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SOCIAL INJUSTICE AND OPTIMAL SPACE-TIME DEVELOPMENT: EXTENSIONS AND AN APPLICATION TO THE MINAMATA MERCURY POLLUTION CASE

by

Yoshifusa Kitabatake

PROGRAM ON POLICIES FOR SCIENCE
AND TECHNOLOGY IN DEVELOPING NATIONS

SOCIAL INJUSTICE
AND
OPTIMAL SPACE-TIME DEVELOPMENT: EXTENSIONS AND AN APPLICATION TO THE MINAMATA MERCURY POLLUTION CASE

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University for the Degree of

Doctor of Philosophy

by

Yoshifusa Kitabatake

August, 1974

BIOGRAPHICAL SKETCH

Yoshifusa Kitabatake was born in Komatsu, Japan, on October 1, 1944. He was raised in a Shinto-priest family and received his elementary and secondary education at local schools in Komatsu and Kanazawa. He attended Hitotsubashi University in Tokyo from which he received a Bachelor of Arts degree in Sociology in 1968 and a Master of Commerce degree in Management Science in 1970. He entered the Ph.D. program in the field of City and Regional Planning at Cornell University in September of 1970. During the spring semester of 1973 he was associated with the Department of Consumer Economics and Public Policy at Cornell University as a part-time lecturer.

He is a member of a national honorary society Phi Kappa Phi, the Regional Science Association, and the Peace Science Society (International).

To

the Victims

of

Minamata Disease

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Lastly, I would like to express my sincere respect to my parents for their painful and life-long struggle to realize their personal values in a family laden with tradition. Without observing their struggle, I would never have been able to see the tragedy of Minamata disease as being more than just a tragedy.

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PAGE	PLACE	CORRECTION
81	line 7	Should read: $M^{x\cdot}(x,t) = \frac{\partial}{\partial t}\frac{\partial}{\partial x} M(x,t)$
	line 13	Change $\dot{C}^x(x,t)$ to $C^{x\cdot}(x,t)$
		Change $\dot{K}^x(x,t)$ to $K^{x\cdot}(x,t)$
	lines 14 and 15	Change $\dot{R}^x(x,t)$ to $R^{x\cdot}(x,t)$
112	Replace lines 20-25 by: We further assume that the following functions are twice continuously differentiable in the product space $(0,B)x(0,t_1)$: $K(x,t), U(x,t), V(x,t), C(x,t), Q(x,t), R_c(x,t)$.	
131	line 4	Change $\dot{Q}^x(x,t)$ to $Q^{x\cdot}(x,t)$
134	Replace lines 7 and 8 by:	Differentiating (4.23) with respect to t gives
134	line 9	Change $\dot{C}^x(x,t)$ to $C^{x\cdot}(x,t)$
136	bottom line	Change $\dot{Q}^x(x,t)$ to $Q^{x\cdot}(x,t)$
137	lines 2 and 5	Change $\dot{Q}^x(x,t)$ to $Q^{x\cdot}(x,t)$
137	one line above the bottom line	Change $\dot{C}^x(x,t)$ to $C^{x\cdot}(x,t)$
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142	line 1	Change $\dot{C}^x(x,t)$ to $C^{x\cdot}(x,t)$
185	line 10	Change $\dot{e}^x(x,t)$ to $e^{x\cdot}(x,t)$
188	the same line as (5.67)	Change $\dot{c}^x(x,t)$ to $c^{x\cdot}(x,t)$
188	one line above the bottom line	Change $\dot{e}^x(x,t)$ to $e^{x\cdot}(x,t)$
196	lines 12-14	Should read: . . . (5.80). We first differentiate (5.75) with respect to x and t. By substituting (5.74) and (5.80) in it, we then obtain
196	lines 15 and 16	Change $\dot{e}^x(x,t)$ to $e^{x\cdot}(x,t)$
201	two and four lines above the bottom line	Change $\dot{e}^x(x,t)$ to $e^{x\cdot}(x,t)$

ERRATA SHEET (Continued)

PAGE	PLACE	CORRECTION
209	Replace lines 5 and 6 by:	Differentiating (5.117) with respect to x and t and substituting (5.110) for $A_1^x(x,t)$ and (5.119) for $\dot{c}(x,t)$ gives
209	line 7	Change $\dot{c}^x(x,t)$ to $c^{x\cdot}(x,t)$
209	Replace one and two lines above (5.123) by:	Differentiating (5.118) with respect to x and t and then substituting (5.111) for $\mathcal{B}^x(x,t)$ and (5.122) for $\dot{e}(x,t)$ gives
209	the same line as (5.123)	Change $\dot{e}^x(x,t)$ to $e^{x\cdot}(x,t)$
223	line 2	Change $\hat{\tilde{X}}(t)$ to $\tilde{Z}(t)$
223	one and two lines above (5.169)	Should read: . . . space axis. Differentiating (5.168) with respect to t and substituting (5.166) in it, we obtain
223	bottom line	Change $\dot{e}^x(x,t)$ to $e^{x\cdot}(x,t)$
230	one and two lines above (5.182)	Should read: . . . (5.167). Differentiating (5.180) with respect to x and t and substituting (5.179) in it, we obtain
230	the same line as (5.182)	Change $\dot{e}^x(x,t)$ to $e^{x\cdot}(x,t)$
278	five lines above the bottom line	Should read: (.00, .01, .16, .20, .61)
291	bottom line	Change $M(0) =$ to $M(0) +$
315	line 7	Change National to Natural
316	line 9	Change Vol. 14 to Vol. 4
99	one line above the bottom line	Should read: . . . with which we are not
280	eight lines above the bottom line	Should read: . . . $(U_x(x,y,t), U_y(x,y,t))$

CHAPTER 1: THE PROBLEM AND ITS SIGNIFICANCE

1.1 General Introduction

In this dissertation we deal with the distributions over space and over time of the benefits and costs generated by a growing economy with a perfectly competitive market in a closed region. We analyze the mechanisms that determine how the economy develops patterns of distributions which are at variance with a particular distributive judgment called 'weak Social Justice. As used here, weak Social Justice' implies the use of two criteria: (1) that the benefits generated by a growing economy increase at every space point and time point in such a way that the inequality in the spatial distribution of benefits diminishes over time; (2) that the costs generated by a growing economy decrease at every space point and time point in such a way that the inequality in the spatial distribution of costs diminishes over time. Certain policy instruments are then developed so that the economy under study will function in accordance with this particular distributive judgment. The remainder of this section presents the conceptual and theoretical characteristics by which we analyze the distribution aspects of pollution and economic growth.

In its most general sense, we are interested in the case in which the benefits of a growing economy are represented by the consumption of goods (i.e., output of goods minus cost of production). On the other hand, the costs of economic growth are represented only by those costs which are caused by pollution. These pollution costs include the consumption of 'bad' commodities and the decrease in the production of certain goods due to pollution.

More specifically, we are interested in the special case in which economic growth occurs in a dual economy composed of a modernized industrial sector and a traditional industrial sector. Furthermore, we deal with one particular type of pollution in which a modernized industry, sector 1 producing good 1, discharges some toxic material into an environment which a traditional industry, sector 2 producing good 2, depends upon for its production activities. These pollution effects are assumed to be represented by both a decrease in the production of good 2 and the contamination of good 2 with the toxic material.

With respect to the causality of pollution effects, we consider two cases: one in which the cause and effect of pollution are known and the other in which both the cause and effect are unknown. If the causality of these pollution effects is unknown, we assume that there is no way, in a perfectly competitive market economy, for the private sector to screen out the "bad" commodity, i.e., contaminated good 2. However, since causality is unknown, there is also no way for a public authority to intervene in the market so as to eliminate these pollution effects. Therefore, we assume that a "bad" commodity is a necessary byproduct of the production of good 1, for the case in which the causality of the pollution effects is unknown. This assumption is compatible with the assumption of a perfectly competitive market economy in that (1) the supply and demand relationships of goods are controlled only by the price mechanism; (2) all consumers aim to maximize their utility; (3) all producers are cost-minimizers as well as profit maximizers; (4) there exists no technological/or institutional reasons which prevent the market from internalizing the externalities. An example of this situation is the case of cigarette smoking in the USA. The supply and demand relationship in the cigarette industry were hardly disturbed by some scattered scientific evidences showing that cigarette smoking may be the cause of cancer. However, after the Surgeon General's warning in 1966 about the dangers of cigarette smoking as a cause of cancer, the sale of cigarettes dropped sharply, if only temporarily.

On the other hand, if the cause of such pollution effects is fully known, we assume that the "bad" commodity will not be consumed. Because the causality is fully known, it is reasonable to assume that either one of the following two situations occur: (1) sector 1 and sector 2 are able to negotiate that sector 1 should pay sector 2 for compensation in damage done to sector 2 by sector 1's production activities; (2) through the auspicies of a public authority, pollution damages done by sector 1 to sector 2 are compensated by the imposition of unilaterally imposed taxes on sector 1. This assumption is shown in Section 2.2.2 to be compatible with the assumption of a perfectly competitive market economy. In this case, our interest is basically in the increased production costs incurred by sector 2 due to the effects of the pollution created by sector 1.

Finally, we consider two types of space, physical space and non-physical space. Physical space is measured in terms of physical distance such as miles when we deal with one dimensional physical space or in terms of square miles when we deal with two dimensional physical space, etc. Non-physical space, for example, includes the space constructed by a distribution of a population by size of income, the space constructed by a distribution of output per worker, etc. Thus, depending on the choice of space, we may get different distribution patterns of benefits and pollution costs, over space and time, as they are generated in a growing economy. For example, let us consider a population distribution in a certain region. We may plot an income distribution of this region along the one dimensional physical space starting with the center of the region. By taking the average of individual incomes along each circumference, we can plot the average income at each space point which corresponds to the radius of that circumference. On the other hand, we can certainly also order people in this region in terms of their size of income. In this case, a space point along the non-physical space corresponds to a rank-order of an individual by size of income. Thus, it is possible to develop an income distribution of this region along a one dimensional non-physical space. There is no reason to believe that these two types of distributions which are based on physical and non-physical space, should always take the same form.

Based on the above characteristics, we summarize in Table 1.1 four alternative conceptual frameworks for analyzing our problem of the distribution aspects of pollution and economic growth.

Table 1.1 Classification of conceptual framework

Type of Space / Type of Causality	Non-Physical	Physical
Unknown	FRAMEWORK 1	FRAMEWORK 2
Known	FRAMEWORK 3	FRAMEWORK 4

In Framework 1 the causality of pollution effects is unknown and the space is non-physical. In this case, we are interested in the distribution of benefits and pollution costs over non-physical space and time. Specifically, we are concerned with the distribution of the consumption of good 1 and the distribution of the consumption of a "bad" commodity (i.e., the contaminated portion of good 2) over non-physical space and time as generated by a growing economy. In Framework 2, the causality of pollution effects is unknown and the space is real physical space. Our interest is in the distribution of benefits and pollution costs, over physical space and time, generated by a growing economy. In Framework 3, the causality of pollution effects is known and the space is non-physical. We do not consider this case further because the causality of pollution effects is assumed to be traced out only in terms of real physical space. In Framework 4 the causality of pollution effects is known and the space is real physical space. Our interest is in the interrelationships between the production of good 1 and the production of good 2. Specifically, we are interested in the distribution of the consumption of good 1 and the consumption of good 2 over real physical space and time, provided that there is no institutional and/or technological reasons which prevents a perfectly competitive market mechanism from internalizing the pollution costs. These three cases are considered in more detail in subsequent parts of this dissertation.

In order to make our analysis more meaningful and realistic, we apply our conceptual framework to a particular case of mercury pollution that occurred in Minamata, Japan. One of the reasons we choose this case lies in the fact that it represents a unique situation in which the causality of pollution effects was unknown for a long time. Thus, bargaining between sector 1 and sector 2 originally took place under conditions of unknown causality. In particular, we are interested in the implications of our conceptual framework on the analysis of this particular case of pollution. The other reason for applying our theoretical method of analysis to the Minamata pollution problem is that it was this problem that first led the author to do research in this area.

1.2 Introduction to the Minamata Mercury Pollution Case

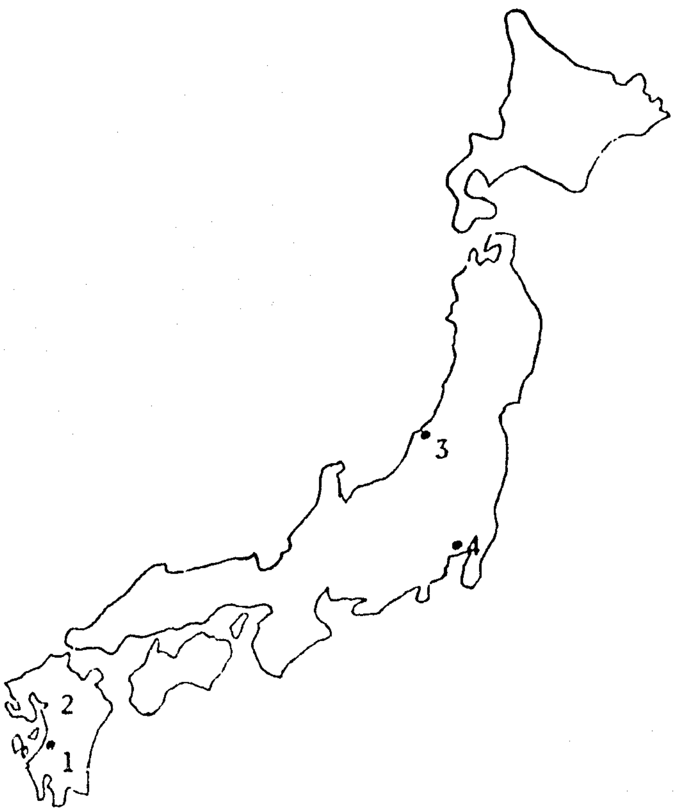
1.2.1 Historical Aspect[1]

In 1953, many cats went into wild gyrations and "dances" and then died in visible agony in two fishing villages near Minamata, a small city facing the Shiranui Sea on the western coast of the island of Kyushu in Japan (see Figure 1.1). In 1954 these abnormalities spread to other fishing villages near Minamata. Some pigs and dogs also apparently went mad and died and even crows fell from the sky.

This was the prelude to "Minamata disease," one of the earliest and most tragic environmental pollution cases that has yet been identified in the world. In May 1956, a medical doctor of the Chisso Company's

1) See Appendix 1 for a detailed history table of Minamata disease. Also, more popular references are: Smith, W. Eugene and Aileen Smith, "Death-flow from a Pipe," LIFE, Vol. 72, No. 21, June 2, 1972; Smith, W. Eugene and Aileen M. Smith, "Minamata, JAPAN," Camera 35, Vol. 18, No. 2, April, 1974, pp. 26-51.

