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SO_X emissions reduction policy and environmental Kuznets curve: Yokkaichi experience

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Abstract

We find an inverted U-shape relationship between local income and SO_X emissions, i.e., the so-called environmental Kuznets curve, in the Yokkaichi area. It is then shown (1) that the income level at the peak of the curve is fairly low relative to those reported for countries and/or the world in the literature, and (2) that the drastic decline in SO_X emissions after the peak of the inverted U-shape was brought about by technical progress in cleaning up the environment but not by the declining output levels, despite increases in output level. It should be noted that the local residents' campaigns moved and backed up the local governments, in contrast to the SO_X reductions in developed economies in 1980 pushed by the international agreements, i.e., Sulphur Protocols. The administrative agencies supported by local residents' campaigns, rather than decreasing returns in production technology, played a critical role even at such a low income level.

JEL Classifications: O18; Q48; R38
Keywords: environmental Kuznets curve; environmental policy; Yokkaichi area

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1. Introduction

Since Grossman and Krueger (1991, 1995) found an inverted U-shape relationship between income and pollution emissions, many empirical studies have explicated such a curve, i.e., the so-called environmental Kuznets curve, although the arguments on the causality between them do not still seem to converge. The purpose of the present paper is to observe the relationship between income and pollution emissions in the Yokkaichi area, one of the regions which had a larger-scale petrochemical complex in Japan even at the beginning of the high-growth era, and then to examine and characterize the factors for the improvement of the environmental quality even at rather low income levels in Yokkaichi. Since it is well known that SO_X causes regional and local environmental problem, we will focus on pollution in the form of SO_X emissions.

Selden and Song (1994) illustrated the empirical result for SO_X emissions supporting the inverted U-shape of Grossman and Krueger (1991), although their estimated income level of the turning point was US$8000 using cross countries data, which is considerably higher than US$4053 (in 1985 U. S. dollars) in Grossman and Krueger (1995). Shafik (1994) also obtained an inverted U-shape between income and pollution emissions for SO_X whose peak was US$3670. Cropper and Griffiths (1994) showed inverted U-shape curves for Latin America, Asia and Africa, using deforestation data of FAO, but their predicted income level at the turning point was also much higher than the observed income levels. Holtz-Eakin and Selden (1995) obtained an inverted U-shape for CO_2 emissions, using the world panel data, and their estimated income level at the turning point was US$8million, which is also higher than the observed income levels. On the other hand, Harbaugh et al. (2002) re-examined the result of Grossman and Krueger (1995) by extending the estimation periods, and showed that the inverted U-shape may not be obtained robustly.[1]

In order to explain the inverted U-shape, theoretical models are proposed, which may be categorized into three types, following Andreoni and Levinson (2001).[2] In the first type, although pollution emissions increase as the economy inclined toward polluting industries along with economic development, they decrease after being sufficiently developed as the industry structure changes from polluting and heavy industries to clean and service industries. See, for example, Arrow et al. (1995) and López (1994) for this type. In this case, polluting industries may move to other developing economies, thereby exporting pollutions.abroad.[3] As for the second type, one assumes that there exists a threshold level of economic activity below which the economy can tolerate pollution with no controls. But after the threshold has been breached, environmental policy is implemented and starts to bind. Forster (1993), John and Pecchenino (1994) and Stokey (1998) showed the relationship to be inverted V-shape under such controls. Finally, Andreoni and Levinson (2001) showed that if the abatement function is increasing-to-scale in polluting activities (i.e., consumption) and abatement spending, we may have an inverted U-shape, without any externalities and any policies. Selden and Song (1995) also showed that, assuming a threshold under which no abatement spending is done, the inverted U-shape may be obtained if the relationship between income and abatement is J-shaped. However, in contrast, Kelly (2003) demonstrated that the inverted U-shape can be obtained rather when the abatement function is decreasing to scale, while Jones and Manuelli (1995) used a theoretical model to show that the relationship may have an inverted U-shape, S shape or increase, depending on the collective-decision mechanism, where the environmental control policy is determined through the political process while capital accumulation is determined in the market.[4]

The present study examine the relationship between residents' per capita income and SO_X emissions in the Yokkaichi area during the period from the latter half of the 1960s to 1990s, during which air pollution caused a serious health problem, which is well known as "Yokkaichi Zensoku (asthma)." Since it is also well known that sulfurous acid gases (SO_2) and/or sulfurous acid mists (SO_3) caused this Yokkaichi Zensoku, we concern ourselves with SO_X emissions from the factories of the petrochemical complexes in this region.[5] Comparing the environmental Kuznets curve in the Yokkaichi area with those discussed in the literature, the present study aims to characterize the process of improving the environmental quality in this region.

