d^K}+r(t)\cdot\left[\frac{\alpha_d^K\cdot w^1(t)}{\alpha_d^L\cdot r(t)}\right]^{\alpha_d^L}\right]\cdot Y_d(t) \tag{6b}$$

$$C_d(t)=\min_{L_d,K_d}\left[w^1(t)L_d(t)+r(t)K_d(t)\right] \tag{7a}$$

$$s.t.\quad Y_d(t)=\eta_d L_d{}^{\alpha_d^L}(t)K_{M'}{}^{\alpha_d^K}(t) \tag{7b}$$

where C_d : the production cost of service for decreasing the water pollutants load (D-service), L_d : the labor input, K_d : the input capital, $\eta_d,\alpha_d^L,\alpha_d^K$: parameter ($\alpha_d^L+\alpha_d^K=1$).

2.6 Fishing industry in region 2

Behavior formulation as a bi-level programming

Upper level : A representative fishing industry behaves as profit maximization.

Lower level : A representative fishing industry fishes and produces the fishing good as cost minimization.

$$\pi_F(t)=\max_{Y_F} p_F(t)Y_F(t)-C_F(t) \tag{8a}$$

$$s.t.\quad C_F(t)=\frac{1}{\eta_F}\left[w^2(t)\cdot\left[\frac{\alpha_F^L\cdot r(t)}{\alpha_F^K\cdot w^2(t)}\right]^{\alpha_F^K}+r(t)\cdot\left[\frac{\alpha_F^K\cdot w^2(t)}{\alpha_F^L\cdot r(t)}\right]^{\alpha_F^L}\right]\cdot Y_F(t) \tag{8b}$$

$$C_F(t)=\min_{L_F,K_F}\left[w^2(t)L_F(t)+r(t)K_F(t)\right] \tag{9a}$$

$$s.t.\quad Y_F(t)=\eta_F(S)\cdot L_F{}^{\alpha_F^L}(t)H_F{}^{\alpha_F^K}(t) \tag{9b}$$

where L_F : the labor input, K_F : the input capital, Y_F : the fishing catch and the production of fishing good, $\eta_F,\alpha_F^L,\alpha_F^K$: parameter ($\alpha_F^L+\alpha_F^K=1$), C_F : the cost function.

2.7 R-firm in region 2

Behavior formulation as a bi-level programming

Upper level : R-firm behaves as profit maximization.

Lower level : R-firm produces the R-good as cost minimization.

$$\pi_R(t)=\max_{Y_R} p_R(t)Y_R(t)-C_R(t) \tag{10a}$$

$$s.t.\quad C_R(t)=\frac{1}{\eta_R}\left[w^2(t)\cdot\left[\frac{\alpha_R^L\cdot r(t)}{\alpha_R^K\cdot w^2(t)}\right]^{\alpha_R^K}+r(t)\cdot\left[\frac{\alpha_R^K\cdot w^2(t)}{\alpha_R^L\cdot r(t)}\right]^{\alpha_R^L}\right]\cdot Y_R(t) \tag{10b}$$

$$C_R(t)=\min_{L_R,K_R}\left[w^2(t)L_R(t)+r(t)K_R(t)\right] \tag{11a}$$

$$s.t.\quad Y_R(t)=\eta_R L_R^{\alpha_R^L}(t) H_R^{\alpha_R^K}(t) \tag{11b}$$

where L_R : the labor input, K_R : the input capital, Y_R : the production of R-good, η_R, α_R^L, α_R^K : parameter ($\alpha_R^L+\alpha_R^K=1$), C_R : the cost function.

2.8 Government in each region

1)Sector of decreasing the water pollutants load (D-government)

D-government behaves as profit maximization.

$$\pi_G^i(t)=\max_{\delta_h^l(t)} p_h^{Wi}(t)x_h^{Wi}(t)-C_W^i(t) \tag{12a}$$

$$s.t.\quad C_W^i(t)=\sum_l \delta_h^l(t)\cdot\left(q_h^i(t)-Q_h^i(t)\right)x_h^{Wi}(t)-pf^i\left(G^i\right) \tag{12b}$$

where C_W^i : the cost of decreasing the water pollutants load, δ_h : the skill for decreasing the water pollutants load exhausted by household, Q_h : the standard of the water pollutants load exhausted by household, G : the institution scale, $pf(\cdot)$: the investment cost, π_G : the profit of D-government.