Figure 1.1 Map of Japan



1: City of Minamata

2: Island of Kyushu

3: City of Niigata

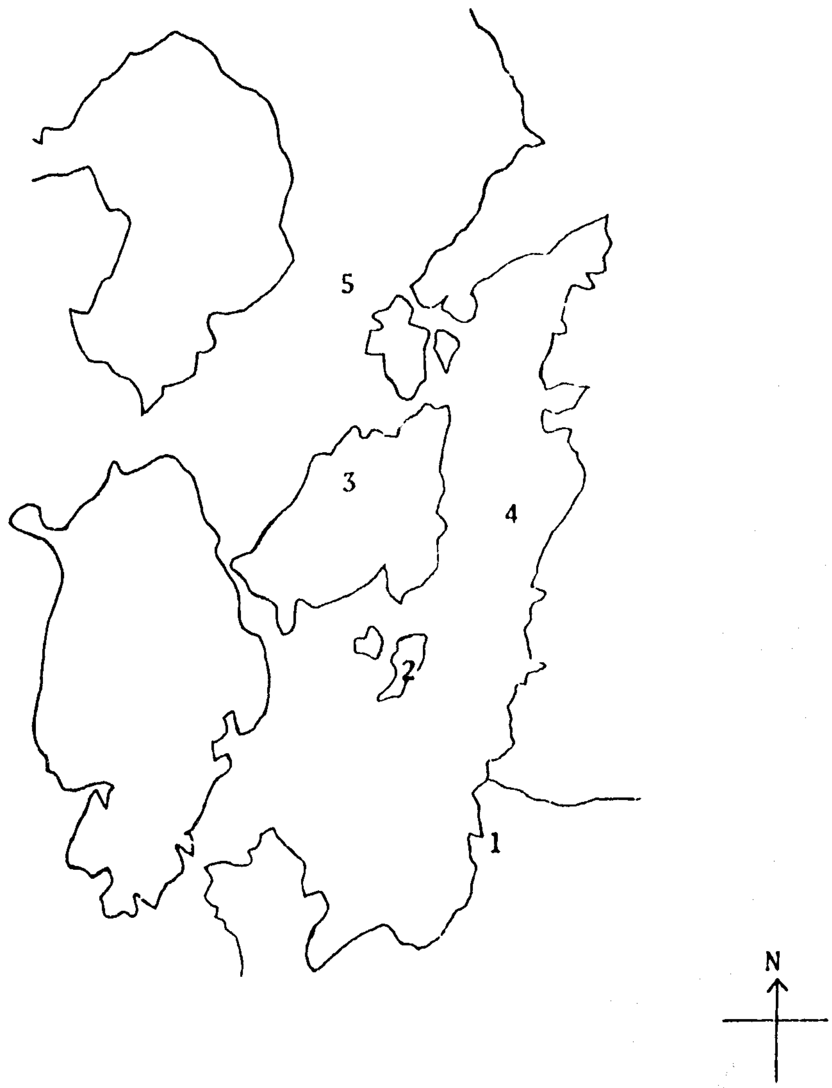
4: Tokyo

Minamata plant hospital reported to the health center of Minamata about a peculiar disease of unknown etiology with such symptoms as brain damage, paralysis, and loss of hearing, speech and sight. Upon the request of the Kumamoto prefectural government (the "state" in which Minamata is located), the Medical School of Kumamoto National University organized the Minamata Disease Research Team which immediately started a full scale investigation to ascertain the cause of the disease.

In July, 1959, after long and difficult probing, Kumamoto University's Research Team announced that Minamata disease was caused by eating fish and shellfish contaminated by organic mercury which may have been contained in the waste water from Chisso's Minamata plant. This announcement prompted the Minamata Fisheries Cooperative, which had suffered from a sudden decrease in the quantity of fish caught in the previous years, to ask for compensation for damage to the fishing ground as well as for construction of an effluent treatment facility. In August of the same year, Chisso and Minamata Fisheries Cooperative reached an agreement in which Chisso paid the Cooperative nearly $100,000 compensation for damages. However, Chisso did not construct any effluent treatment facility.

Meanwhile the abnormalities of the cats spread to the other side of the Shiranui Sea (see Figure 1.2) and new patients appeared in other areas besides Minamata. In October, 1959, the Kumamoto Fisheries Union, on behalf of all of the fisheries cooperatives along the Shiranui Sea, requested that Chisso pay compensation for damages to the fishing ground and halt the Chisso Minamata plant's operation. Shortly after this, Japan's Ministry of International Trade and Industry notified Chisso to

Figure 1.2 Vicinity of Minamata



1: City of Minamata

2: Town of Goshonoura

3: Town of Ariake

4: Shiranui Sea

5: Ariake Sea

improve its waste water treatment facility. This order was based on the newly legislated Water Quality Conservation Law and Factory Effluents Control Law.[2]

Because of the fact that Minamata was, economically and politically speaking, a typical 'one-factory town,' most citizens of Minamata stood firmly behind Chisso and condemned the Fisheries Union's demand for the shut-down of the chemical plant. (For example, about 85 percent of the labour force in manufacturing sector was shared by the employees of Chisso in 1960, while 1 percent of the total labour force was in fishery sector in the same year. Furthermore, about 50 percent of the Minamata's tax revenues came from the Chisso Company and its employees in 1961.) In addition, the existence of alternative theories on the cause of Minamata disease, such as the amine theory and the ammunition theory, also contributed to a settlement of this second dispute in favor of the Chisso Company. In December, 1959, Chisso again paid a total of about $100,000 compensation but this time they also immediately installed a waste purification device. Simultaneously, Chisso also paid a total of about $205,000 to the Minamata disease patients organization for their pension funds and as a solatium. In these agreements, Chisso received a pledge that even if their waste water was officially determined to be the cause of the disease, the fishermen and the patients would not demand any additional compensation. This pledge was to have a significant

---

2) These laws gave the Japanese government the authority to establish effluent standards for certain designated areas but provided no other measures to enforce the standards other than issuing orders demanding improvements of effluent facilities.

implication in the court trial which occurred later, since a medical doctor of Chisso's Minamata plant hospital had already reported to the factory management that his cat experiments showed the cause of Minamata disease to be the plant's waste water. The management has kept his report secret even after the press learned the existence of his report in 1968.

From 1960 through 1964, Minamata disease was generally forgotten by the general public because of the bright news of Japan's successful economy. Meanwhile, researchers at Kumamoto University finally detected organic mercury in the muddy residuum discharged from Chisso's Minamata plant thus verifying the Kumamoto researchers' earlier theory on the cause of the Minamata disease.

The final showdown began in June, 1965, with the outbreak of Minamata disease in the Agano River Basin in Niigata City on Japan's northwest coast (see Figure 1.1). On behalf of the knowledge accumulated by Kumamoto researchers, it did not take long for the Ministry of Health and Welfare to announce that Niigata's Minamata disease was caused by eating fresh water fish which were contaminated by an organic mercury compound which had been discharged from the Kanose plant of the Showa Denko Company into the Agano River.

Meanwhile, Japan's National Diet passed a law to provide officially designated victims of pollution and of pollution related diseases free medical care. They also replaced the age-old pollution control laws by a new Water Pollution Control Law in which any violation of the effluent standards would immediately be penalized. With growing support from the general public, the organization of Minamata disease patients at Niigata brought a lawsuit against the Showa Denko Company. Subsequently the organization of Minamata disease patients at Minamata also brought a lawsuit against the Chisso Company. The former organization won their case in September, 1971, the other in March, 1973. As of August, 1973, there were 602 victims of Minamata disease including 78 deaths in the Minamata region.

1.2.2 Ecological Aspect

Figure 1.3 shows the various mechanisms through which the discharged mercuric compound can be transferred from its source, in this case, the Chisso factory, to the nervous system of human beings. Table 1.2 shows the amount of mercury discharged into waste water by Chisso's Minamata plant from 1932 through 1966. A total of about 81 tons had been discharged into the environment over this period of time. Chisso's Minamata plant used a mercury compound (the concentrated acedic solution of mercury sulfate) as a catalyst in manufacturing acetaldehyde. What proportion of this discharged mercury was inorganic mercury, which does not affect the human nervous system, and what proportion was organic mercury is not yet known. Nevertheless, from the findings of the Kumamoto researchers, we know some portion of the discharge was organic mercury. The organic mercury compounds, particularly, methylmercury, are extremely harmful to humans mainly because of their low excretion rates and their specific attack on the central nervous system. The arrow in Figure 1.3 from Chisso to the hydrosphere represents the amount of methylmercury directly discharged by the plant. However, it has also

Figure 1.3 The passage of methylmercury

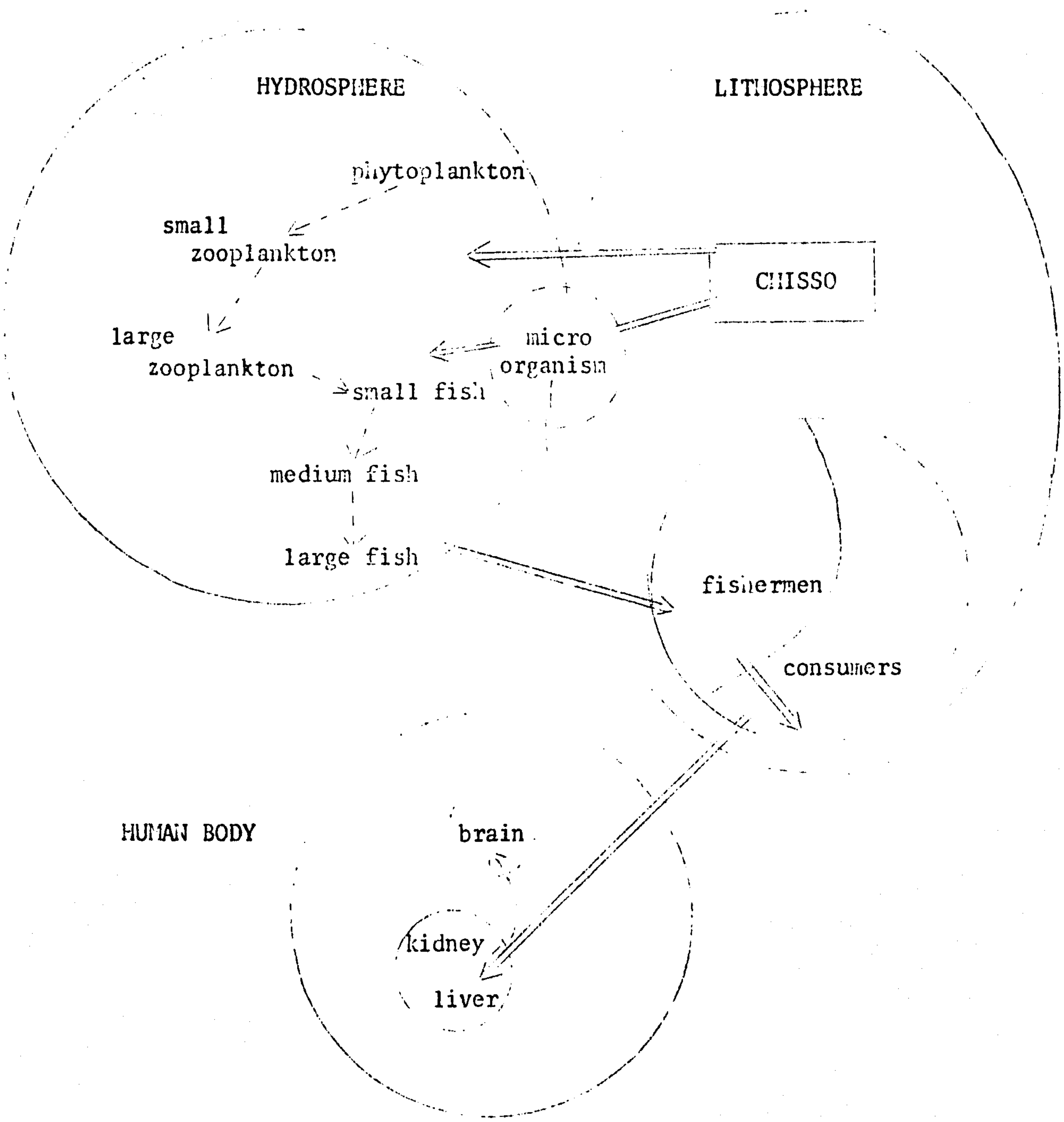


Table 1.2 Production of acetaldehyde and amount of discharged mercury

Year	Production of Acetaldehyde (tons)	Amount of Mercury Discharged into Waste Water (kg)
1932 - 1945	78,922	23,907
1946 - 1953	35,802	12,001
1954*	9,059	2,851
1955	10,633	3,989
1956	15,919	4,678
1957	18,085	6,461
1958	19,436	4,097
1959 (Jan.-March 1960)	42,445	12,910
1960	45,141	4,956
1961	42,437	1,426
1962	24,033	808
1963	41,027	1,803
1964	26,581	764
1965	17,960	614
1966	16,115	37
RECYCLING SYSTEM OF WASTE WATER WAS COMPLETED IN JUNE 1966		
1967	11,961	0
1968	783	0
TOTAL	456,352	81,302

* Data for 1954 through 1958 are for calendar years and data for 1960 through 1968 are for fiscal years. The fiscal year begins April 1 and ends March 31, the following year.

een proved[3] that micro-organisms in mud may transform inorganic mercury into two organic mercury compounds, monomethyl- and dimethyl-mercury. This process is indicated by another arrow from Chisso to hydrosphere.

Once methylmercury gets into the hydrosphere, it is suspected of being transferred upward through the food chain of an aquatic environment, beginning with the first trophic level of phytoplankton and ending with the highest trophic level of the human being. Furthermore, the concentration of methylmercury may increase at an alarming rate as the trophic level increases. Although this biological magnification theory has not yet been verified in an aquatic ecosystem, its general validity has been well documented since the publication of "Silent Spring."[4] A typical explanation of this phenomenon is the "10 percent rule" of ecological efficiency originally presented by Lindeman.[5] According to this rule, roughly speaking, 10 percent of the energy captured by any one trophic level will be passed on to the next trophic level. If there are four trophic levels in a food chain, the last trophic level will capture 0.1 percent of the total energy captured by the first trophic level. But this rule can be applied only in the case of food, not in the case of metals which may be found in the food. In other words, it

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3) Wood, J. M., F. S. Kennedy, and C. G. Rosen, "Synthesis of methylmercury compounds by extracts of a methyanogenic bacterium," Nature, Vol. 220, October 12, 1968, pp. 173-74.

4) Carson, Rachel, Silent Spring, Fawcett Publications, Greenwich, Conn., 1962.

5) Lindeman, Raymond L., "The Trophic-Dynamic Aspect of Ecology," Ecology, Vol. 23, 1942.

is hypothesized that although about 90 percent of the captured energy will be dissipated as heat and only 10 percent of it stored in the animal's flesh, any amount of toxic metal such as mercury never disappeared as heat. The accumulation effect plus the long "half-life" of mercury results in an increasing concentration of mercury along the food chain.

Even if we do not agree with the validity of the above biological magnification process in an aquatic ecosystem, there is ample evidence[6] that fish may absorb toxic substances such as insecticides directly from water possibly through their skin or gills. In spite of Reinert's conclusion that the accumulation of insecticides via the food chain is negligible in aquatic ecosystem, Figure 1.4 shows clearly how important a role the biological magnification mechanism played in the Niigata mercury pollution case. On the horizontal axis, the distance from the mouth of the Agano river is measured in kilometers. The river in Figure 1.4 is shown to flow from right to left. The Kanose plant, which discharged mercury into the river, is located at a point 60 km on the horizontal axis. On the upper-hand vertical axis, the mercury content in fish is measured in parts per million wet basis.[7] The figure shows that downstream fish concentrate mercury more than upstream ones, while exactly the riverse result holds for benthos organism (the lower scale).