2. SO_X emissions and per capita income in the Yokkaichi area – Environmental Kuznets curve

2.1 Operations of the Yokkaichi petrochemical complex – Historical review[6]

The No. 2 Navy Fuel Depot (Kaigun Dai-ni Nenryo Sho) and other private oil factories, for example, Ishihara Sangyo and Daikyo Oil (Daikyo Sekiyu), were destroyed by the heavy bombings of the Allied Forces in July of 1945. After World War II, the No. 2 Navy Fuel Depot site in the Shiohama area was first sold to Mitsubishi Petrochemical (Mitsubishi Yuka), and one of the largest petrochemical complexes in Japan was then scheduled for construction in order to realize the Petrochemical Growth Action Project (Sekiyu-kagaku Ikusei Taisaku) which was a part of the "First Stage Plan for the Petrochemical Industry (Sekiyu-kagaku Dai-ichi-ki Keikaku)" drawn up by the Hatoyama Cabinet. The oil plant of Showa-Yokkaichi Oil (Showa-Yokkaichi-Sekiyu) was built in 1956, and the ethylene production facility of Mitsubishi Petrochemical was constructed. The No. 1 complex (which is called the Shiohama complex) began full-scale operations in 1959. The No. 1 complex consisted of 10 main companies, which was then expanded westward beyond the former No. 2 Navy Fuel Depot site. As a consequence, factories of the complex came up against residential housing nearby.

The construction of the No. 2 petrochemical complex (which is called the Umaokoshi complex) started in 1961, and the complex went on stream in 1963. The Yokkaichi area has since developed into one of the greatest petrochemical industrial cities in Japan. The No. 3 complex (called the Kasumi complex) started operations in 1972.

On the other hand, although the sea near Yokkaichi was a good fishing spot because of the meeting of the Kiso, Nagara and Ibi Rivers, the fish caught there around 1958 reeked of petroleum. The sea range where fish smelled of petroleum then expanded to about 4 km from the coast of Yokkaichi in about 1960 when the first petrochemical complex began operations. This situation caused fishermen and other persons involved along with local residents to launch an appeal to Mie Prefectural Authorities. The Mie Prefectural Office responded by organizing the Promotional Council on Water Pollution Prevention in Ise Bay (Ise Wan Osui Taisaku Suishin Kyogikai), headed by Professor Yoshida of Mie Prefectural University (at present, Mie University). The Council concluded that the foul petroleum smell of fish was caused by their absorption of the liquid waste discharged by the petrochemical complex. In 1960, a grass roots campaign by local residents turned the pollution problem in Yokkaichi into a public issue, so-called "Yokkaichi Pollution (Yokkaichi Kogai)." As the Yokkaichi City Authority was requested to take the measures to improve the situation by the residents near the No. 1 petrochemical complex, the Authority organized an Air Pollution Prevention Council (Yokkaichi Kogai Boshi Taisaku Iinkai). The Council reported that the sulfurous acid gases mainly caused the air pollution in the Yokkaichi area. In the meanwhile, malodorous sulfurous-chemical compounds from the complex became a problem in the Shiohama area.

The damage caused by asthma in the Isozu area meanwhile became serious about 1961. Moreover, the sulfur oxide air concentration and the amount of soot and dust drops began to be measured at 11 sites in Yokkaichi City. The fact that sulfurous acid gases affect the human body was proved by the Pollution Control Panel of Yokkaichi, lead by Professor Yoshida at the Department of Medicine at Mie University in 1962.

Two points should be noted about the Yokkaichi experience: First, both research and investigation of malodorous fish and measurement of air pollution and the amount of soot and dust drops had never been done, at least, in Japan before; second, in response to the damage outcry by its residents, Yokkaichi City investigated the problem at an earlier stage and Mie Prefecture took measures to improve the situation (i.e., The Regulations on Total Discharge Amount (Soryo Kisei) in 1972). In Japan as a whole, the public sector embraced an industrialization policy aimed to expand national production and income, and due care might not be given to preserving the nation's living environment.[7] Even in such a situation, it should not be overlooked that Yokkaichi City and the Mie Prefectural Authority adopted aggressive measures against pollution emissions and/or medical damage, which were reflected in the basis for the measures later taken by the Japanese government. In 1964, before the rest of the country, Yokkaichi City started to publicly bear the medical costs of patients who suffered from the pollution. It was 5 years after Yokkaichi acted alone that the central government enforced the Law Concerning Special Measure for the Relief of Pollution Victims (Pollution Victims Relief Law) in 1970 (ICETT, 1994, p. 52), while The Regulations on Total Discharge Amount, adopted initially by the Mie Prefectural Authority, was also introduced into the Air-Pollution Prevention Act by the central government of Japan in 1974.[8]

2.2 Growth and environmental problem – Environmental Kuznets Curve

Now we examine the relationship between SO_X emissions and per capita income in Yokkaichi City from the second half of the 1960s to the 1990s.[9] The Environmental Conservation Division of Yokkaichi City has published data for SO_X in the Yokkaichi area since 1972, while per capita income in Yokkaichi has been published by the Mie Prefectural Office.[10] First, making use of the data on fuel-oil inputs in naphtha production available since 1972 and the Survey on the Evaluation of Development and Environment (1994), we can estimate SO_X emissions before 1971, and using the data on per capita income since 1972, we can also estimate the relevant data before 1971.[11] These calculations will be explained in Section 3.