2)Sector of purifying the water (P-government)

P-government behaves as the revenue and the expenditure are balanced

$$ep_M(t)x_M^i(t)+ep_A(t)x_A^i(t)+ep_R(t)x_R^i(t)=p_d(t)x_d^{Gi}(t) \tag{13}$$

2.9 Change of the water quality in the closed water area

Change of the water quality is formulized as follows,

$$\dot{S}=g^W\left[Q_M(t),Q_A(t),Q_h^i(t)\right]-g^P\left[e(t)\right]-bS \tag{14}$$

where $g^W[\cdot]$: deterioration of the water quality deterioration, $g^P[\cdot]$: improvement of the water quality, b : the ratio of natural purification.

2.10 Equilibrium

Labor market : $\sum_i\sum_j L_{ij}(t)=L_S^i(t)$ (15a)

Capital stock market : $\sum_i\sum_j K_{ij}(t)=\sum_i K_h^i(t)$ (15b)

Industrial good market : $\sum_i x_M^i(t)=Y_M(t)$ (15c)

D-Service market : $\sum_i x_d^{Gi}(t)+\sum_j x_d^j(t)=Y_d(t)$ (15d)

Farmer good market : $\sum_i x_A^i(t)=Y_A(t)$ (15e)

R-good market : $\sum_i x_R^i(t)=Y_R(t)$ (15f)

Fishing catch and fishing good market : $\sum_i x_F^i(t)=Y_F(t)$ (15g)

3. Benefit Incidence Table

3.1 Constant condition

We assume that the endogenous variables dose not change, in other words the zero economic growth (the constant condition) such as all the variables are constant (See figure 1). Therefore, (14) is rewritten as follows on this assumption.

$$\dot{S} = g^W\left[Q_M(t), Q_A(t), Q_h^i(t)\right] - bS - g^P\left[e(t)\right] = 0 \tag{16}$$

3.2 Benefit Incidence Table

We can obtain the differentials of indirect utility function and profit functions in each firm. We make the Benefit Incidence Table (BIT) by using these differentials as Table 1. We should list the economic agents in the top row and item of benefit/cost in the column. BIT shows the process where each item benefit/cost are enjoyed/burdened by economic agents related to the water purification policy. The BIT explicitly shows the cancel-out properties explained in the row where the sum is zero in right column. Therefore, the SNB is shown as follow,

$$\begin{aligned} SNB= & \int_{A\to B}\left[u_R^1\left(S^B\right)-u_R^1\left(S^A\right)\right]dc_R^1 + e\left[V\left(c_R^{1\infty}\right), S^B\right] - e\left[V\left(c_R^{1\infty}\right), S^A\right] + \int_{A\to B}\sum_j p_j^W dx_j^W - \int_{A\to B}\sum_j p_d dx_d^j \\ & + \int_{A\to B} p_h^W dx_{1h}^W - \int_{A\to B} p_d dx_d^{G1} + \int_{A\to B}\left[u_R^2\left(S^B\right)-u_R^2\left(S^A\right)\right]dc_R^2 + e\left[V\left(c_R^{2\infty}\right), S^B\right] - e\left[V\left(c_R^{2\infty}\right), S^A\right] \\ & + \int_{A\to B} p_h^W dx_{2h}^W - \int_{A\to B} p_d dx_d^{G2} + \int_{A\to B} p_F \frac{\partial Y_F}{\partial S} dS \end{aligned} \tag{17}$$

4. Economic evaluation

4.1 The water purification policy

The water purification policy is set in Ise bay area, and determined the decreasing rate of the water pollutants load as Table 2.

4.2 Measurement benefits and costs

We measured benefits and costs depended on the water purification policy in Ise bay area. The result of measurement shows Table 3 (BIT).

5. Concluding remarks

We have development a model for the cost benefit analysis of the water purification policy in the closed water area. The major contributions are,

1) This model catches the behavior with exhausting water pollutants load, the characteristic that the water pollutants accumulate in closed water area, and the behaviors with decreasing the water pollutants load.
2) We showed the relationship of benefits and costs on economic agents in each region by making BIT.
3) Cancel out property simplifies measuring the SNB.
4) We showed practicality by measuring benefits and costs depended on the water purification policy in Ise bay area.

We have many remaining tasks to try in next step of the study. We need to not only calculate on the constant condition but also do dynamic analysis. We must analyze the efficient allocation of the water pollutants load which is decreased as SNB maximize.