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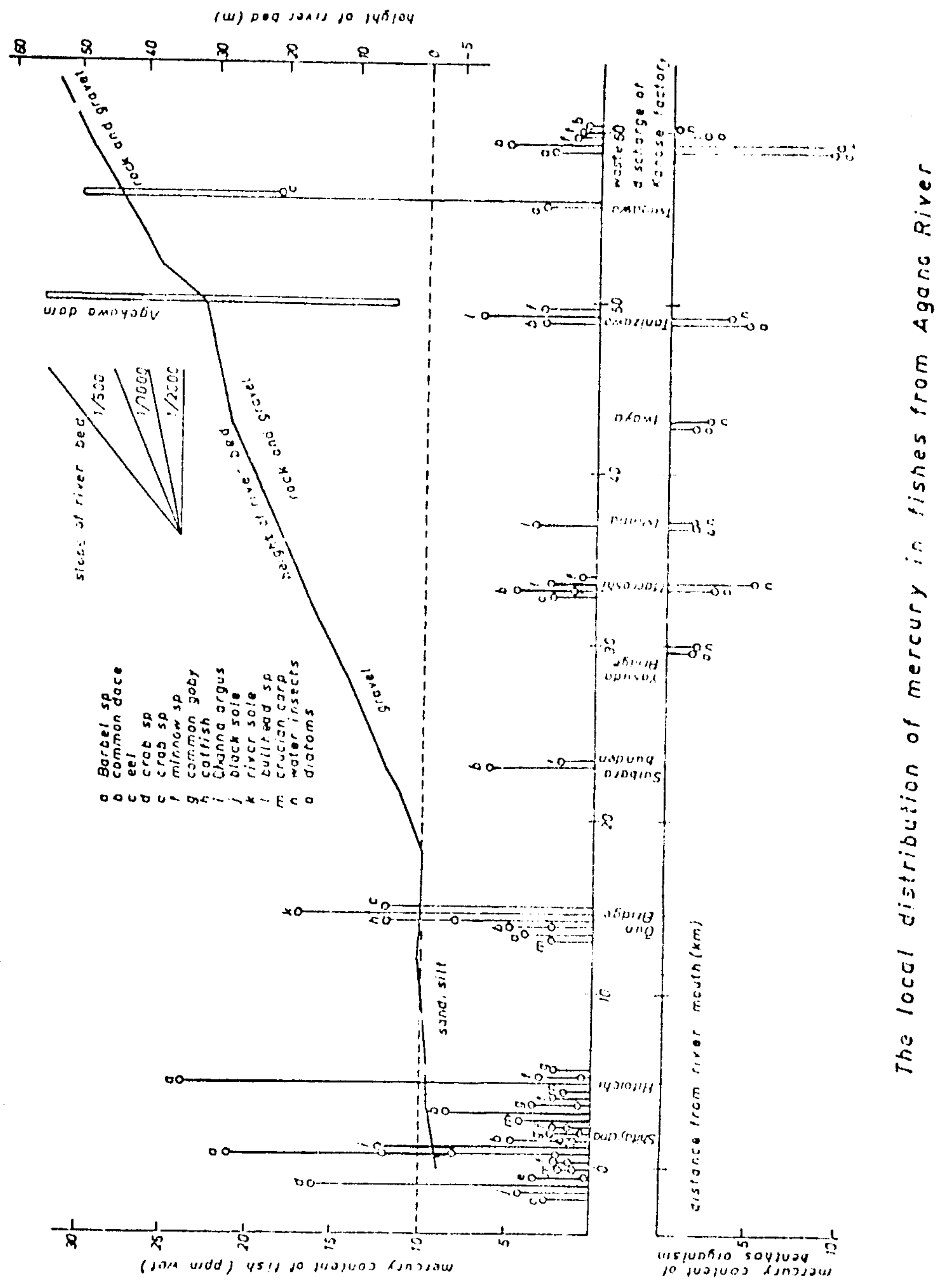
6) See, for example, Reinert, R., The Accumulation of Dieldrin in an Alga, Daphnia, Guppy Food Chain, Ph.D. Dissertation, The University of Michigan, 1967.

7) Wet basis refers to the situation in which the samples are analyzed as they are. Fresh fish are often analyzed on wet basis. On the other hand, some samples such as shellfish and algae must be dried first in order to prevent rottenness. In this latter case, we say that the samples are analyzed on dry basis. (The author is indebted to Dr. M. Fujiki for the above information.)

Figure 1.4 **Distribution of mercury in fish and Benthos organisms along the Agano River**



Reprinted from Figure 7 in Jun Ui, "Mercury Pollution of Sea and Fresh Water: Its Accumulation into Water Biomass," <u>Revue Internationale D'Oceanographie Medicale</u>, Vol. 22-23, 1971.

If the high concentration of mercury in fish is caused solely by the direct intake of mercury from water through skin or gills, the distribution of the mercury content in fish should have taken its peak near the discharging point where the concentration of mercury in water is highest. These results indicate that the biological magnification mechanism may be at work in aquatic ecosystems and, particularly in the case of a river ecosystem, the mercury concentration in fish seems to be related to the physical distance considered from the discharging point.

As shown in Figure 1.3, we assume that a portion of the fish caught by commercial fishermen are consumed by the fishermen and their families and the rest are sold to other consumers. Once a human being eats fish contaminated by methylmercury, it remains primarily in the parenchymatous organs such as the kidneys and liver. However, some passes through the blood-brain barrier and inflicts severe toxic effects on the nerve cells.[8] Some intensive studies have been going on at Kumamoto National University on the elucidation of the mechanism by which methylmercury is transported from the parenchymatous organs to the brain.

We have identified at least conceptually how the discharged mercuric compound can be transferred from its industrial source to the human being through the trophic levels of the food chain. This also explains why the prelude to Minamata disease was exhibited by various symptoms in cats, pigs, dogs, and crows. Since these animals are situated on the lower trophic levels of the food chain than the trophic level which the human occupy.

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8) Takeuchi, T., "Biological reactions and pathological changes in human beings and animals caused by organic mercury contamination," in <u>Environmental Mercury Contamination</u>, edited by R. Hartung and B. Dinman, Ann Arbor Science Publishers, Ann Arbor, Mich., 1971.

1.3 Abstraction of the Minamata Pollution Problem

In this section we show the relationships of the Minamata pollution case described in Section 1.2 to the more abstract problem described in Section 1.1. Recall that this more abstract problem deals with the distribution over space (physical and/or non-physical) and over time of the benefits and pollution costs generated by a growing economy with a perfectly competitive market in a closed region.

1.3.1 The Case of Unknown Causality and Non-Physical Space (Framework 1)

First, we look at the Minamata mercury pollution case from the viewpoint that the causality of the pollution effects is unknown. In this instance, we are interested in the consumption of a "bad" commodity such as contaminated fish. However, there are no data available from Minamata or other affected areas on how much contaminated fish people have consumed in any given time interval. Instead we must resort to the use of a proxy variable for the consumption of contaminated fish. We use the number of Minamata disease patients as such a proxy variable.

Table 1.3 shows the occupational distribution of patients with Minamata disease in the city of Minamata. In the time interval 1953-1957, approximately 58 percent of the total number of 87 patients are from the category of fishermen. In the time interval 1958-1959, the results are more distinctive. Approximately 73 percent of the total of 30 newly found patients are from the stated category. Table 1.4 shows the occupational distribution of patients detected by a general medical examination held in three different areas between August 21, 1971, and March 14, 1973. The percentage of fishermen category in Minamata dropped from 58 percent

Table 1.3 Occupational distribution of Minamata disease patients in Minamata

	1953 - 1957*			1958 - 1959*		
	Total No. of Patients	%	No. of Deaths	Total No. of Patients	%	No. of Deaths
Fishermen (Including Their Families)	51	58.6%	19	22	73.3%	10
Farmers (Including Their Families)	8	9.2	2	1	3.3	1
Retail	0	0	0	0	0	0
Other Manufacturing	6	6.9	0	2	6.7	0
Chemical (Chisso Employees)	3	3.5	1	0	0	0
Others	19	21.8	9	5	16.7	1
TOTAL	87	100.0%	31	30	100.0%	12

* The time interval indicates the period within which patients first showed symptoms of Minamata disease. In the period 1953-1957, three out of the total of 87 patients are double counted as fishermen and farmers.

Table 1.4 Occupational distribution of patients with Minamata disease detected by a general medical examination held between August 21, 1971, and March 14, 1973*

Area / Occupation	Minamata		Town of Goshonoura		Town of Ariake	
	No. of Patients	%	No. of Patients	%	No. of Patients	%
Fishermen	75	33.9	17	47.2	8	80
Farmers	38	17.2	7	19.4	2	20
Retail	8	3.6	2	5.6	0	0
Other Manufacturing	20	9.0	0	0	0	0
Chemical (Chisso Employees)	22	10.0	0	0	0	0
Others	58	26.3	10	27.8	0	0
Total with Minamata Disease	221[a]	100.0	36[b]	100.0	10[c]	100
Total No. of Examinations	1278		1856		931	

* A general medical examination was held in three regions in the city of Minamata and in three regions in the town of Goshonoura, both of which had been suspected of having many undetected Minamata disease patients. As a control area, three regions in the town of Ariake were selected and a general medical examination was also held.

a) Six out of total 221 patients are double counted as fishermen and farmers.

b) Two out of total 36 patients are double counted as fishermen and farmers.

c) Two out of total 10 patients are double counted as fishermen and farmers.

in 1953-1957 (Table 1.3) to 33.9 percent in 1971-1973 (Table 1.4). Accordingly, the number of patients with Minamata disease in other categories increased in this same time span in the city of Minamata.

From Table 1.3 and Table 1.4, it is not unreasonable to assume that there has been a diffusion of Minamata disease in the city of Minamata over the occupational distribution of workers such as from fishermen to farmers, to retailers, to industry employees. If we can somehow order occupational category on some non-physical space, then our inference is that there has been in the city of Minamata a diffusion of Minamata disease over a non-physical space over time.

Table 1.5 shows the breakdown of Minamata disease patients in three areas in terms of the time intervals within which patients first showed symptoms of Minamata disease. Detection was by a general medical examination held in the city of Minamata and in the towns of Goshonoura and Ariake. As shown in Figure 1.2, Goshonoura is on an island 16.5 km across the Shiranui Sea from Minamata. On the other hand, Ariake is located northwest of Goshonoura and faces the Ariake Sea. These two urban areas can be arranged in terms of their physical distance from Minamata. On a scale with Minamata as the base, Goshonoura would be second (about 16 km from Minamata) and Ariake third (about 30 km from Minamata). Then Table 1.5 indicates that at each time period the number of patients with Minamata disease decreases as physical distance from the city of Minamata increases. On the other hand, the proportion of Minamata disease patients in the city of Minamata decreases as time increases. That is, in the time interval 1941-1951, all of the total number of 10 Minamata disease patients are from Minamata. In the

Table1.5 Distribution over three consecutive time intervals of Minamata disease patients detected by a general medical examination held between August 21, 1971, and March 14, 1973, where each time interval indicates the period within which patients first showed symptoms of Minamata disease

Time Interval / Area	1941-1951		1952-1962		1963-1972	
	No. of Patients	%	No. of Patients	%	No. of Patients	%
City of Minamata	10	100%	172	92.5%	87	80.55%
Town of Goshonoura	0	0	14	7.5	15	13.9
Town of Ariake	0	0	0	0	6	5.55
TOTAL	10	100%	186	100%	108	100%

time interval 1952-1962, 92.5 percent of the total number of 186 Minamata disease patients are from Minamata and the rest are from Goshonoura. The percentage of Minamata disease patients in Minamata dropped from 92.5 percent in 1952-1962 to 80.55 percent in 1963-1972. Accordingly, the percentage of Minamata disease patients in Goshonoura and in Ariake increased respectively from 7.5 percent in 1952-1962 to 13.9 percent in 1963-1972 and from 0 percent in 1952-1962 to 5.55 percent in 1963-1972. Hence from Table 1.5 we may infer that the diffusion of Minamata disease has taken place over physical space over time.

Table 1.4 also shows that in every occupational category the number of patients with Minamata disease decreases with the increase in the physical distance from the city of Minamata. Therefore, Table 1.4 and Table 1.5 suggest that the diffusion of Minamata disease has taken place over physical space, over a non-physical space, and over time, provided that we can order each occupational category on a non-physical space axis. However, we are unable to verify this last inference, i.e., over physical space, over non-physical space, and over time. Unfortunately, data are not available at this writing on the occupational distribution of Minamata disease patients in the towns of Goshonoura and Ariake at two different time points.

In sum, we have inferred from Table 1.3, Table 1.4, and Table 1.5 two diffusion hypotheses: (1) a diffusion of Minamata disease has taken place in the city of Minamata over a non-physical space over time; (2) a diffusion of Minamata disease has taken place over physical space over time. Our ultimate interest is to find an economic mechanism to explain and analyze these diffusion phenomena (see Chpater 4). In the meantime, we briefly pinpoint some practical reasons for these two diffusion hypotheses.

First, we consider the question of why fishermen are the most numerous victims of Minamata disease? Table 1.6 shows the difference in nutritional characteristics between a Minamata fisherman selected at randon and an average Japanese. One significant difference between them lies in the fact that the fisherman consumes more than four times as much fish as an average Japanese. Because many fish in the Minamata region have been contaminated by methylmercury, we can safely say that fishermen are more vulnerable to Minamata disease than workers in other category. Furthermore, because of the relatively high prices of meat and dairy products, poorer people are more dependent on fish for a source of animal protein. This may explain why in Table 1.3 and Table 1.4 the occupational categories of the poor such as fishermen and farmers have more patients with Minamata disease than the more affluent occupational categories such as employees of the Chisso Company.

Second, we consider the question of why the number of patients with Minamata disease decrease with increasing distance from the city of Minamata. This is due mainly to the fact that as one goes farther away from Minamata, fish are less contaminated by mercury and methylmercury. According to Kumamoto researchers' recent findings,[9] fish contain on the average 0.475 PPM of mercury (wet basis) in the Bay of Minamata,

9) See Table 33 on page 80 in Epidemiological, Clinical and Pathological Studies of Minamata Disease After a Decade (in Japanese), Unpublished report by Study Group of Minamata Disease at Kumamoto National University, 1973.

Table 1.6 Per capita nutrients per day of a Minamata fisherman and an average Japanese (per grams)

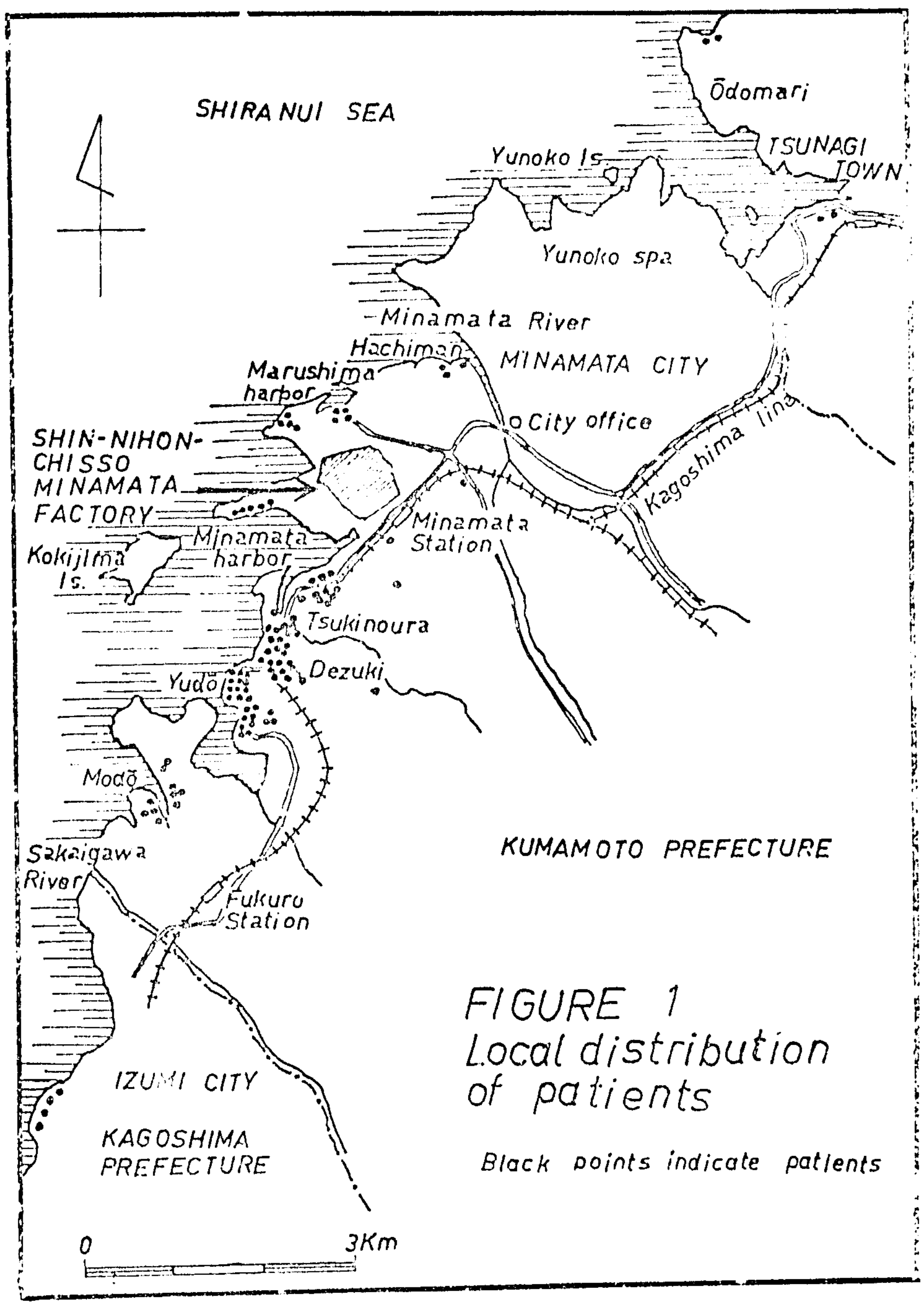
	One Minamata Fisherman* (Aug., 1972)	An Average Japanese (1971)
Cereals	468	374.7
Potatoes	32	38.8
Sugar and confectionery	30	57.0
Fats and Oils	23	17.3
Nuts and Pulses	22	72.9
Vegetables	396	268.6
Fruit	245	110.5
Seaweeds	0	6.8
Condiments and Beverages	138	140.2
Fish and Shellfish	410	84.2
Meat, Eggs, and Milk	88	162.6
Dairy Products and Processed Food	0	25.5
TOTAL	1,613 g	1,359.1 g

* When the data was taken in August, 1972, this fisherman lived near the city of Minamata and his age was then 45 years old. See for data source Appendix 9.