The relationship between per capita income and per capita SO_X emissions in Yokkaichi is illustrated in Figure 1. In this study we are interested in the period from the mid-1960s (when pollution caused by SO_X emissions was recognized as an environmental problem) to the beginning of the 1990s (when the SO_X emission intensity of SO_X became fairly low).[12]

Fig 1 real per capita income and SOx emissions

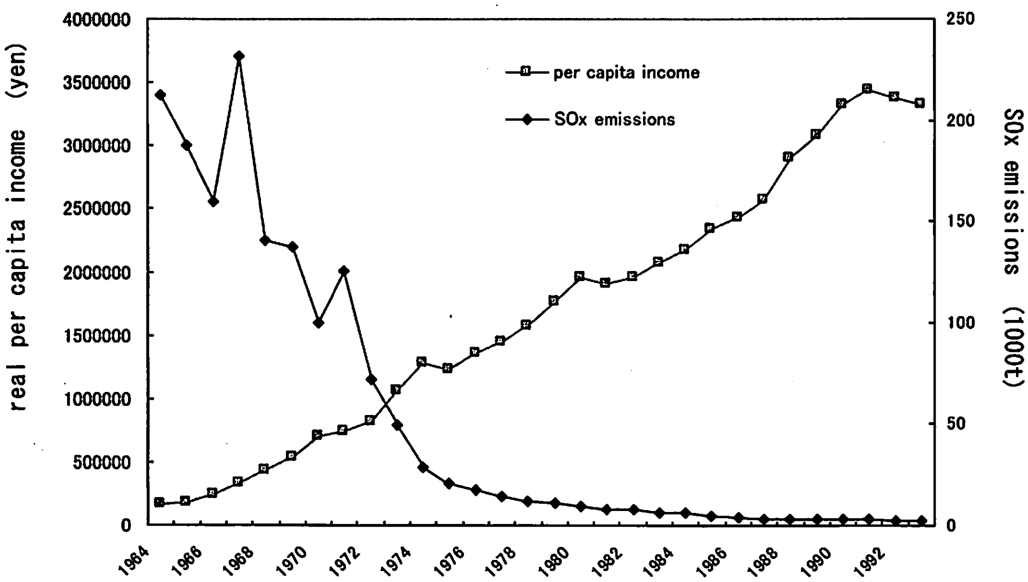


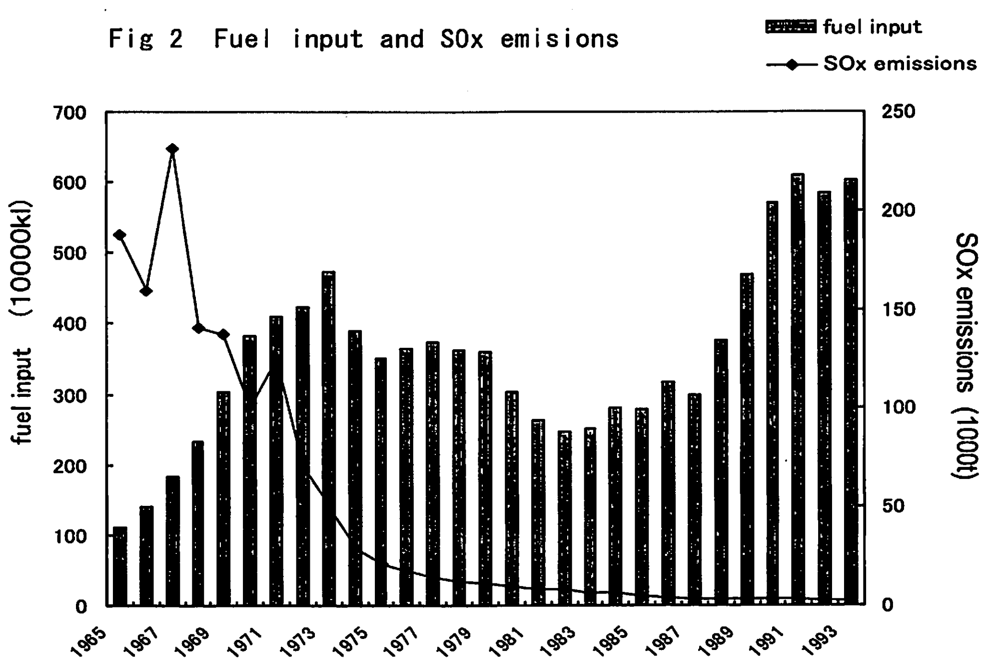
Table 1 Rates of changes in fuel inputs and GDP (FY1965−FY1972)

Fiscal Year	Rate of Changes in Fuel Inputs	Growth Rate of GDP
1965	28.24	11.07
1966	29.39	11.05
1967	27.98	12.32
1968	30.07	12.04
1969	25.90	8.32
1970	6.90	5.13
1971	3.62	9.26
1972	11.56	5.01

1) Real GDP : 63SNA (Ministry of International Affairs and Communication "Long-term Statistics Series in Japan")