Reference

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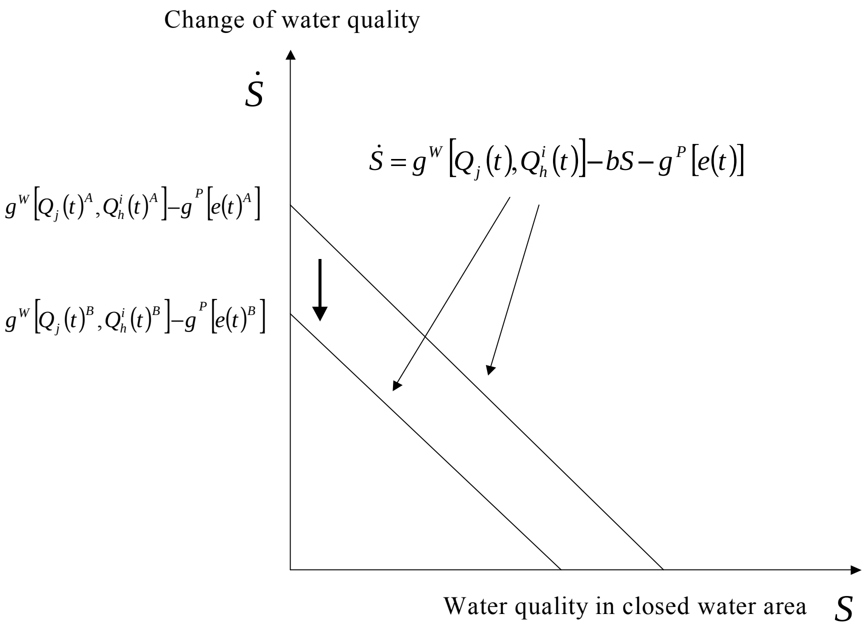

Figure 1　Constant Condition

Table 2　The decreasing rate of the water pollutants load (COD) on the water purification policy in Ise bay area

	Household	Industry	Farmer	Non-point source	total
COD without the policy (t/day)	169	115	16	105	405
COD with the policy (t/day)	62	75	10	89	236
The decreasing load (t/day)	107	40	6	16	169
The decreasing rate (%)	63	35	35	15	42

Table 1 Benefit Incidence Table

	Region 1							Region 2				total
	Household	Industry		Farmer		W-firm	Government	Household	Fishing Industry	R-firm	Government	
		Production Sector	Decrease Sector	Production Sector	Decrease Sector							
Cost for decreasing the water pollutants load discharged by firm		$-\int_{A\to B} x_M^W dp_M^W$	$\int_{A\to B} x_M^W dp_M^W$	$-\int_{A\to B} x_A^W dp_A^W$	$\int_{A\to B} x_A^W dp_A^W$							0
Cost for overdecreasing the water pollutants load discharged by firm			$\int_{A\to B} p_M^W dx_M^W$		$\int_{A\to B} p_A^W dx_A^W$							$\int_{A\to B} \sum_j p_j^W dx_j^W$
Cost for overdemanding D-service to firm			$-\int_{A\to B} p_d dx_d^M$		$-\int_{A\to B} p_d dx_d^A$							$-\int_{A\to B} \sum_j p_d dx_d^j$
Cost for discharging the water pollutants load by household	$-\int_{A\to B} x_{1h}^W dp_h^W$						$\int_{A\to B} x_{1h}^W dp_h^W$	$-\int_{A\to B} x_{2h}^W dp_h^W$			$\int_{A\to B} x_{2h}^W dp_h^W$	0
Cost for overdischarging the water pollutants load by household							$\int_{A\to B} p_h^W dx_{1h}^W$				$\int_{A\to B} p_h^W dx_{2h}^W$	$\int_{A\to B} \sum_i p_h^W dx_{ih}^W$
Cost for overdemanding D-service to government							$-\int_{A\to B} p_d dx_d^{G1}$				$-\int_{A\to B} p_d dx_d^{G2}$	$-\int_{A\to B} \sum_i p_d dx_d^{Gi}$
Tax for the water purification policy	$-\int_{A\to B} \sum_j x_j^1 dep_j$						$\int_{A\to B} \sum_j x_j^1 dep_j$	$-\int_{A\to B} \sum_j x_j^2 dep_j$			$\int_{A\to B} \sum_j x_j^2 dep_j$	0
Cost for the water purification policy							$-\int_{A\to B} p_d dx_d^{G1}$				$-\int_{A\to B} p_d dx_d^{G2}$	$-\int_{A\to B} \sum_i p_d dx_d^{Gi}$
Changes in industrial good market	$-\int_{A\to B} x_M^1 dp_M$	$\int_{A\to B} Y_M dp_M$						$-\int_{A\to B} x_M^2 dp_M$				0
Changes in D-service market			$-\int_{A\to B} x_d^M dp_d$		$-\int_{A\to B} x_d^A dp_d$	$\int_{A\to B} Y_d dp_d$	$-\int_{A\to B} x_d^{G1} dp_d$				$-\int_{A\to B} x_d^{G2} dp_d$	0
Changes in farmer good market	$-\int_{A\to B} x_A^1 dp_A$			$\int_{A\to B} Y_A dp_A$				$-\int_{A\to B} x_A^2 dp_A$				0
Change in Fishing catch and good market	$-\int_{A\to B} x_F^1 dp_F$							$-\int_{A\to B} x_F^2 dp_F$	$\int_{A\to B} Y_F dp_F$			0
Change in R-good market	$-\int_{A\to B} x_R^1 dp_R$							$-\int_{A\to B} x_R^2 dp_R$		$\int_{A\to B} Y_R dp_R$		0
Changes in wage income	$\int_{A\to B} L_1 dw_1$	$-\int_{A\to B} L_M dw_1$		$-\int_{A\to B} L_A dw_1$		$-\int_{A\to B} L_d dw_1$		$\int_{A\to B} L_2 dw_2$	$-\int_{A\to B} L_F dw_2$	$-\int_{A\to B} L_R dw_2$		0
Direct increase of production depended on the change of water quality									$\int_{A\to B} p_F \frac{\partial Y_F}{\partial S} dS$			$\int_{A\to B} p_F \frac{\partial Y_F}{\partial S} dS$
Increase in R-service	A							B				$A+B$
Increase in option value	C							D				$C+D$
Total	E	0	0	0	0	0	0	F	0	0	0	SNB