0.066 PPM (wet basis) of mercury near the town of Goshonoura, and 0.033 PPM (wet basis) of mercury near the town of Ariake.

In utilizing these data in Table 1.3, Table 1.4, and Table 1.5, we may employ either Framework 1 or Framework 2 of Table 1.1. However, there is a practical reason which prevents us from using Framework 2: the towns of Goshonoura and Ariake, particularly the latter, can hardly be grouped together with Minamata to form a closed economy. Therefore, we employ only Framework 1 by fixing a physical space point to be the administrative area of the city of Minamata as shown in Figure 1.5. Then the diffusion process of Minamata disease is considered to be taking place over time and over a social space which is, in this case, composed of different occupational groups or different economic sectors. We can order various economic sectors in terms of the ratio of the number of Minamata disease patients belonging to an economic sector to that sector's labour force, that is, in terms of patients per worker. For example, the larger the number of patients per worker the farther away from the origin that sector is located. Alternatively, we may order along the social space axis different economic sectors in terms of the ratio of a sectorial value of output to that sector's labour force, that is, in terms of value of output per worker. The smaller the value of output per worker the farther away from the origin. If these two different sequences generate the same ordering of economic sectors along each social space, we have an ideal case in which we can use one social space to represent the two distributions. If not, we have to prefer one to the other. As we shall soon see, the available data we can obtain from Minamata suggests that we must use the latter case. Therefore, we order the economic sectors in terms of value of output per worker.

Figure 1.5 The administrative area of the city of Minamata



Reprinted from Jun Ui, "Mercury Pollution of Sea and Fresh Water: Its Accumulation into Water Biomass," Revue Internationale D'Oceanographie Medicale, Vol. 23-23, 1971.

Table 1.7 showing the value of output per worker by economic sector has six columns and two rows. The second column shows the economic sectors ordered in terms of increasing value of output per worker (the data in column 6). The third column shows the sectorial total value of output; the fourth, the sectorial labour force, N_i; the fifth, the sectorial share of total labour force, N_i/N; and finally, the sixth column, value of output per worker by economic sector. The data shown are for two time points. As can be seen from this table, the ordering of economic sectors in terms of value of output per worker is different for 1957 and 1971. In spite of this fact, we shall maintain the initial ordering made in terms of 1957 data since this change in sequence is not important to the definition of our problem. Table 1.7 (bottom) also shows the values of two types of inequality measures,[10] Theil's inequality measure and the Gini index, both of which indicate the decrease of inequality measures from 1957 to 1971.

Table 1.8 shows patients per worker corresponding to each economic sector ordered in terms of increasing value of output per worker. Both Theil's inequality measure and the Gini index again indicate the decrease of inequality in patients per worker among economic sectors from 1957 to 1971.

Now, we summarize the first rows of Tables 1.7 and 1.8 in Figure 1.6 and the second rows of Tables 1.7 and 1.8 in Figure 1.7. In both figures, each economic sector is ordered in terms of the 1957 value of output per worker (Table 1.7) decreasing along the horizontal or social

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10) See Appendix 2 for these computations.

Table 1.7 Value of output per worker by economic sector

Year	Sector	Value of Output	Labour Force N_i	N_i/N	Value of Output Per Worker Y_i
1957	Fishery	$ 10,510	224	0.0163	$ 46.92
	Agriculture	$ 698,152	5,707	0.4163	$ 122.33
	Other Manufacturing	$ 2,610,980	1,572	0.1146	$ 1,660.92
	Retail	$ 5,380,577	2,559	0.1867	$ 2,102.60
	Chemical	$22,570,022	3,644	0.2658	$ 6,193.74
1971	Fishery	$ 637,364	182	0.020	$ 3,501.9
	Agriculture (1970)	$ 2,844,444	3,680	0.409	$ 772.94
	Other Manufacturing	$22,249,194	1,909	0.212	$11,654.00
	Retail	$22,775,680	2,152	0.239	$10,583.49
	Chemical	$26,753,694	1,066	0.118	$25,097.27

Theil's Inequality Measure I_y (1957) = 0.26609 I_y (1971) = 0.1997

Gini's Index G_y (1957) = 0.57188 G_y (1971) = 0.4974

Table 1.8 Patients with Minamata disease per worker by economic sector

Year	Sector	No. of Patients	Labour Force N_i	N_i/N	Patients Per Worker q_i
1957	Fishery	51	224	0.0163	0.2276
	Agriculture	8	5,707	0.4163	0.0014
	Other Manufacturing	6	1,572	0.1146	0.0038
	Retail	0	2,559	0.1867	0
	Chemical	3	3,644	0.2658	0.0008
1971	Fishery	75	182	0.020	0.41208
	Agriculture	38	3,680	0.409	0.01032
	Other Manufacturing	20	1,909	0.212	0.01047
	Retail	8	2,152	0.239	0.00371
	Chemical	22	1,066	0.118	0.02063

Theil's Inequality Measure I_q (1957) = 1.14632 I_q (1971) = 0.687668

Gini's Index G_q (1957) = 0.7988 G_q (1971) = 0.5805 space axis. Since each economic sector occupies a fixed portion of the space axis which is proportional to its share of total labour force, the labour force density along the space axis is uniform in both Figures 1.6 and 1.7. In both figures, the left vertical axis measures in dollar terms the value of output per worker and the right vertical axis the number of patients with Minamata disease per worker by sector.

From Tables 1.7 and 1.8, or equivalently, Figures 1.6 and 1.7, and the values of the inequality measures, we notice that:

(1.4.1a) the value of output per worker increased from 1957 to 1971 at every space point (in the social space);

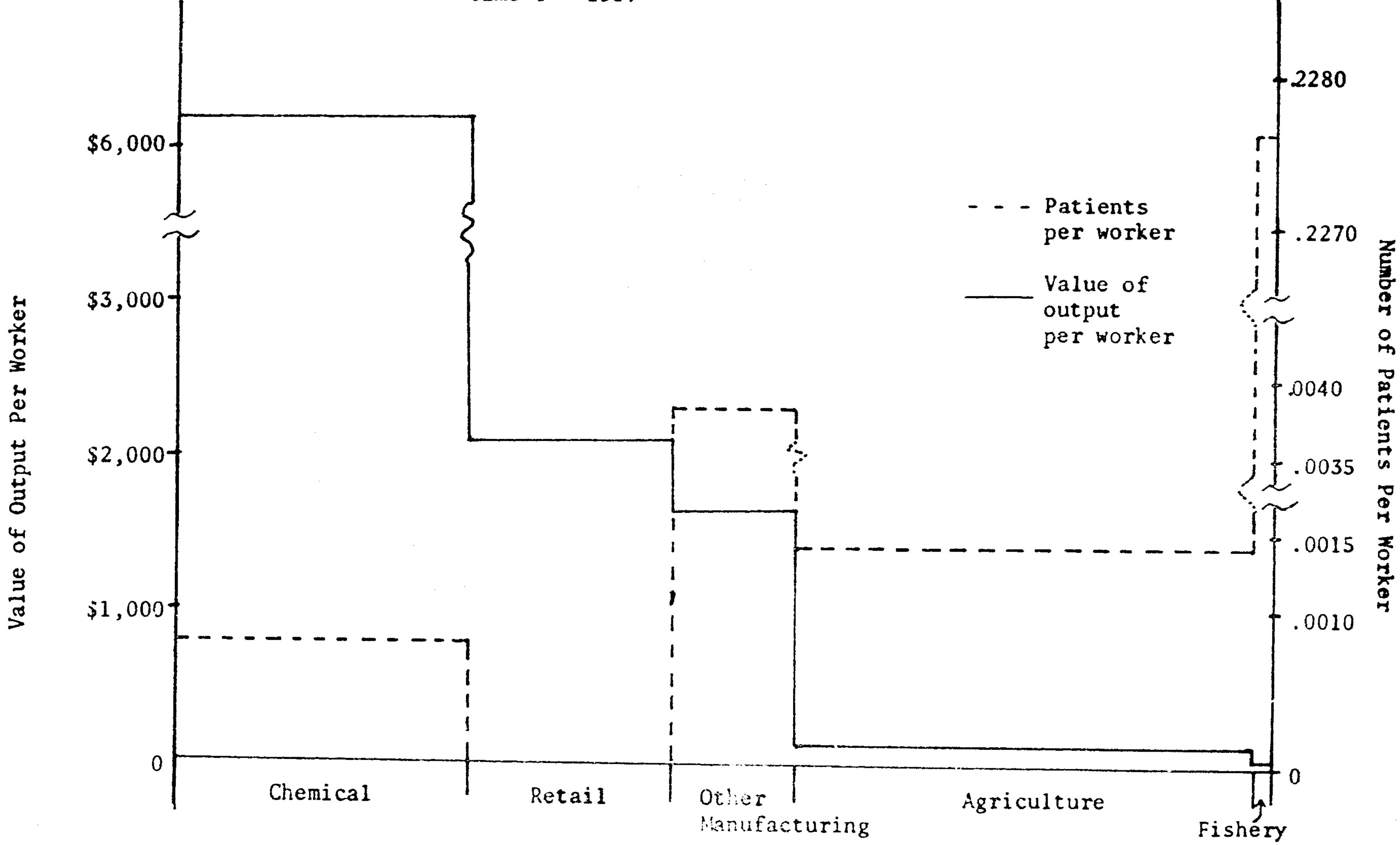
(1.4.1b) the inequality measure of value of output per worker decreased from 1957 to 1971;

(1.4.2a) the number of patients with Minamata disease per worker by sector increased from 1957 to 1971 at every space point (in the social space);

(1.4.2b) the inequality measure of number of patients with Minamata disease per worker decreased from 1957 to 1971.

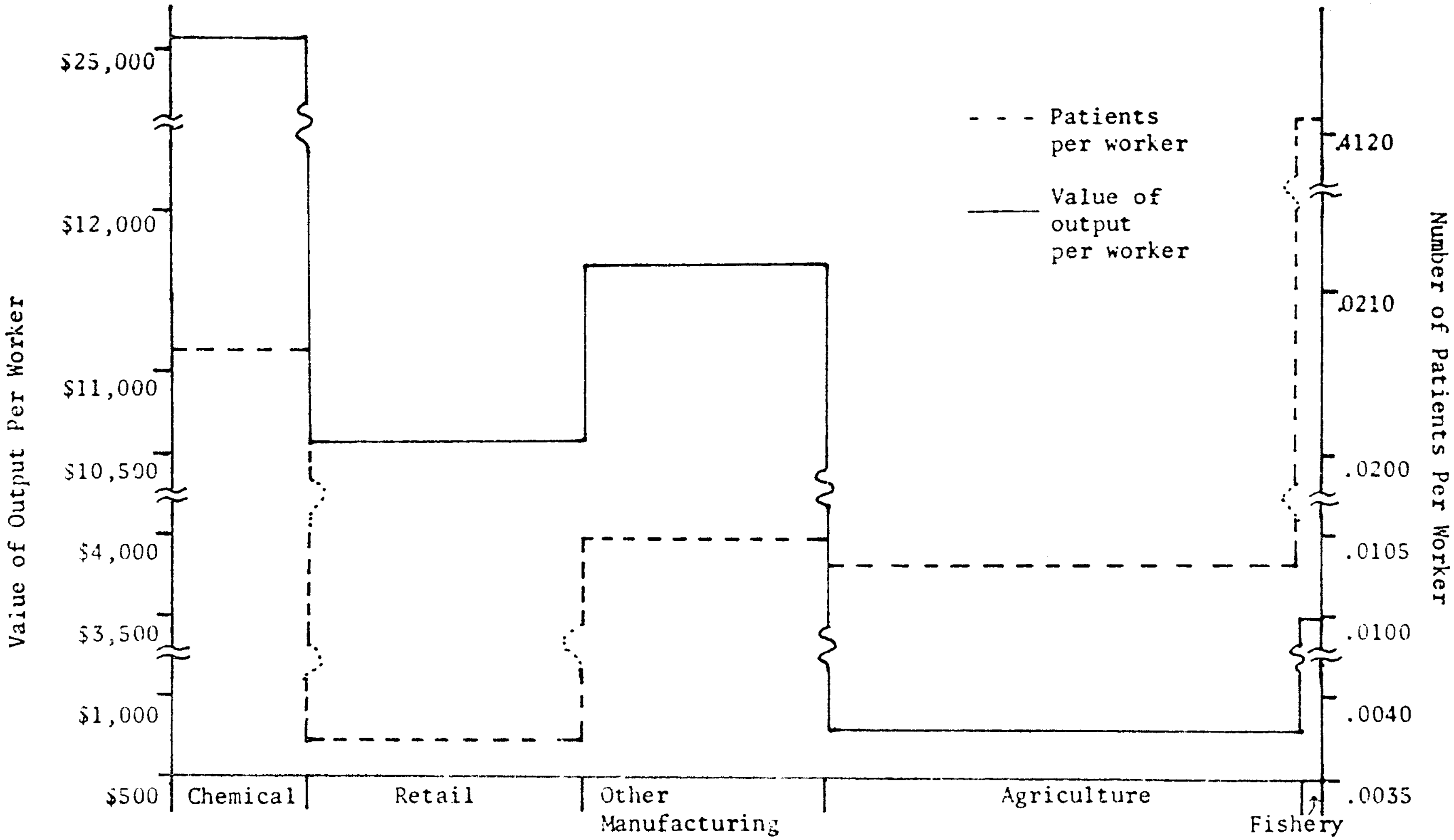
(1.4.1a) and (1.4.1b) are clearly in accordance with our particular distributive judgment "weak Social Justice" discussed in Section 1.1. A benefit (the value of output per worker) generated by Minamata's growing economy increased at every space point (in a social space) and time point in such a way that the inequality in the spatial distribution of this benefit diminished over time. Hence, (1.4.1a) and (1.4.1b) imply that, generally speaking, people in Minamata are better off now than before. On the other hand (1.4.2a) and (1.4.2b) do not fully satisfy

Figure 1.6 **Distribution of value of output per worker and Minamata disease patients per worker over non-physical space at time t = 1957**



(The space along the x-axis occupied by each sector is proportional to the labour force in that sector)

Figure 1.7 Distribution of value of output per worker and Minamata disease patients per worker over non-physical space at time t = 1971



the weak Social Justice criteria. A cost (the number of patients with Minamata disease per worker) generated by Minamata's growing economy did not decrease at every space point (in a social space) and time point, although the inequality in the spatial distribution of the cost diminished over time. That is (1.4.2b) implies that the suffering is shared more equally now than before, while (1.4.2a) indicates that the suffering increased at every space point over time. Therefore, the first problem we deal with (Problem 1--the case of unknown causality and non-physical space) can be defined as follows:

Problem 1.A) Under what conditions could the situation described in (1.4.1a) through (1.4.2b) occur in Minamata? (i.e., the improvement in distribution of the value of output coupled with the diffusion of Minamata disease over a social space over time).