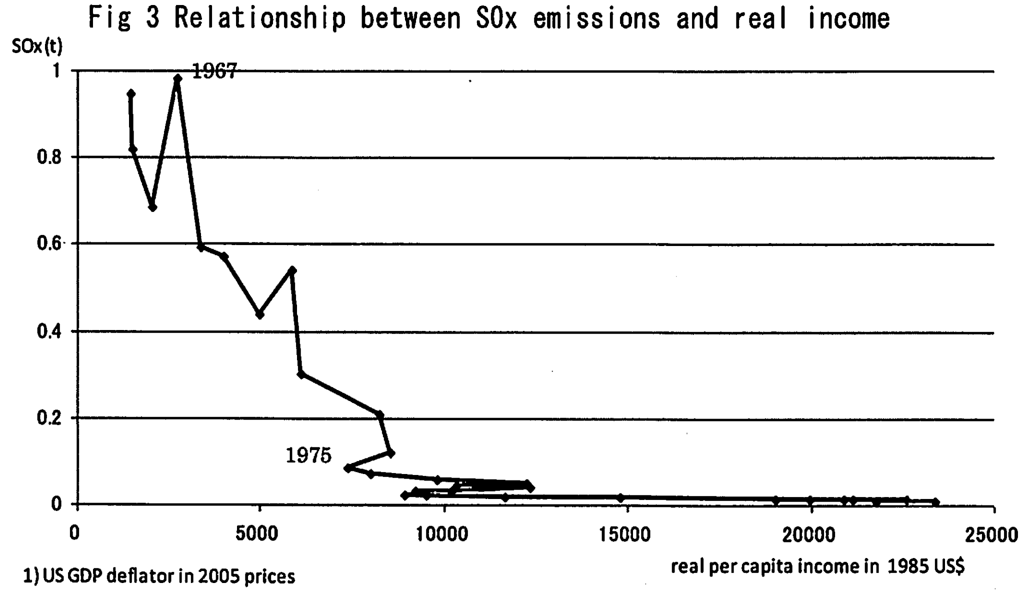
Per capita income in Yokkaichi increased for most of the period from 1964 to 1991, i.e., just before the so-called 'bubble' burst, while SO_X emissions almost monotonically decreased except for 1966. However, the decreases in SO_X emissions were not brought about by reductions in the activity level of the petrochemical complex. The magnitude of fuel input reflects the activity level of the complex and corresponds to the production level of naphtha and other products. In fact, Figure 2 illustrates that though fuel-oil inputs increased, the amount of SO_X emissions decreased from 1967 to 1973. However, Table 1 shows that the fuel-oil inputs (and therefore the activity level of the complex) increased at higher rates than GDP during the period from 1965 to 1972 except for 1971. Thus, the fuel-oil production in this area did not plausibly decrease relative to those in other regions of Japan. In this sense, Yokkaichi did not export pollution.[13] In fact, the No. 3 (Kasumi) complex began full-scale operations in 1972. As anecdotal evidence, a construction plan of Mishima-Numazu petrochemical complex was subject to vigorous residents' campaigns, influenced by those in Yokkaichi, and eventually the plan had to be abandoned around 1964 (Yoshida, 2002; Ono, 1971). This fact implies the difficulty of relocating petrochemical production elsewhere in Japan even in the early 1960s.

Fig 2 Fuel input and SOx emisions



Next, we look at the relationship between SO_X emissions and per capita income. Since pollution by SO_X emissions has strong local characteristics, and the pollution prevention measures were undertaken in this area by the local government, we take per capita income as a proxy reflecting the economic condition in the Yokkaichi area. Per capita income in terms of the 1985 US dollar is calculated as follows: Per capita income in each year is converted to US currency using the current exchange rates (i.e., the basic exchange rate until 1972 and then spot rates), and then converting them into 1985 US dollars by deflating nominal per capita income by the GDP deflator in the US (based on 2005 prices).[14] Thus, we obtain the relation between per capita income and per capita SO_X emissions, i.e., the environmental Kuznets curve in Yokkaichi. The relationship is depicted in Figure 3, where, following the literature, the ordinate measures per capita emissions of SO_X, and per capita real income in the 1985 dollars is measured on the abscissa.

Fig 3 Relationship between SOx emissions and real income



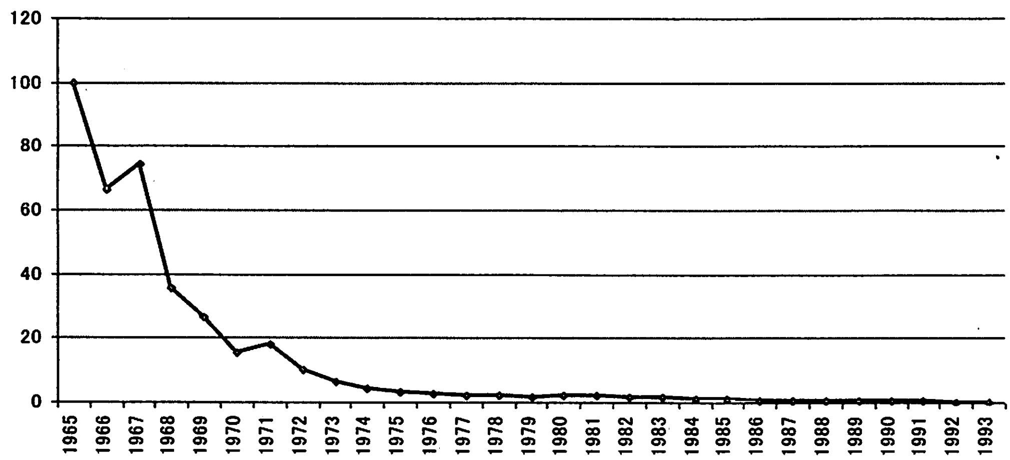
1) US GDP deflator in 2005 prices
2) 1964-1972: Basic exchange rate; 1973-1993: Spot exchange rate