$$A : \int_{A\to B} \left[u_R^1(S^B) - u_R^1(S^A)\right] dc_R^1 \;,\; B : \int_{A\to B} \left[u_R^2(S^B) - u_R^2(S^A)\right] dc_R^2 \;,\; C : e\left[V\left(c_R^{1\infty}\right), S^B\right] - e\left[V\left(c_R^{1\infty}\right), S^A\right],\; D : e\left[V\left(c_R^{2\infty}\right), S^B\right] - e\left[V\left(c_R^{2\infty}\right), S^A\right],\; E : \int_{A\to B} \left[u_R^1(S^B) - u_R^1(S^A)\right] dc_R^1 + e\left[V\left(c_R^{1\infty}\right), S^B\right] - e\left[V\left(c_R^{1\infty}\right), S^A\right]$$

$$+ \int_{A\to B} \sum_j p_j^W dx_j^W - \int_{A\to B} \sum_j p_d dx_d^j + \int_{A\to B} p_h^W dx_{1h}^W - \int_{A\to B} p_d dx_d^{G1} \;,\; F : \int_{A\to B} \left[u_R^2(S^B) - u_R^2(S^A)\right] dc_R^2 + e\left[V\left(c_R^{2\infty}\right), S^B\right] - e\left[V\left(c_R^{2\infty}\right), S^A\right] + \int_{A\to B} p_h^W dx_{2h}^W - \int_{A\to B} p_d dx_d^{G2} + \int_{A\to B} p_F \frac{\partial Y_F}{\partial S} dS$$

Table 3 Benefit Incidence Table (The measuring result)

	Region 1							Region 2				total
	Household	Industry		Farmer		W-firm	Government	Household	Fishing Industry	R-firm	Government	
		Production Sector	Decrease Sector	Production Sector	Decrease Sector							
Cost for decreasing the water pollutants load discharged by firm		-506	506	-5	5							0
Cost for overdecreasing the water pollutants load discharged by firm			-9									-9
Cost for overdemanding D-service to firm			-495		-5							-500
Cost for discharging the water pollutants load by household	-1,006						1,006	-25			25	0
Cost for overdischarging the water pollutants load by household							-817				-19	-836
Cost for overdemanding D-service to government							-189				-6	-195
Tax for the water purification policy	-580						580	-15			15	0
Cost for the water purification policy												0
Changes in industrial good market	-542	556						-14				0
Changes in D-service market			-2		0	-3	-1				0	0
Changes in farmer good market	-5			5				0				0
Change in Fishing catch and good market	26							1	-27			0
Change in R-good market	-218							-5		223		0
Changes in wage income	50	-52		0		3		228	-6	-223		0
Direct increase of production depended on the change of water quality									32			32
Increase in R-service	4,090							90				4,180
Increase in option value	490							19				509
Total	2,305	0	0	0	0	0	0	279	0	0	0	2,584