Problem 1.B) Was it necessary that (1.4.2a) occur in order to achieve (1.4.1a)? In other words, was it necessary in Minamata's growing economy to increase the cost (the number of patients per worker) in order to increase the benefit (the value of output per worker)?

Problem 1.C) If 1.B is true, why?

Problem 1.D) Are there any policies which may eliminate the possibility of (1.4.2a) while maintaining (1.4.1a), (1.4.1b) and (1.4.2b)?

We restate this problem in more technical terms at the beginning of Chapter 4.

1.3.2 The Case of Known Causality and Physical Space (Framework 4)

We now look at the Minamata mercury pollution case from the viewpoint that the causality of pollution effects is known. We are interested in the interrelationships between the production of good 1 (i.e., the production of acetaldehyde, which creates a pollutant, and the production of good 2 (i.e., the production of fish), which is contaminated by this pollutant. Because causality is known, these contaminated fish are not consumed, i.e., they do not appear in the market place.

Table 1.2 in Section 1.2.2 shows the production of acetaldehyde in Chisso's Minamata plant and the amount of mercury discharged into waste water. Most of this mercury is still in the Bay of Minamata at this writing. Table 1.9 shows the size of the Minamata fisheries annual catch from 1954 to 1958 and their annual growth rates all of which are negative. Part of the data of Table 1.2 and 1.9 are plotted in Figure 1.8. This figure shows the effect of metallic pollution on the activities of the fisheries. Table 1.10 shows the distribution of Minamata fishermen over physical space not the social space. Space point 0 indicates the location of the discharging point of mercury contaminating waste water which is just outside of Chisso Minamata plant. Space point 1 through 7 indicate the names of the fishing villages which are also shown in Figure 1.5 of the administrative area of the city of Minamata. These space points are increasing distances from the discharging point. Now we may construct in Figure 1.9 the physical space axis with space point 0 at the origin. The right vertical line indicates the amount of fish caught at each space point divided by labour force of that space point. Then this size of fish catch

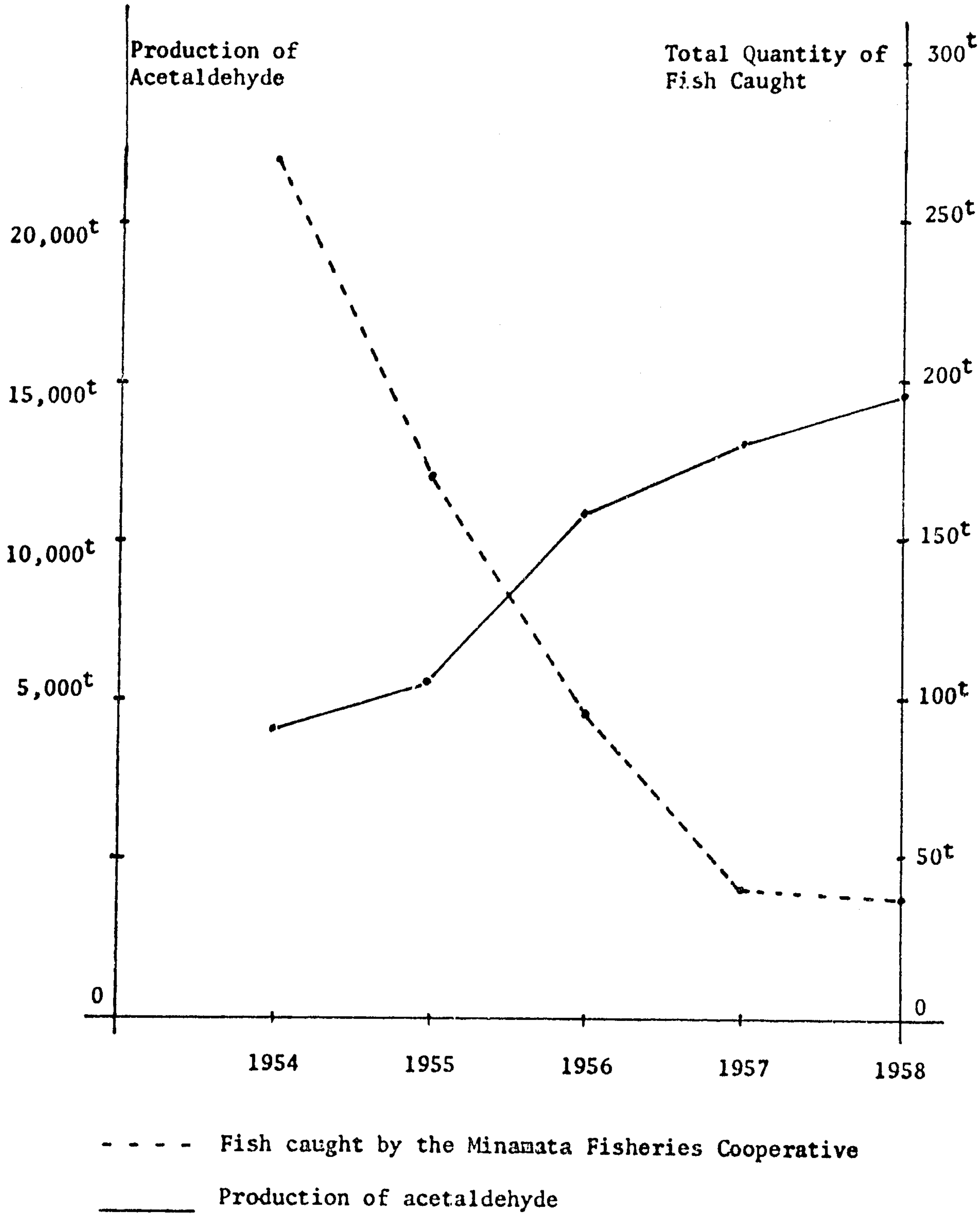
Table 1.9 Fish caught by the Minamata fisheries cooperative

Year	Total quantity of Fish Caught (kg)	% Change in Quantity of Fish
1954	279,435	- 38.3
1955	172,305	- 44.51
1956	95,598	- 57.51
1957	40,560	- 2.04
1958	39,731	- 2.04

Table 1.10 Distribution of fishermen over physical space

Space Point	0 Discharging Point	1 Umedo	2 Marushima	3 Tsukino-Ura	4 Funazu	5 Yudo	6 Modo	7 Yunoko
No. of Fishermen	0	23	82	49	44	52	85	23
Labour Force	?	?	?	?	?	?	?	?

Figure 1.8 **Production of acetaldehyde and fish caught by the Minamata fisheries cooperative, 1955-1958**



per worker may take the shape[11] of a monotone increasing function over physical space (see Figure 1.9). Although the author has no data to verifiy this monotoner increasing function, his personal observation of this area reveals that the ratio of fishermen to the labour force is higher as you go further away from the center of the city of Minamata. This appears to be so since most industries are concentrated at the origin, i.e., the center of the city of Minamata. Therefore, if we assume the equal productivity of fishermen, then

$$\frac{\text{size of fish catch}}{\text{size of labour force}} = \frac{\text{size of fish catch}}{\text{number of fishermen}} \times \frac{\text{number of fishermen}}{\text{size of labour force}}$$

That is, the size of the fish catch per worker becomes proportional to the ratio of fishermen to labour force which is likely to take the form of a monotcne increasing function, although we do not have data on labour force at each physical space point. This may justify the positively sloped curve in Figure 1.9. The left vertical line in Figure 1.9 measures the per worker acetaldehyde production, the curve of which is negatively sloped along the physical space axis, since the number of workers working for the production of acetaldehyde will decrease with physical distance from the origin. Combining Figure 1.8 and Figure 1.9 we get Figure 1.10, in which the size of fish catch per worker is decreasing with time at every space point while the per worker acetaldehyde production is increasing with time at every space point.

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11) For convenience, the curve is drawn in continuous form.

Figure 1.9 Distributions of size of fish catch per worker and per worker acetaldehyde production over physical space

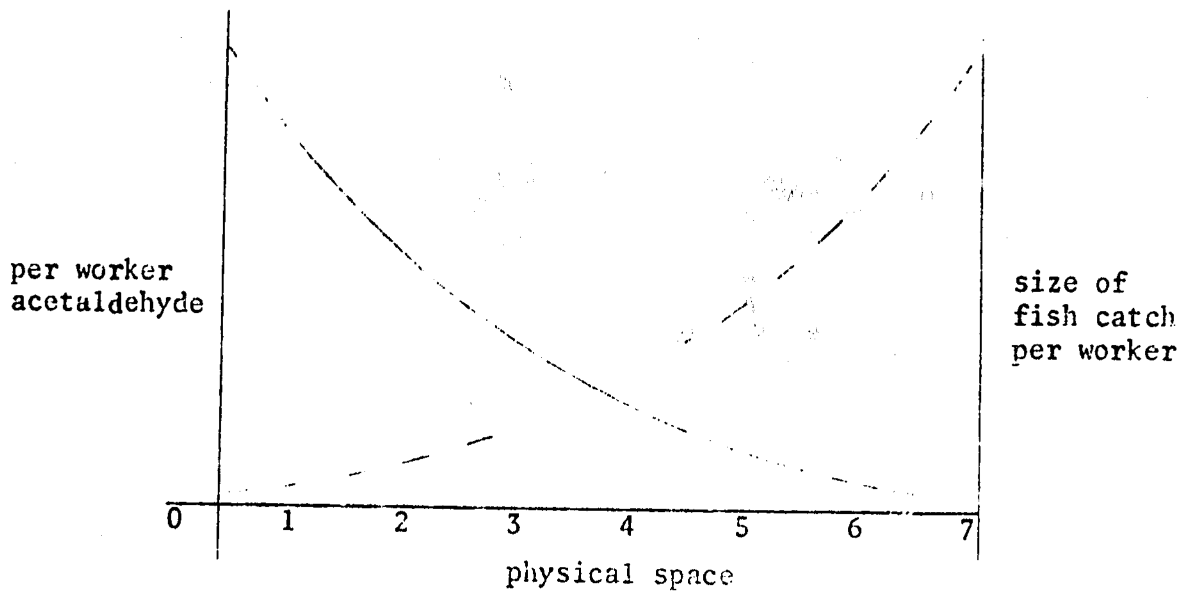

Figure 1.9

Distributions of size of fish catch per worker and per worker acetaldehyde production over physical space

\- - - size of fish catch per worker

_____ per worker acetaldehyde production

This gives rise to our second problem (Problem 2--the case of known causality and physical space):

Problem 2A) Figure 1.10 shows the steady decrease in size of fish catch per worker along the physical space as contrasted with the steady increase in per worker acetaldehyde production along the same physical space. Under what conditions can this situation occur?

Problem 2B) Are there any policies which may correct this kind of situation? Such policies must be based on appropriate objectives.

We restate this problem in more technical terms at the beginning of Chapter 5.

Before going on to the next section, we discuss the realism of our adopted Frameworks 1 and 4 (see Table 1.1) in analyzing Problems 1 and 2 as described above.

Framework 1 assumes that the causality of pollution effects is unknown and space is non-physical. Specifically speaking, the causality of Minamata disease is assumed to be unknown. In stating Problem 1, we have implicitly assumed that Framework 1 is still valid for the 1973 data on the occupational distribution of Mianmata disease patients. However, as Section 1.2.1 indicates, the causality of Minamata disease was discovered publicly in the mid 1960's. This discovery proved that Minamata disease was caused by eating fish and shellfish contaminated by organic mercury contained in the waster water from Chisso's Minamata plant. In light of this discovery, is it realistic to assume that Framework 1 is

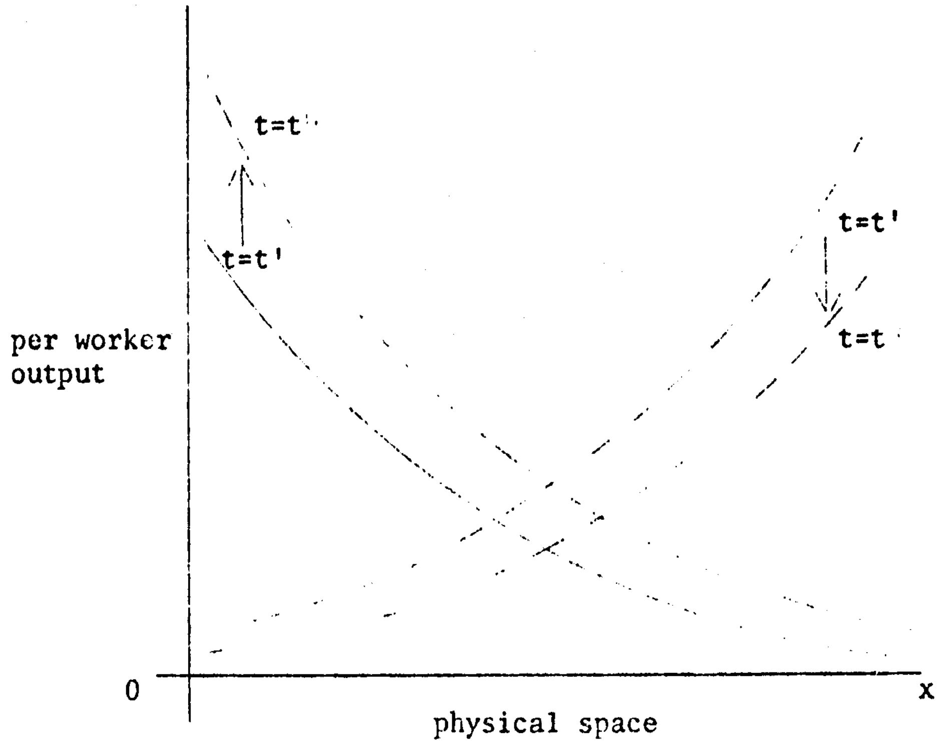

Figure 1.10

Distribution of size of fish catch per worker and per worker acetaldehyde production over physical space at time t' and t'', where t' < t''

_ _ _ size of fish catch per worker

_____ per worker acetaldehyde production still valid for the 1973 data? The answer to this question is yes. For as Section 1.2.1 shows, we do not yet know completely the mechanism by which discharged mercury is transported to the human nerve cells. The knowledge of the causality of Minamata disese does help medical doctors to diagnose their patients' illness but does not prevent people from consuming contaminated fish because it is generally impossible to tell the difference between contaminated and non-contaminated fish. If we know the whole mechanism, we may then be able to differentiate in a practical way between contaminated and non-contaminated fish (e.g., by screening out fish from contaminated areas). Therefore, together with the fact that most discharged mercury is still in the Bay of Minamata, we may reasonably assume that Framework 1 is still valid for the 1973 data.

Framework 4 assumes that the causality of pollution effects is completely known and space is physical. Specifically speaking, it assumes that the technological relationships between the production of acetaldehyde (good 1) and the production of fish (good 2) can be specified in terms of the characteristics of pollution effects and the characteristics of fish population. Furthermore, Framework 4 assumes that the bargaining between the Chisso Company and the Minamata fishermen was done based on these known technological relationships. As shown in Section 1.2.1 and in Figure 1.8, the fact is that the Minamata fishermen had endured hardships caused by a decrease in the size of their fish catch for at least 5 years (i.e., 1954 - 1959) before asking for compensation from the Chisso Company. The bargaining between the Minamata fishermen and the Chisso Company was done in 1959 under conditions of unknown causality and of unknown technological relationships between the production of good 1 and the production of good 2 since Kumamoto researchers' organic mercury theory was not yet verified at that time.