Although we cannot see the inverted U-shape because of the data availability, one can expect that the emission level is on the abscissa at zero output and that the level increases as income rises.[15] If so, the peak of the inverted U-shape curve seems to lie at a rather low per capita income level in 1967 or earlier.[16] If the peak is 1967, the per capita income level was US$2729.3 at the 1985 price.[17] This level of per capita income is fairly low relative to US$4000 and accounted for only about 70% of it, although Grossman and Krueger (1995) showed that the income level turning point for SO_X emissions for the United States and Canada was about US$4035 at 1985 PPP prices. De Bruyn (1997) suggested from various empirical studies that the income level of turning-point ranged from $3000 to $10000 at 1985 PPP prices, while Markandya et al. (2006) summarized that the turning points in the SO_2 emission studies for sample dominated by OECD countries ranged from $8200 to $10600 at 1990 PPP prices.[18] It should be noted that the per capita SO_X emissions level had already passed the peak of the environmental Kuznets curve in Yokkaichi at US$4000 and that per capita SO_X emissions became only 60% of the 1967 level at the income level of $4015 in 1985 US dollars in 1969. The literature concluded that the inclusion of no-urban regions and/or developing countries leads to a much higher estimated income level (and often levels above the observed incomes) at the peaks of the inverted U-shape curves (e.g., Selden and Song, 1994; Shafik, 1994; Holtz-Eakin and Selden, 1995; Stern et al., 1996; De Bruyan, 1997; Makandya et al., 2006). In light of these results, it is surprising that well before pollution problems had been seriously confronted worldwide, Yokkaichi City and the Mie Prefectural Office had already undertaken pollution emissions control measures and/or controlled SO_X emissions even with such a low income level.

It should be noted that the local residents' campaigns pushed the authorities to take the plunge by directly appealing to authority and/or appealing to the courts indirectly and that the "pollution patrol" organized by Yokkaichi City in 1963, for example, exerted pressure on the factories to change their attitudes (e.g., Yoshida, 2002, p. 58). Furthermore, it should be also noted that the speed of decline in SO_X emissions was considerably high. Such a rapid decline may well have been affected by the fact that the complex factories were contiguous to residents' houses. In fact, the resident's houses, a primary school and the complex factories stand across a municipal road, and more than 30000 people reside within about 2 km of the complex. On the other hand, per capita SO_X at the peak in the Yokkaichi area was 0.983 tons in 1967, which was quite high, for example, in comparison to the peak of 0.1453 tons per capita SO_2 emissions in the United States in 1973 (see Brock and Taylor, 2010).[19] Given the heavy emissions together with the high population density, the damage to the inhabitants of the areas must have been very severe, thus requiring swift, sure measures. In fact, ICETT (1994) reported that many companies had also continued to "strive to prevent the environment of Yokkaichi from becoming worse (p. 31)" even before 1966.[20] This contrasts with the case referred to by De Bruyn (1997) that significant declines in SO_X emissions in the developed economies in the 1980s were induced only by the drastic policies backed up by the international agreements.[21]

Defining the emission intensity as the ratio of SO_X emissions/fuel-oil inputs, and setting it in 1965 as equal to 100, the time path of the pollution intensity is depicted in Figure 4.[22] Before the public counter measures were undertaken, and more importantly, even at the peak of the environmental Kuznets curve in 1967, the pollution intensity continued to be on the downward trend.[23] Therefore, we may say that private companies adopted some environmental measures before the peak of the environmental Kuznets curve. This downward trend in pollution intensity is consistent with the illustration of the US data in Brock and Taylor (2010), who argue that, given a constant rate of environmental technology progress, large increases in output due to the decreasing marginal productivity may cause the inverted U-shape at earlier stages of development at low income levels (and eventually the output effect will be dominated by technological progress). However, Figure 2 shows that the pollution intensity did not rise even when output levels evidenced a large increase, for example, in the 1970s and the 1990s; and Figure 4 shows that the pollution intensity decreased rapidly, especially around 1970.[24] Thus, the argument by Brock and Taylor (2010) falls to fact.

Fig 4 Emission intensity (:=Sox/Fuel) 1965=100



This point may be explained as follows. An Environmental Pollution Control Department (Kogai Taisaku-shitsu) was established in the Mie Prefectural Office in 1963, and then The Smoke and Soot Regulation Law was passed. The policy authorities thereby tightened the pollution controls for the complex companies. However, decisive technologies to reduce SO_X emissions had not been developed at that stage. Therefore, companies could only make chimneys higher at most, thus diffusing and diluting polluting gases, or reduce their operation levels as their pollution prevention measures. Around 1967, the heavy-oil desulfurization equipment went on stream, and, together with the higher chimneys, the SO_X levels were drastically reduced in the area surrounding the complex. Some companies converted to low sulfide oil imported from Indonesia or Southeast Asian countries, or input naphtha as a fuel. Then, flue-gas desulfurization technology, which removes sulfur from flue gases, was developed and went into practical use around 1974. Production facilities with that technology began operations the following year. With equipment in full-scale operation, the total SO_X emissions were decisively reduced far below the level called for by the 1976 standard. Such equipment served to reduce 25125 tons of SO_X emissions per year. The amount emitted into air was 2290 tons, that is, one-tenth the level before the equipment came into use. The important point here is that the development of emissions-reducing technologies was triggered by the public environmental measures vociferously demanded by local residents' campaigns.

2.3 Environmental measures and pollution prevention investment

Needless to say, environmental quality does not automatically improve as the income level rises. As explained in the previous section, public pollution prevention control measures forcefully promoted by local residents' campaigns played a key role. The Regulations on Total Discharge Amount were adopted on August 15, 1972, six months ahead of the scheduled date in response to plaintiff citizens' win in the civil suit. These regulations were decisive in reducing SO_X emissions in Yokkaichi. The regulations are as follows:

・By 1975, the SO_X pollution density in Yokkaichi should be reduced to 0.025 ppm from 0.05 ppm of the national standard.