What then is the implication of Framework 4 in analyzing Problem 2 in light of this apparent contradiction? We are interested in finding whether or not we can reconstruct the situation described in Figure 1.10 (i.e., the steady decrease over time in the production of good 2 along the physical axis as contrasted with the steady increase over time in the production of good 1), provided that we assume a perfectly competitive market and the known causality of pollution effects. Particularly, we are interested in identifying the form of technological relationship between the production of good 1 and the production of good 2, which brings about the situation described in Figure 1.10. Compared to the analysis of Problem 1, the approach we adopt in analyzing Problem 2 is more normative. The situation we deal with in Problem 2 is not the one that actually existed in Minamata where the market economy did not take into account the pollution effects caused by the production of good 1 on the production of good 2, until 1959 when the situation became worse and the bargaining took place between the Chisso Company and the Minamata fishermen. Instead we deal with a situation in which a market economy internalizes these pollution effects whenever they exist. In anlayzing Problem 2, we are interested in the extent to which this market economy internalizes the pollution effects in order to bring about the given situation described in Figure 1.10.

1.4 Important Policy Implications

In this section we discuss some reasons for using the particular distributive judgment called 'weak Social Justice' in analyzing problems such as those outlined in this study. Specifically, we pinpoint some weaknesses in the marginality principle as used to evaluate public policies in certain areas including the pollution aspect of economic growth.

A dilemma which both developed and developing countries now face is the problem of how to harmonize economic development and environmental preservation. The main driving force in economic development has been the continual investment of savings in production facilities so as to increase the size of the economic pie. For example, in the stage of economic development in which most developing countries are found, it is highly inconceivable that a policy scientist would recommend that the nation's scarce resources be used for the construction of waste treatment facilities rather than the construction of fertilizer factories. A typical case in point is represented by the following statement by Oliver Weerasinghe, ambassador from Ceylon to the UN, at a United Nations symposium on the impact of urbanization on man's environment:

> The two-thirds of mankind who live in developing countries do not share the same concern for the environment as the other one-third in more affluent regions. The primary problem for these developing areas is the struggle for the bare necessities of life. It would, therefore, not be realistic to expect governments of these areas to carry out recommendations regarding environmental protection which might impede or restrict economic progress.[12]

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12) This statement was reported as a part of news "Pollution concern is relative thing" in Industry Week, June 29, 1970.

On the other hand, at a more advanced stage of economic development, as in Japan, for example, it is equally inconceivable that a policy scientist would recommend that industry be allowed to discharge untreated waste water into the environment.

The question then is how do we know at what stage of development we should start to take into account the problem of environmental protection. Particularly, how do we know when we should switch our policy from say, one oriented to maximizing economic growth to one oriented to greater preservation of the environment. The former policy carries an implication that public investments must be concentrated in those areas which constitute a bottleneck for the nation's economic growth. The latter policy may carry an implication that public funds should be used to counter any threat by a growing economy to the maintenance of the carrying capacities of the environment.

We may pose the same question from an entrepreneur's viewpoint. As an entrepreneur, how do we know when we should start investing marginal capital in waste treatment facilities rather than in the expansion of production facilities. A typical answer to this latter question has been provided by the marginality principle which specifies the following: if the net marginal benefit of additional capital invested in production activities becomes less than the shadow price or the net marginal benefit of a new waste treatment facility, then the entrepreneur should start investing in the waste treatment facility. To the extent that net marginal benefits may contain non-monetary elements, the shadow price may certainly depend on such psychological cost as people's negative attitudes towards pollution.

In a capitalist society, it is conceivable that the private sector uses this marginality principle in evaluating alternative investment projects. But the society as a whole may incur a grave consequence if we apply the marginality principle to the question of evaluating alternative public policies such as maximizing economic growth or emphasizing greater preservation of the environment. The use of the marginality principle as the only basis for public policy evaluation is irresponsible.

Suppose a policy scientist does not recommend a change in a government's policy from one of maximizing economic growth to one oriented to greater preservation of the environment until the net annual benefit of such a growth policy becomes less than the annual shadow price of the preservation policy. Under these conditions, there are at least three reasons why such a policy is a great disservice to society. First, the marginality principle disregards any distributive aspects of benefits and costs. For example, as long as the costs of economic growth, such as pollution effects are concentrated on a minority group such as fishermen, the marginality principle may certainly indicate that the government need not change its economic growth policy, since the marginality principle depends only on aggregate indicators and not on any distributive indicators. As Section 1.2.1 has shown, the tragedy of Minamata disease was partly due to the fact that pollution took place when the Japanese economy, with strong support from governmental policy, was growing at a very rapid rate.

Second, the marginality principle is unable to detect any potentially damaging phenomena outside of the market place.[13] Specifically speaking, it is unable to account the high degree of uncertainty regarding the impact of advanced technology on the environment. The Minamata mercury pollution case is a prime example of such a situation. Who knew in the 1950's that the discharge of inorganic mercury can be converted into organic mercury by microbial reactions and that a food chain can concentrate a toxic substance at an alarming rate? The marginality principle cannot calculate the proper cost of such a discharging operation unless the whole mechanism of the mercury transfer process is taken into account by the market (i.e., the price mechanism). In effect, it is possible that under circumstance of unknown causality, the use of the marginality principle would result in recommending the transfer of labour from the fishery sector to the chemical industry sector simply because the fishery sector's productivity is extremely low compared to the chemical industry sector's productivity. Such action would result in the generation of even more pollution.

Finally, because of the above two reasons, the marginality principle may force certain minority groups (e.g., the fishermen in the Minamata case) to become a scape goat for the misallocation of resourses. It may also allow a situation to go to a point of no return. For example, the mercury content in Japanese people's hair (6.5 ppm) is more than twice

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13) If the theory of second-best develops beyond its present stage, it may enable the marginality principle to take into account the phenomena outside of the market place. See for the theory of second-best Section 2.2.3.

as much as that in American people's hair (2.57 ppm).[14] Seemingly, the only way to reduce this level of mercury would be to eat nothing. We conclude that the marginality principle as represented by the public authorities' handling of the Minamata disease contributed to postponing a real solution to the nationwide mercury pollution problem in Japan.

Thus, if the marginality principle is used to evaluate policy, we may not escape the criticism of being irresponsible in the sense that we fail to detect a problem at an early stage of development and take precautionary measures against the further development of the problem. If the marginality principle is inappropriate, what kind of criterion or policy objective should be used to evaluate public policy? We have already indicated in Section 1.1 that we use as a distributive judgment "weak Social Justice" which has certain advantages over the marginality principle. "Weak Social Justice," under certain conditions, would at least enable a policy scientist to detect a problem if any exists, at an earlier stage than the marginality principle would. As an example, let us take a look at Figure 1.8. This figure clearly implies that the income of fishermen is decreasing since 1954 and the income of employees of Chisso Minamata factory is increasing since 1954. Therefore, we could know as early as in 1955 that the income distribution in Minamata did not comply with "weak Social Justice" which required in this case a steady increase of income of every worker and the equalization of income among workers over time. On the other hand, the marginality principle would certainly say that the benefit due to the increase in the

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14) Shiraki, Hirotsugu, "Mercury Pollution in Japan" (in Japanese), Research on Environmental Disruption Toward Interdisciplinary Cooperation, Volume 2, Number 3, Winter, 1973.

production of acetaldehyde was more than enough to compensate for the loss due to the decrease in the quantity of fish caught. Thus, "weak Social Justice" could have raised a question as early as in 1955 on the validity of a set of public policies in Minamata, while the marginality principle could not. The existing set of public policies in 1955 did not, of course, restrict the plant's discharging operation.

However, raising a question over an existing set of public policies does not mean that we have also identified policies that can be used to cope with a situation where "weak Social Justice" is not satisfied. In order to identify appropriate policies, we have to know the structural characteristics of the economy in question. Otherwise, all we can do is to insert policies arbitrarily into the economy with the hope that the cycle of trial and error may lead to a set of effective policies. But it is unlikely that this kind of arbitrary public intervention will be beneficial while disturbing the market mechanism from achieving the efficient allocation of resources. As an example, suppose in 1955 we found that the income distribution in Minamata did not meet the criteria suggested by "weak Social Justice." Without knowing that the external diseconomy had not been internalized by the market economy, we would have been unable to devise any effective policy which could make the income distribution in Minamata comply with "weak Social Justice." In other words, any systematic study of the Minamata's income distribution was impossible at least until July, 1959, when the Kumamoto University's Research Team announced the organic mercury theory (see Section 1.2.1), thus suggesting the existence of an external diseconomy in the Minamata's market economy.

In Chapter 3, we present a systematic way of arriving at public policies which can be used to achieve "weak Social Justice" in any market economy. In Chapters 4 and 5, we analyze Minamata's growing dual economy by assuming two different causality schemes for the existence of an external diseconomy. We then derive a set of public policies for each causality scheme. Finally, in Chapter 6 we integrate these two different sets of public policies into a set of policies which can be applied in a more general case.

CHAPTER 2: LITERATURE REVIEW

2.1 Purpose of Review

This chapter has two objectives. One is to clarify the historical developments leading to the methodology for space-time analysis recently developed by Isard and Liossatos. In so doing, we begin with a review of the static analysis of modern welfare economics based on a particular set of value judments called Paretian value judgments. Then we see the difficulties that the application of static welfare economics has had to the study of dynamic resource allocation in economic development. After that we introduce the work of Isard and Liossatos as a way to remedy the stated difficulty.

The second objective is to clarify some of the important assumptions which we employ in analyzing our problem. This is done at appropriate times in later sections of this chapter.

2.2 Welfare Economics

2.2.1 Pareto Optimality

Modern welfare economics is based on a particular set of axioms called the Paretian value judgments which Nath[15] summarizes as follows:

> (i) The concern is to be with the welfare of all the individuals in the society rather than with that of some mythical entity called 'Society' or 'State,' or with that of some special group or class...
>
> (ii) Any non-economic causes affecting an individual's welfare can be ignored...

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15) Nath, S. K. A Reappraisal of Welfare Economics, Augustus M. Kelley Publishers, New York, 1969, pp. 8-10.

> (iii) An individual should be considered the best judge of his economic welfare...
>
> (iv) If any change in the allocation of resources increases the income and leisure of everyone or at least of one person (or more strictly one household) without reducing those of any other, then the change should be considered to have increased social welfare...

The first axiom above specifies the social welfare function, W, as a function of individual utility functions, u^g, and nothing else such that $W = W(u^1 \ldots u^s)$ where s is the number of individuals in the society. In effect, this says that there is no room for other living things or the natural environment to be represented in the process of evaluation of social welfare except through man's welfare. This axiom might have prompted Boulding who said that:

> Economics... emerged out of a civilization, part of Western Europe, that was created largely by Christianity and which regarded man as the measure of all things and the universe as existing mainly for his pleasure and salvation.... The economist... is much more apt to look at things from a strictly human view and while he would no doubt regret the passing of the whooping crane, when the chips are really down, the question he asks himself is, what would it cost to preserve it?--cost in terms of strictly human values.[16]

The second axiom limits the scope of variables affecting an individual utility function to only those which are exchangeable in the market place such as commodities and the productive services necessary to produce these commodities. The third axiom assures that each individual is capable of ordering different levels of utility and can decide what

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16) See Boulding, Kenneth, "Economics and Ecology," in Future Environments of North America, edited by Darling, Frank Fraser, and John P. Milton, The Natural History Press, Garden City, New York, 1966, pp. 225-234.

is most suitable for his own welfare. Based on the second and third axioms we may write down the following ordinary utility function for each one of s individuals

$$u^g = u^g(y_1^g \; . \; . \; . \; y_n^g, \; v_1^g . \; . \; . \; v_m^g) \qquad g = 1 \; . \; . \; . \; s$$

where

y_i^g = the g^{th} individual's share of commodity Y_i

v_j^g = the g^{th} individual's share of productive service V_j

Finally, the fourth axiom, which is by itself sometimes referred to as the Paretian value judgment, specifies that the partial derivative of the social welfare function with respect to any individual utility function is positive. In other words, if we increase the utility of one individual, say, g, while keeping the remaining (s-1) individuals' utilities fixed, this increase in g's utility is assumed to have a positive contribution to the value of social welfare function such that $\partial W / \partial u^g > 0$.

The economy consists of both the production and distribution of commodities and the productive services necessary to create these commodities. Assume a social transformation function, which specifies the technological relationship between commodities and their productive services such that

$$T(Y_1 \; . \; . \; . \; Y_n, \; V_1 \; . \; . \; . \; V_m) = 0$$

where n is the number of different commodities and m is the number of different productive services,

$$Y_i = y_i^1 + \ldots + y_i^s \quad \text{for} \quad i = 1 \ldots n$$

$$V_j = v_j^1 + \ldots + v_j^s \quad \text{for} \quad j = 1 \ldots m$$

Then the above defined Pareto-type social welfare function, $W = W(u^1 \ldots u^s)$, can be used to determine the socially optimum distribution of n commodities among s individuals, the socially optimum composition of output of these n commodities, and the socially optimum allocation of the m productive factors among the production of the n commodities. These three optimum compositions characterize the social optimum according to a given social welfare function and are consistent with the above social transformation function and two resource constraint conditions. The crux of Paretian welfare economics is the proposition that this social optimum achieved by the constrained maximization of a social welfare function can be realized through a perfectly competitive market system.[17] This proposition states that a perfectly competitive market mechanism characterized by atomistic profit maximizing producers and atomistic utility maximizing consumers satisfies in equilibrium the necessary conditions for (1) a technological production optimum (a technologically efficient allocation of scarce productive factors) in which the output of any commodity cannot be increased without reducing the output of some other commodity; and for (2) a Paretian exchange optimum (an optimum distribution of both commodities and their productive services among consumers) in which no consumer can be benefited without hurting another. The necessary conditions for a technological production optimum and a Paretian exchange optimum are called the Paretian optimum conditions.

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17) For the rigorous proof of this proposition under certain assumptions, see, for example, Nikaido, H., Convex Structures and Economic Theory, Academic Press, 1968, Sect. 17 of Chapter 5.

2.2.2 Externality

After Buchanan and Stubblebine[18] we may define an externality in consumption such that an external effect or an externality is present given the following utility functions for any two individuals, r and g:

$$u^r = u^r(y_i^r, v_j^r)$$

$$u^g = u^g(y_i^g, v_j^g, y_k^r) \qquad \text{for } i, k = 1 \ldots n, \quad j = 1 \ldots m$$

That is, the utility of an individual, g, depends not only on his own commodity-productive service bundle $(y_1^g \ldots y_n^g, v_1^g \ldots v_m^g)$ but also on r's (the other individual's) share of the k-th commodity, y_k^r. Furthermore, Buchanan and Stubblebine define that a marginal external economy exists when $\partial u^g / \partial y_k^r > 0$ (i.e., r's share of k-th commodity makes a positive contribution to u^g) and a marginal external diseconomy exists when $\partial u^g / \partial y_k^r < 0$ (i.e., r's share of k-th commodity makes a negative contribution to u^g).

After stating this original analytical definition of an externality Buchanan and Stubblebine went on to declare that "full Pareto-equilibrium can never be attained via the imposition of unilaterally imposed taxes and subsidies until all marginal externalities are eliminated"[19].

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18) Buchanan, James M. and Wm. Craig Stubblebine, 'Externality,' Economica, November, 1962, pp. 371-84.

19) Pigou, on the other hand, had argued that the presence of external economies and diseconomies presents a prima facie case for the public authority to intervene by taxes or subsidies to bring about a Pareto optimum. See Pigou, A. C., The Economics of Welfare, Third Edition, MacMillan and Company, London, 1929, Part II, Chapter 9 , pp. 174-205.