・The allowable total emissions in each region are to be determined, and the outlet of each factory should be controlled correspondingly. This regulation is expected to reduce 38.5 million tons of total fuels and about 70% of 0.1 million tons of SO_X emissions, respectively, annually.

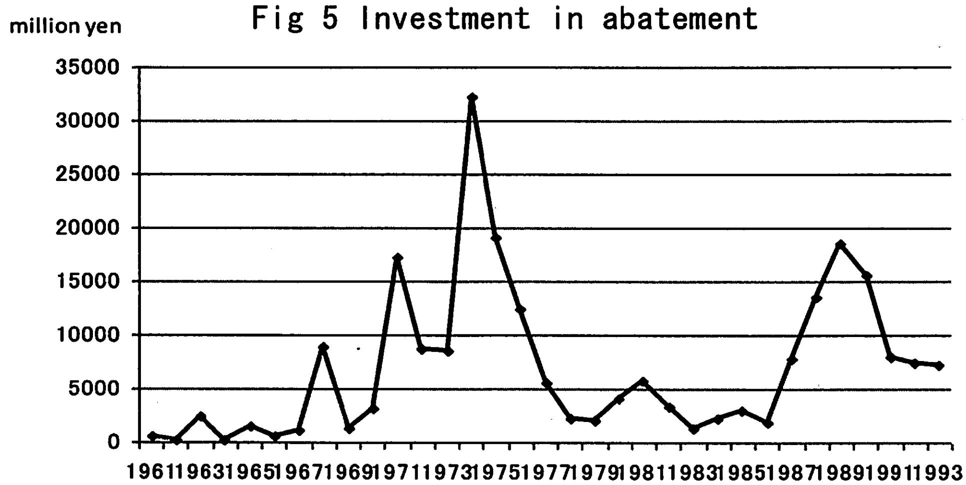
Following the report of the project team in December 1972, the Rules of Enforcement of the Prefectural Ordinance on Pollution Control and the Enforcement Rules were revised, and came into force on April 1, 1973, as follows:

・The SO_X level should be lowered to 0.025 ppm as an intermediate goal by the end of 1974, and eventually reduced to 0.017 ppm as the final goal (i.e., the annual average density which achieves 99% of the threshold intensity set by the City Life Council of Yokkaichi City from the past data in Yokkaichi).

・Sulfide in fuel gases should be controlled more strictly as the fuel inputs increases.

By these regulations, although the fuel-oil inputs seemed to be leveling off, SO_X emissions drastically declined from 0.1 million tons before regulations to about 20 thousand tons in 1975. And the annual average density of all observation points in Yokkaichi became lower than 0.017 ppm of the goal.

Fig 5 Investment in abatement



Such regulations were expected to require huge costs for countermeasures of the complex companies. Figure 5 depicts the time path of the estimated total (nominal) amount of environmental or pollution prevention investment, i.e., investment in abatement.[25] It is notable that investment in abatement did not increase largely until 1967, but thereafter it increased rapidly toward the peak in 1974, even if the peak of the inverted U-shape was reached in 1967.[26] This is in contrast to the features of the time-evolution in environmental or pollution prevention investment, for example, of the US illustrated in Brock and Taylor (2010).[27] As shown earlier, total SO_X emissions began to decline in Yokkaichi in spite of the technological constraints in the latter half of the 1960s. However, a huge amount was then invested in abatement. Around 1965, environmental or pollution prevention investments were mainly those of heightening chimney stacks. The Air Pollution Control Law (1968) included the K-value regulation which set the allowable volume of SO_X emissions in proportion to the square number of the height of the chimneys. Responding to the Regulations on Total Discharge Amount in 1972 and tightening them in the years to follow, desulfurization equipment was developed and installed, rapidly increasing the costs of investments and reducing SO_X emissions (see Figure 3). On the other hand, increases in the latter 1980s were explained as those undertaken in the name of Third and Fourth Regional Environmental Pollution Control Program for urban and city life.

3. Data

3.1 Calculation of per capita income in Yokkaichi

The Mie Prefectural Office estimates the municipal residents income from the Mie Prefectural Income Account data. Although the Mie Prefectural Income Account has been estimated since 1950, the Mie Prefectural Office published only the net municipal product (factor income) as the municipal residents' incomes from 1955 to 1969, and both net municipal product (factor income) and municipal residents' income (distributed income) since 1972. Thus, we first estimated the correlation between net municipal product (factor income) and municipal residents' income (distributed income), and then, using the relationship, we estimated municipal residents' incomes from the net municipal product for the period before 1971:

Estimation period: FY1972 to FY1993

$$DY = \underset{(-2.41)}{-39484.4} + \underset{(32.37)}{0.918943}\,YY$$

$$\bar{R}^2 = 0.9822;\quad \text{Standard Errors} = 26236.81$$

where DY denotes per capita municipal residents' income (distributed income), YY is per capita net product (factor income) and the values in parentheses are t-statistics.