Full Pareto equilibrium is defined to be present when the marginal rate of technical transformation between the k-th commodity and the numeraire commodity, j, (i.e., the marginal cost of k-th commodity, $(\partial T/\partial Y_k)/(\partial T/\partial Y_j)$), is equal to the sum of two terms: (1) g's marginal subjective rate of substitution between r's share of k-th commodity and g's share of j-th commodity (i.e., $(\partial u^g/\partial y_k^r)/(\partial u^g/\partial y_j^g)$) and (2) r's marginal subjective rate of substitution between r's share of k-th commodity and r's share of j-th commodity (i.e., $(\partial u^r/\partial y_k^r)/(\partial u^r/\partial y_j^r)$). In other words, the following relationship holds at some point y_k^r = (say) $\hat{y}_k^r$

(2.1) $$\frac{\partial u^g/\partial y_k^r}{\partial u^g/\partial y_j^g} + \frac{\partial u^r/\partial y_k^r}{\partial u^r/\partial y_j^r} = \frac{\partial T/\partial Y_k}{\partial T/\partial Y_j}$$

where

$$Y_k = y_k^r + y_k^g$$

$$T(y_1 \ldots Y_n, V_1 \ldots V_m) = 0 .$$

But, after Nath[20] we can say that were either one of the following two situations are feasible, the perfectly competitive market mechanism can achieve the situation depicted in equation (2.1):

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20) Nath's discussion is mainly in terms of marginal external economies. See Nath, pp. 65-72. We have confined our discussions to marginal external diseconomies. For these are relevant to our problem.

(2.2) the marginal external diseconomy imposing individual, r, and the marginal external diseconomy suffering individual, g, are able to negotiate that the former should pay the latter for compensation in damage done to the latter by the former's production activity;

(2.3) through the auspices of some central agency, any damage done by the marginal external diseconomy imposing individual to the marginal external diseconomy suffering individual will be compensated by the imposition of unilaterally imposed taxes.

Thus (2.3) shows that full Pareto-equilibrium can be obtained with the imposition of unilaterally imposed taxes even if a marginal external diseconomy exists.

This is the position we take in our own work in Chapter 5. In other words, we assume that there is no institutional and/or technological reasons which prevents the market from bringing about the necessary condition for Paretian optimality as shown by equation (2.1). External diseconomies, which satisfy (2.2) or (2.3), are referred to later as a Buchanan-Stubblebine type external diseconomy (see Chapters 3 and 5).

2.2.3 Second-Best

Lipsey and Lancaster[21] analyzed the question of whether or not it was desirable to meet the other Paretian optimum condition if for some reason one of the Paretian optimum conditions cannot be fulfilled. In answering this question, they defined a "second-best" optimum point as

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21) Lipsey, R. G. and K. Lancaster, "The General Theory of Second-Best," Review of Economic Studies, Vol. 24, No. 63, 1956, pp. 11-32.

the one in which a social welfare function was maximized subject to a social transformation function and a constraint that one of the Paretian optimum conditions was violated. A violation of the Paretian conditions may occur if there exists institutional and/or technological reasons which prevents the equality in (2.1) from being achieved. This situation may be due either to the failure to induce r to pay compensation for damages to g or to the failure to impose a marginal tax, or to miscalculate the value of this tax, on r's performance of his activities. Externalities caused by this second-best situation are referred to later as a Nath-type externality (see Chapter 3).

Lipsey and Lancaster proposed the following general theorem for the second-best optimum:

> ... given that one of the Paretian optimum conditions cannot be fulfilled, then an optimum situation can be achieved only by departing from all the other Paretian conditions.

This theorem[22] has been proved wrong first by Davis and Whinston[23] in the case of a separable social welfare function and a separable social transformation function.[24]

This theorem shocked economists. For a long time they had lived with an implicit belief that, in Nath's words: "... the greater the number of the various necessary conditions which could be satisfied in an economy, the nearer the system would be to such an optimum."

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22) See Nath, pp. 49.

23) Davis, O. A. and A. B. Whinston, "Welfare Economics and the Theory of Second-Best," Review of Economic Studies, Vol. 32, No. 89, January, 1965, pp. 1-14.

24) A function $f(x_1 \ldots x_n)$ is separable if and only if

$$f(x_1 \ldots x_n) = f_1(x_1) + \ldots + f_n(x_n).$$

In other words, economists believed that the greater the number of Paretian optimum conditions which could be satisfied in an economy, the more efficient use of resources would be achieved. This assumption is an important theoretical basis for the analysis of public investment. Morrison[25] also shows the possibility that the application of certain policy instruments may preserve the Paretian conditions at the second best point.

In Chapter 3, the theory of second-best is included in our methodological framework of the analysis. However, the second-best problem can be ignored in the Minamata situation because we assume condition (2.2) described in Section 2.2.3 has been satisfied.

2.3 Isard-Liossatos's Methodology

2.3.1 Optimal Growth Theory

Ramsey[26], by ignoring distributional considerations altogether, was able to apply to the dynamic problem of resource allocation over time a technological concept of efficiency (i.e., the concept of a technological production optimum) which was developed as a result of the static analysis of welfare economics. Thus, he became the founder of optimal growth theory.

Ramsey analyzed the problem of a society with a given initial amount of capital choosing the optimal growth path of consumption over an infinite

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25) Morrison, Clarence C., "Generalizations on the Methodology of Second-Best," Western Economic Journal, Vol. 6, No. 2, March, 1968.

26) Ramsey, Frank P., "A Mathematical Theory of Saving," The Economic Journal, Vol. 38, 1928, pp. 543-59.

time horizon. In this case, society's objective was to maximize, over the infinite time horizon, the cumulative sum of the society's net enjoyment per unit of time. Ramsey, after Marshall,[27] defined society's net enjoyment per unit of time as the difference between the instantaneous rate of social utility of consumption and the instantaneous rate of social disutility of labour. Hence, by ignoring the distribution of commodities produced by society, Ramsey was able to avoid a Paretian exchange concept (i.e., the Paretian value judments) and succeeded in extending a static concept of technological efficiency to the dynamic resource allocation problem over time.

In analyzing his problem, Ramsey rejected the practice of discounting future utilities in comparison with earlier utilities by simply saying that such practices are "ethically indefensible." Unlike Ramsey, many modern students of optimum growth theory have used a discounting method as a means to insure that the cumulative sum over a time horizon of a society's instantaneous utility function takes a finite value. Ramsey's views have been reemphasized recently by d'Arge and Kogiku:[28]

> If the human race faces the possibility of extinction by pollution (or other means) over a finite interval, are intergenerational utility comparisons defensible? Within a different context, Dasgupta recently suggested that a "small positive discount of the future" may be accepted as "ethical" .... However, if we assume that each generation can be exactly separated from others, then current generations with higher rates of time preference may actually eliminate the existence of some distant future generation. The faster we consume in a closed resource system, the more rapidly extinction

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27) Marshall, Alfred, Principles of Economics, Volume 1, MacMillan and Company, London, 1898, Chapter 2 in Book 5 and Note 12 in Appendix, pp. 409 and 795.

28) d'Arge, R. C. and K. C. Kogiku, Economic Growth and the Natural Environment, Working Paper #1, Program in Environmental Economics, Dept. of Economics, Univ. of Calif., Riverside, Calif., April 1971.

> occurs. While the utility of distant generations may seem valueless now, if we were that distant generation, we very well could value our continued existence at our approaching infinity.

Because we believe that in the study of pollution, the practice of discounting is truly "ethically indefensible," this study deals with a non-discounted finite time horizon.

A problem which naturally arises at this point is to define in economic terms, what is meant by a finite time horizon. Stone[29] provides us with an answer. He divides the time horizon into two parts, short-run and long-run, and assumes that social welfare functions for the short-run and the long-run have been specified. The world specified by the long-run social welfare function is a world of steady growth in which relevant variables such as consumption, the labour available, etc. grow at some constant rate. This long-run social welfare function deduces the boundary conditions on the values of stock variables such as capital, etc. at the end of the short-run time horizon. Then the short-run problem is to find an optimal growth path of stock variables over the finite time horizon in the light of the short-run social welfare function so as to satisfy the prescribed initial and boundary conditions.

Optimal growth theory has been applied extensively to the economics of development aiming at the efficient allocation of scarce resources over time so as to maximize the prescribed aggregative national welfare. In most cases, the assumption has been made that distributive judments such as interregional equity or interpersonal equity is considered to be a

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29) Stone, R. Mathematics in the Social Science and Other Essays, The M.I.T. Press, Cambridge, Massachusetts, 1966 , pp. 31-32.

matter of subjective judgment. A typical case of this value free attitude on the part of optimal growth theorists is represented by the following statement by Datta-Chaudhuri:[30]

> Given the savings behaviour of the two regions, the planning problem is to allocate the total savings of the nation among the two regions at each instant of time in such a way that the nation as a whole acquires a desired level of capital stock, irrespective of its geographical distribution, in the shortest possible time (emphasis added).

However, a few scientists have felt uncomfortable with this value free assumption and have tried to integrate the efficiency aspect and the equity aspect of resource allocations. For example, Mera[31] analyzes the dynamic resource allocation process in a nation with two regions. He maximizes the efficiency objective of national welfare subject to a prescribed value of an equity objective which specifies the relative welfare relationships among regions. As Mera noted, his analysis is essentially in line with the approach advocated by Marglin[32] in the field of benefit-cost analysis in which distributive judgments are given the status of a constraint on the analysis of efficient allocation of resources.

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30) Datta-Chaudhuri, Mrinal, "Optimum Allocation of Investments and Transportation in a Two-Region Economy," in Karl Shell (editor), Essays on the Theory of Optimal Economic Growth, The M.I.T. Press, 1967.

31) Mera, K., Efficiency and Equalization in Interregional Economic Development, Ph.D. Thesis, Harvard University, June, 1965, Chapter 8.

32) Marglin, S. T., "Objectives of Water-Resource Development: A General Statement," in Design of Water Resources Systems, edited by Arthur Maass, Harvard University Press, 1962, pp. 17-87.

In analyzing his problem, Mera divides an infinite time horizon into a set of discrete points and makes an important assumption as to the interaction between the equity aspect and efficiency aspect of resource allocations. He assumes that at the end of each discrete time period the government redistributes either capital or labour or both so as to meet the equity objective. In the next time period, the redistributed productive factors in each region are used in such a way that the efficiency objective of national welfare is maximized. This cycle of redistribution of productive factors and efficient use of redistributed productive factors is repeated throughout the entire time horizon.

Mera's analysis, however, makes the redistribution process of productive factors external to the market mechanism characterized by the efficiency objective of national welfare. He does not consider the functional relationship between the equity aspect and efficiency aspect of resource allocation. This lack of functional specification makes Mera's analysis inapplicable to the case of equitable resource allocation in a capitalist economy. For in a capitalist economy the government may achieve the equity objective not by dominating the market mechanism but by employing certain policy instruments in compliance with the workings of the market mechanism. Therefore, Mera's approach is not appropriate for the analysis of our problem.

2.3.2 Optimal Space-Time Development Theory

In a series of papers, Isard and Isard and Liossatos made a very important contribution to the analysis of dynamic resource allocation problems. After a critical analysis of notions of time, Isard presents a conceptual framework to analyze the evolutionary characteristics of a society. His conceptual framework is based on general relativity theory and field theory in physics. Isard and Liossatos then go on to apply his conceptual framework to the analysis of a particular evolutionary process in a society: the development of a primitive agriculture in an isolated region. In doing so, Isard and Liossatos present a methodology called optimal space-time development theory. Thus, they succeed in introducing a general concept of space (both physical and non-physical) into optimal growth theory in order to analyze the dynamic resource allocation processes over both time and space. This section summarizes their contribution.

As one of the critical areas for future research, Isard[33] suggests the need for the analysis of the evolutionary characteristics of a society in order to integrate spatial analysis and temporal analysis in social sciences into a general dynamic or general evolutionary theory.

In the first of his triology on the interrelations between the two primitives, time and distance (space), Isard critically evaluates existing theories:

> I observe our location theories, our transportation-land use-rent theories, our general equilibrium theories, our spatial classification and description techniques, and our welfare analysis. They do not capture the evolutionary character of our society, its life cycles, the sequences of actions and reactions that characterize its decision making, etc. They do not capture real time itself in its diverse manifestations.

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33) Isard, W., General Theory: Social, Political, Economic, and Regional, Cambridge, Massachusetts: The M.I.T. Press, 1969, Chapter 16.

> We may justifiably ask, "Why do we have so little good dynamical social theory?" Could it be that we have failed properly to conceive and define the key concept--namely time, as it relates to processes?[34]

Then Isard goes on to examine the concept of time in order to arrive at some society-neutral concept of time so that we can obtain a deeper understanding of the evolutionary characteristics of all types of societies. He identifies as operational concepts of time two general models: cardinal time and ordinal time. Ordinal time is defined in terms of an ordering of processes or events over time. Cardinal time, on the other hand, includes any linear transformation of universe time, such as calendar time, geological time, and life-cycle time, Isard defines universe time to be distance in terms of unit time from some sunrise at which we assume the earth began, where the unit of time is defined to be the distance which one marks off along the scale to represent what transpires between two successive sunrises. Geologic time used by geologists may start at the zero point as does universe time, but its units are eras or ages. Life-cycle time is distance from some reference point in calendar time such as the birth of the organism, the state of a business cycle, etc. Isard then describes the ongoing processes of a society in terms of these two general models of time. Any society can, therefore, be represented by a point in n dimensional Euclidean time-space whose coordinates are either cardinal and/or ordinal time.

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34) Isard, W. On Notions and Models of Time," Papers of the Regional Science Association, Vol. 25, 1970.

Then Isard considers the other primitive, distance. There are many concepts of distance which social scientists have spoken of. As examples, Isard identifies:

> physical distance;
> economic distance measured in terms of transportation costs;
> time-cost distance;
> social distance.

We may certainly plot a state of a society in m dimensional Euclidian distance-space where n is the number of different distance concepts, that is, components of a distance vector. One problem, then, is to analyze the interrelationships between the n-dimensional Euclidean time space and the m-dimensional Euclidean distance space as they relate to various social processes. To help solve this problem, Isard explores the interrelationships between the two primitives, time and distance.

As is clear from Isard's definition of universe time, one can measure any type of cardinal time in terms of distance from a point of reference. For example, we measure calendar time in terms of distance from some zero point, such as the birth of Christ. Ordinal time, on the other hand, can be marked off along a line in terms of "greater" or "less" distance from a predetermined or arbitrarily set reference point. Hence, time becomes essentially a derivative of the basic concept of distance. Certainly, the possibility of dealing with these concepts in a reverse way exists. In Isard's words,

> We may conceive of distance as time in the sense that we can take a common experience, two successive sunrises, and observe how much distance is covered by a ray of light during what transpires between these two successive sunrises. This distance could then be viewed as synonymous with, and thus translated into, a unit time.... It would be more feasible, for example, to translate into a unit of

> time the distance defined by the change in position of a shadow cast by a specific fixed object on two successive sunrises, averaged over the 365 (or 366) pairs of successive days during the course of a year. Given the distance as equivalent to a unit of universe time, all distances could then be converted into units of universe time.[35]

However, as Isard notes, it is much easier in terms of operational efficiency to measure time in terms of distance than to measure distance in terms of time. Hence, Isard employs distance as the basic primitive to integrate both spatial analysis, as is done in m dimensional Euclidian distance-space, and temporal analysis, as is done in n dimensional Euclidian time-space. Now we have a single coordinate system, called a space-time continuum, that can be used as a framework to describe the evolutionary character of a society.

Nevertheless, it is highly possible that different societies have different perceptions of space and time. This is so especially when societies are subject to different rates of change (e.g., the growth and decay of relevant variables) and to changes in these rates (e.g., acceleration and decceleration). In order to make the properties of a space-time continuum variant among societies, Isard develops a framework where the geometry of space-time is affected by the distributive characteristics of relevant variables as well as changes in these characteristics. Also, the distributive characteristics can be affected by the geometry of space-time.

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35) See Isard (1970).