3.2 Calculation of SO_X emissions before 1971

Since the emission of SO_X is expected to be highly related to the observed SO_X pollution intensity, we estimated the average emissions in Yokkaichi before 1971 from the estimated equation of the observed SO_X density in the Isogo region. The SO_X pollution density in the Isogo area and the average SO_X pollution density in Yokkaichi have been published in "Environmental Conservation in Yokkaichi (Yokkaichi no Kankyo-Hozen)," respectively. Since the measures for heightening chimneys to lower the SO_X pollution density had been in place since 1965, a strong correlation between SO_X emissions and the pollution density in the air could be expected.

Estimation periods: FY1972 to FY1993

$$ISO = \underset{(14.36)}{0.007} + \underset{(14.03)}{0.0003}\,SOX$$

$$\bar{R}^2 = 0.9077;\quad \text{Standard Errors} = 0.00178$$

where ISO denotes the density in the Isogo region, SOX is the SO_X pollution density in the air and the values in parentheses are t-statistics. Since the adjusted-to-degree-of-freedom coefficient is 0.9077, the performance of the estimated equation may be considered to be fairly good. Estimation of the coefficient of SOX in the Isogo area is statistically significant because of the t-value of 14.03.

Although the data on fuel inputs are available after 1972, the data of the ratio of sulphur content in the fuel input are not. So, we estimated the ratio by using the calculation of the average percentage constituent of sulphur in the "Survey on the Evaluation of Development and Environment (1994)" (data after 1959 are available). We also calculated the fuel-oil inputs before 1971 from the equation estimated by the activity level of the complex and the relative prices of fuels.

Given the restricted availability of data, the activity level of the complex is substituted by the national production level of naphtha as a proxy, which is considered to have a strong correlation, and the relative price is defined as the ratio of the import price of oil (on yen basis)/ the wholesale prices of petroleum and coal products. The result is as follows:

Estimation periods: FY1972 to FY1992

$$\log(FUEL) = \underset{(9.225)}{3.701} + \underset{(8.227)}{0.372}\log(NAFU) - \underset{(5.882)}{0.4.07}\log(WPI/PI) + \underset{(8.196)}{0.444}\,DUM$$

$\bar{R}^2 = 0.90975$; Standard Errors=0.0817

where $FUEL$ denotes fuel inputs, $NAFU$ is the naphtha production level, WPI is the wholesale price, PI is the import price and values in parentheses are t-statistics. DUM stands for a dummy, which takes 1 during 1989 and 1992, and 0 for other periods. The degree-of-freedom-adjusted coefficient is 0.909 and the t-statistics are all within the 1% statistically significant rejection ranges.

Making use of the equation, we calculated the fuel-oil inputs before 1971 and connected to the data after 1972. Multiplying the estimated fuel inputs by the average percentage constituent of sulphur in the "Survey on the Evaluation of Development and Environment" (1994) for each year and converting to the SO_X weight, we obtain the SO_X weight in the fuel inputs.

3.3 Calculation of investment in abatement

We estimated the total private investment in abatement as follows: The amount of investment in abatement has been published in The Regional Environmental Pollution Control Program in Yokkaichi (Yokkaichi Kogai-Boshi Keikaku) since 1971. This includes investments in abatement both by the public and the private sector in the Yokkaichi area. However, there are some reservations. First, since public investment includes not only investments against industrial pollution but also those against pollution from urban and city life, we must take away the latter for our purpose. Second, although the investment by the private companies are those in Yokkaichi, some investments by the public sector, e.g., the Mie Prefecture and local governments of surrounding districts, may be done outside of Yokkaichi. We must also take away these except for investments financed by subsidies from other governments to Yokkaichi.

Finally, there remains a problem in estimating investments in abatement before The Regional Environmental Pollution Control Program in Yokkaichi. Even before the Plan, investments such as heightening chimneys were undertaken since the Yokkaichi petrochemical complex had operated since 1957. Because of the nature of statistics, no breakdown of investors was given for the investments during the period. Hence, we estimated environmental or pollution prevention investment for factories in a convenient way: Investments in (1) river-basin sewerage systems; (2) installation of public sewerage systems and (3) installation of waste-disposal plants are excluded as they are not environmental or pollution prevention investments for industries; and (6) investments in industrial waterworks which the Mie Prefecture alone undertook is also excluded. For environmental or pollution prevention investments of private companies, we used the data from "Survey on the Evaluation of Development and Environment" (1994). Since the capturing rate of this data is about 60.9% on average for the period after the Regional Environmental Pollution Control Program in Yokkaichi (i.e., 1971 to 1993) and is steady, we used this rate to allocate investment between Yokkaichi and other governments. We obtained the data on sundry expenses involved in pollution prevention investments from the budgets of Yokkaichi City after 1960. Since the amount of sundry expenses underestimates environmental or pollution prevention investments undertaken by Yokkaichi City, we estimated the public investment of the period from 1960 to 1970 by allocating with the average capturing rate of the sundry expenses on environmental or pollution prevention investment (15.7%) for the period of The Regional Environmental Pollution Control Program in Yokkaichi (i.e., from 1971 to 1993).