In the second and third paper of his trilogy,[36, 37] Isard, therefore, presented the problem of describing the state of a society (the distribution of relevant variables in a society) in terms of a non-rigid (Riemann) space-time continuum. In analyzing this problem, Isard shows quite rigorously the usefulness of the field approach as characterized by general relativity theory and field theory in physics. The field approach is shown to be useful in describing the interdependence between (1) the distributive characteristics of relevant variables and their changes in a society, and (2) the space-time continuum.

Isard and Liossatos went on to apply this field approach to the analysis of a particular evolutionary process in a society: the development of a primitive agriculture in an isolated region. They explain the background for their problem:

> ... imagine the development of a primitive agriculture in an isolated region wherein there is, loosely speaking, a continuous distribution of population (and labour) eking out subsistence from hunting and gathering of wild fruits. The introduction of this primitive agriculture is sparked by some point in space and time (x,t) which we designate (0,0). As a consequence of the successful application of this advance, we have as initial conditions for our model a spatial pattern of consumption of a new agricultural good which falls off very sharply from x = 0, and a spatial pattern of capital which is also highly concentrated. This primitive agriculture catches on and spreads out in space and grows in time.[38]

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36) Isard, W. "On Relativity Theory and Time-Space Models," Papers of the Regional Science Association, Vol. 26, 1971.

37) Isard, W. "Spatial Interaction Analysis: Some Suggestive Thoughts from General Relativity Physics," Papers of the Regional Science Association, Vol. 27, 1971.

38) Isard, W. and Panagis Liossatos, "On Optimal Development over Space and Time," Regional Science Perspective, Vol. 3, 1973.

They then build a mathematical model to describe the development of a primitive agriculture in this isolated region.

In analyzing this problem, Isard and Liossatos postulate that the spatial spread is only along a line, the x-direction over a finite interval [0,B], where B indicates the furthest space point in this isolated region. They define

$Y(x,t)$ = output of a new agricultural good (the good) per unit of length and per unit of time at space-time point (x,t).

$C(x,t)$ = consumption of the good per unit of length and per unit of time at space-time point (x,t).

$K(x,t)$ = capital stock for production of the good per unit length at (x,t).

$\dot{K}(x,t)$ = investment of capital per unit of length and per unit of time at (s,t).

$U(x,t)$ = the flow of the good through a space point x per unit of time at time t.

$U^x(x,t)$ = net export of the good per unit of length and per unit of time at (x,t).

$w(x,t) = f(C(x,t))$ = welfare at (x,t), per unit of length and per unit of time, which is a function of the consumption of good at (x,t).

Then Isard and Liossatos proceed to describe the behaviour of a whole region with regard to the diffusion of a primitive agriculture over space and time. They specify the equations which characterize the dsitribution of the good over space and the change in this distribution over time. That is, they specify the system interrelationships in terms of the space-time continuum, where the system is defined to be the set of all space points. In deriving these system interrelationships, Isard and Liossatos employ the field theory approach. In their words:

> Treatment of space as a continuous variable is in one sense a natural outgrowth of the introduction of field theory into our framework, since in field theory a change at one point in the field affects the neighboring points and so on in unending fashion. Thus, system interrelationships are expressed in terms of local relationships, that is, in terms of partial differential equations which together with appropriate initial and boundary conditions specify the behaviour of a whole system over space and time.[39]

The equation for these local relationships at space-time point (x,t) is given as[40]

$$C(x,t) = Y(x,t) - \dot{K}(x,t) - U^{x}(x,t) \tag{2.4}$$

which is called the local supply = demand equation for the good. Isard and Liossatos present a model for optimal growth with two independent variables, space and time, for the development of a primitive agriculture in an isolated region. They call this an optimal space-time development model:

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39) Isard and Liossatos, Regional Science Perspectives, 1973.

40) An extension of this equation to the three dimensional space-time continuum is presented in Appendix 3. Isard and Liossatos presented a derivation for this equation which does not use the field approach. For this, see Isard, W. and P. Liossatos, "Trading Behaviour (Transport), Macro and Micro, in an Optimal Space-Time Development Model," London Studies in Regional Science, Vol. 5, 1974.

Maximize

$$(2.5) \qquad W = \int_0^R \int_0^{t_1} f(C(x,t))\, dx\, dt$$

subject to

$$(2.4) \qquad C(x,t) = Y(x,t) - \dot{K}(x,t) - U^x(x,t)$$

where W is the social welfare or system welfare function of this region and t_1 is the planning horizon.

However, this model generates unsatisfactory results in which the output of the good, capital stock, and consumption of good are all constant for all space points for any fixed point in time. This uniform distribution situation is apparently contradictory with the assumed way in which a primitive agriculture is transmitted from point to point in the isolated region. Hence Isard and Liossatos modify (2.4) by postulating that the cost of capital investment increases with distance from the initial point of agricultural development. In other words, (2.4) becomes

$$(2.6) \qquad C(x,t) = Y(x,t) - (1+ n(x))\dot{K}(x,t) - U^x(x,t)$$

where $n(x)$ is some rapidly increasing function of x and $n(0) = 0$.

Then the new optimal space-time development model is to maximize (2.5) subject to (2.6). This model still yields a nonsensical result in which consumption of the good is constant over space for any fixed point of time. On the other hand, capital stock and output of the good comply with the assumed pattern in which both capital stock and output of the good are negatively sloped curves along the space axis and increase at all points of space over time. In order to eliminate this contradictory result, Isard and Liossatos introduce the concept of transport cost by postulating that shipment of the good through any space point is done by the people at that space point. Thus (2.6) is rewritten as

$$(2.7) \qquad C(x,t) = Y(x,t) - (1 + n(x))K(x,t) - U^{x}(x,t) - \sigma U(x,t)$$

where σ = transport cost per unit flow of the good per unit length.

Then the final version of the orginal optimal space-time development model is to maximize (2.5) subject to (2.7). This optimal space-time development model succeeds in describing the development of a primitive agriculture in an isolated region. That is, capital stock, output of the good, and consumption of the good decline with an increase in x for any fixed time point, but at all space points on x, these three variables increase with time.

In subsequent papers, Isard and Liossatos generalize this simplified optimal space-time development model in several directions.[41] We review only those parts of their papers which are relevant to our problem, the analysis of the impact of pollution in Minamata. First, they introduce labour as a basic factor of production so that the production for any space-time point is postulated as

$$(2.8) \qquad Y(x,t) = F(K(x,t),L(x,t))$$

where $L(x,t)$ = the amount of labour employed in production at (x,t), the available labour being unbounded.

41) For a summary of their findings, see Isard, W. and P. Liossatos, "Optimal Space-Time Development: A Summary Presentation," The Proceedings of the Conference on Dynamic Allocation in Space, Hasselby Castle, Stockholm, Sweden, August 20-22, 1973.

Accordingly, Isard and Liossatos employ a Marshall-Ramsey type welfare function

$$w(x,t) = f(C(x,t)) - v(L(x,t))$$

where $f(C(x,t))$ = a utility function of consumption of the good at (x,t)

$v(L(x,t))$ = a disutility function of labour at (x,t).

Then the original optimal space-time development model can be modified (version 1) as follows:

Maximize

(2.9) $$W = \int_0^B \int_0^{t_1} (f(C(x,t)) - v(L(x,t)))\, dx\, dt$$

subject to

(2.7) and (2.8).

Under the assumption of increasing return to scale for a disutility function, version 1 generates a new result, in addition to those results yielded by the final version of the original optimal space-time development model. In version 1, the amount of labour used decreases with an increase in distance from the origin, x, and increases with time at every space point.

Secondly, Isard and Liossatos[42] introduce pollution as a basic variable affecting space-time development into version 1. They deal with growth situations where there exists initially a large stock of pollution,

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42) Isard, W. and P. Liossatos, "Transport Rate and Pollution as Basic Variables in Space-Time Development," London Studies in Regional Science, Vol. 4, 1973.

and where this stock increases with distance from the origin. Isard and Liossatos define a new variable:

$R(x,t)$ = the stock of pollution (a "bad" commodity) per unit of length at (x,t).

Accordingly, the welfare function is postulated to be

$$w(x,t) = f(C(x,t)) - g(R(x,t)) - v(L(x,t))$$

where $g(R(x,t))$ = a disutility function of the stock of pollution at (x,t).

Furthermore, Isard and Liossatos postulate that the time rate of change of the stock of the "bad" commodity depends on the production of the good and the amount of the abatement good, $J(x,t)$. That is

(2.10) $$\dot{R}(x,t) = \mu F(K(x,t),L(x,t)) - \gamma J(x,t)$$

where μ and γ are dimensional coefficients transforming the good from good units to pollution units. Since the abatement good, $J(x,t)$, is defined to be the amount of good which is used up to yield abatement, the local supply=demand identity equation (2.7) is modified to read

(2.11) $$C(x,t) = Y(x,t) - (1 + n(x))K(x,t) - U^x(x,t) - \sigma U(x,t) - J(x,t).$$

The new modification (version 2) of the original optimal space-time development model is then to

maximize

(2.12) $$W = \int_0^B \int_0^{t_1} (f(C(x,t)) - g(R(x,t)) - v(L(x,t)))\, dx\, dt$$

subject to (2.8), (2.10), and (2.11).

This modification (version 2) yields, in addition to those results generated by version 1, the equation governing the abatement process and what Isard and Liossatos describe as two "unexpected" findings: (1) the stock of a "bad" commodity increases with distance, that is, $\partial R(x,t)/\partial x > 0$; (2) the stock of a "bad" commodity declines with time, that is $\partial R(x,t)/\partial t < 0$. These latter findings are not so unexpected in light of the situation described in Figure 1.7 in Section 1.2.2. In that case, the stock of a "bad" commodity, R(x,t), corresponds to the amount of mercury in fish. As Figure 1.7 shows, this pollution stock variable increases with distance if we take the origin at the discharging point of mercury contaminated waste water, that is, 60 km from the mouth of Agano river. Furthermore, it is highly conceivable that this pollution stock variable decreases with time with the introduction of abatement good.

Nevertheless, version 2 is inadequate for the analysis of one of our problems, for in Minamata the sufferings have come from eating "contaminated fish." In other words, we are interested in the consumption of a "bad" commodity, not in the stock of a "bad" commodity.[43]

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43) It is true that the stock of a "bad" commodity (the amount of mercury in fish) can affect the extent to which people who consumed the "bad" commodity suffer. But, as Section 1.2.2 of Chapter 1 has shown, we do not yet know completely the mechanism by which discharged mercury is transported to the human nerve cells. Especially, we do not yet know the exact interrelationships between the amount of mercury discharged by a factory and the amount of mercury stored in fish, and between the amount of mercury consumed by an individual and his degree of sufferings. Under these circumstances, it may be more effective to concentrate our analysis on the consumption of a "bad" commodity rather than assuming some arbitrary relationship between the stock of a "bad"

commodity and its rate of change over time. Therefore, in Chapter 4 we postulate that a "bad" commodity is a byproduct[43a] of a composite good. In other words, we assume that as long as the production of the good continues, fish are contaminated assuming of course that the production of the good is accompanied by the discharge of mercury into the sea.

43a) Based on the definition of a "byproduct" given by Whitcomb, we define a "bad" commodity j as a byproduct of a good commodity i if the production functions for i and j are given by

$$Y(y, v_0, v_i) = 0 \qquad i = 1 \ldots n$$

$$Z(z, v_0, v_j) = 0 \qquad j = n+1 \ldots m$$

where

y = output of good i
z = output of "bad" j
v_i = input for the production of good i
v_j = input for the production of "bad" j
$v_{.}$ = a joint input

In the case of Minamata mercury pollution, the joint input is discharged mercury.

See Whitcomb, David K., Externalities and Welfare, Columbia University Press, New York and London, 1972, pp. 22-28.

Finally, Isard and Liossatos[44] analyze the problem of public investment in transportation facilities. Accordingly, the transport cost per unit flow of good, σ, is postulated to be a function of the public capital stock, $K_T(t)$, invested in transportation facilities at time t:

(2.13) $$\sigma(t) = g(K_T(t))$$

where $dg/dK_T < 0$ (i.e., for increasing K_T, σ decreases).

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44) Isard, W. and P. Liossatos, "Transport Investment and Optimal Space-Time Development," Papers of the Regional Science Association, Vol. 31, 1973.

For simplicity, Isard and Liossatos drop the labour factor and the pollution factor from this model. Then they deal with this public transport investment problem in two cases: an open economy and a closed economy.

With respect to an open economy case, Isard and Liossatos assume that the funds for public transport investment are provided by flows of goods from the outside world into the system at the origin. Then version 3 of the original optimal space-time development model is to maximize

$$(2.5) \qquad W = \int_0^B \int_0^{t_1} f(C(x,t))\, dx\, dt$$

subject to

$$(2.14) \qquad C(x,t) = Y(x,t) - \dot{K}(x,t) - \dot{K}_T(t)\delta(x) - g(K_T(t))U(x,t) - U^x(x,t)$$

where $\delta(x)$ is a delta function defined as

$$\int_{-\infty}^{\infty} \delta(x)dx = 1 \quad \text{and} \quad \delta(x) = 0 \quad \text{for} \quad x \neq 0.$$

Version 3 yields, in addition to those generated by the final version of the original model, the important result that the spatial inequality in the consumption of goods decreases with time due to the public transport investment. If there is no transport cost as in the original optimal space-time development model, the flow of a good between two different space points depends upon, among other things, the price differential of a good at these two space points.[45]

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45) For example, see Ohlin, B. Interregional and International Trade, Harvard University Press, 1967, Chapter 1.

If the price of a good is higher at space point x_2 than at space point x_1, the good will flow from x_1 to x_2, thus leading toward equalization of the price of the good at these two space points. In a perfectly competitive market, in which our optimal space-time development models function, the price of a good is equal to the marginal utility of the consumption of that good. If there exists no transport cost, then the price and the consumption of a good are equalized at every space point, instantaneously, as the original optimal space-time development model has shown. With the introduction of a positive transport cost, the rate of flow of a good from space point x_1 to x_2 and of the consumption of good at x_1 and x_2 is delayed as the final version of the original optimal space-time development model has shown. Therefore, the decrease in transport cost through public investment in transportation facilities acts to speed up the equalization of the consumption of a good at x_1 and x_2 as version 3 has shown.

With respect to the closed economy case, Isard and Liossatos postulate that the funds for transport investment must be provided by the system itself through taxation. Then the local supply=demand identity equation (2.14) is replaced by

$$(2.15) \qquad C(x,t) = (1 - \gamma)Y(x,t) - \dot{K}(x,t) - K_T(t)\,\delta(x) - g(K_T(t))U(x,t) - U^x(x,t)$$

where γ = a flat (constant) tax rate on the production of goods at all space points, $0 < \gamma < 1$.

Furthermore, Isard and Liossatos require that the sum of taxes collected in the system is exactly equal to the inflow of good, $U(0^-,t)$, into the system at the origin:

$$(2.16) \qquad U(0^-,t) = \delta \int_0^B Y(x,t)\, dx$$

where $U(0^-,t) = \lim_{\varepsilon \to 0} U(-\varepsilon,t)$.

Then version 4 of the original optimal space-time development model is to maximize (2.5) subject to (2.15) and (2.16). Version 4 specifies that the consumption of goods increases with time and decreases with space, and capital stock decreases with space, provided that the public transport investment is increasing with time.

2.3.3 Social Justice Criteria

In their analysis of optimal space-time development models, Isard and Liossatos made another important contribution in their paper[46] in which a distributive judgment was finally integrated with the analysis of efficient allocation of resources over time.

They first clarify their notion of a distribution by presenting it in two observable forms, namely, a distribution over real physical space and a distribution over non-physical, abstract space. Examples of the latter type of distribution are:

a frequency distribution of population (household units) by size of income;

a frequency distribution of population (household units) by number of effective contacts (interactions) with key public officials.

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46) Isard, W. and P. Liossatos, "Social Injustice and Optimal Space-Time Development," Journal of Peace Science, Vol. 1, No. 1, 1973.