4. Conclusion

We may conclude the analysis as follows: (1) The Yokkaichi area has succeeded in reducing SO_X emissions even at a relatively low income level, and (2) the inverted U-shape was brought about by technical progress in cleaning up the environment but not by the declining output levels, despite increases in output level. The technical progress was made possible by local residents' campaigns and administrative environmental measures backed up by the campaigns. Both the strong preference of the residents for environmental quality and the environmental measures of the Yokkaichi City and the Mie Prefecture government, backed up by the local residents' campaign, played critical roles in encouraging environmental technical progress and thereby improving the quality of the environment. It should be noted that the local residents' campaigns moved and backed up the local governments, in contrast to the SO_X reductions in developed economies in 1980 pushed by the international agreements, i.e., Sulphur Protocols (see De Bruyn (1997)). The fact that the pollution intensity decreased before the environmental Kuznets curve reached its peak means that the environmental technology of companies could still not catch up with the regulations, not that the regulation was ineffective.[28]

If rapid economic development is not possible for developing economies without heavy industrial sectors rather than industrialization as suggested in Ang (1987), Haung (1993) and Ang and Lee (1994), the pressure on appropriate environmental policies will become greater. Although the situation facing developing economies may be different from that experienced by Yokkaichi as the pollution prevention technologies have already been developed sufficiently, the experience of Yokkaichi may have important implications for other, especially developing, economies. In fact, ICETT (1997) showed that three-year-earlier introduction of the total discharge amount regulation would decrease human damage substantially by a simulation analysis of air pollution in Yokkaichi, while Yoshida (2002, p. 110) introduced the grave concern of the Japanese central government that a heavy toll of pollution victims could deal a fatal blow to the industrialization in Japan in the mid-high-growth era.

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Notes

1. For a survey on SO_X emissions environmental Kuznets curve studies, see also Markandya et al. (2006) and Tsurumi and Managi (2010). Stern and Common (2001) suggested that the coverage of sample countries or regions affects the result, while Halkos (2003) showed that the result may depend on the choice of econometric method.

2. See also Copeland and Taylor (2003).

3. Levinson (2010) showed that the United States has imported less-polluting goods since the 1970s, that is, it has not exported pollution. Contrastingly, Murdoch et al. (1997) asserted that reductions in SO_X emissions in the 1980s were not a burden to the economies which export most of their pollution. See also the survey by Thompson and Strohm (1996).

4. For an empirical and theoretical survey, see, for example, Carson (2010).

5. Factories of the petrochemical complex are considered as the factories (e.g., Mitsubishi Petrochemical) which are supplied fuel oil by oil refining companies (e.g., Showa-Yokkaichi Oil).

6. We are greatly indebted to ICETT (1994) for this subsection.

7. A period from 1955 to 973 is called the high growth era, whose average economic growth rate was over 10%. In 1968, the level of GDP in Japan became No. 2 in the world.

8. The pollution prevention measures undertaken by Mie Prefectural Authority will be surveyed in the next section. Yoshida (2002, P. 203) emphasized that the Compensation Act on Pollution-Caused Health Damages (Kogai Kenko Higai Hosho Ho) included compensation for the loss of ability to work, and the surcharge system for financing the compensation costs played an important role in reducing SO_X emissions as the strongest surcharge system in the world. The system imposed surcharges on companies depending on their respective SO_X emissions.

9. Given the availability of the data, we use variables for Yokkaichi in fiscal years in the present paper.

10. Although the per capita income data have been published since 1972, they did not reflect various changes in estimation methods. However, we use these data without corrections or revisions in spite of the problems.

11. The survey was carried out in August 1994 as a part of the research for ICETT (1997). For details, see Nishigaki et al. (1995) and ICETT (1997).

12. Yokkaichi City (2000) stated that it overcame the pollution problem through reducing SO_X intensity below the national standard in 1976, whereupon the city received the Global 500 Award from the UNEP (United Nations Environment Program) in 1995. Yoshida (2002) also mentioned that the "Yokkaichi Kogai (pollution)" was nearing a solution in the second half of the 1970s. The incidence rate of new asthma patients in the polluted area became as low as those in other areas in 1981, and the difference in mortality from chronic bronchitis between the

two areas disappeared in 1980 (Yoshida 2002, p. 201). Miyamoto et al. (2008), on the other hand, asserted that the problem has still not been resolved, as can be seen from the problem of stock pollution such as ferro-silt buried by Ishihara Sangyo.

13. Population in the coastal area had decreased by 20 thousand during the period from 1965 to 1975 (Miyamoto et al., 2008, p. 39; Yoshida, 2002, p. 95). Residents mostly moved to the hilly areas on the west side of the city or other cities and towns. In this sense people were crowded out of the area.

14. The exchange rate in each year is the simple average over the monthly rates.

15. Most of the empirical literature found an inverted U-shape or a monotonically increasing curve. Harbaugh et al. (2002), for example, showed the possibility of the inverted U-shape, while mentioning that a U shape is impossible since pollution emissions are zero when the income and production level are zero. Although the datum of per capita income and emissions for the period from the end of the World War II to the date of the operation of the No. 1 (Shiohama) petrochemical complex, the production facilities were destroyed and the production level was plausibly expected to be near zero at the end of the War.

16. Harbaugh et al. (2002) also reported that SO_2 concentrations in Canada and the United States have declined over time at ever decreasing rates. Stern and Common (2001) derived a linear relationship from the sulphur emissions data of a world sample of 73 countries and the inverted U-shape from samples of high-income economies for 1960 to 1990. ICETT (1994) reported that both the ratios of areas polluted by 0.5 mg/day and 0.1 mg/day of SO_X in the Yokkaichi region were the highest in 1971, since the polluted area expanded to the west regions, for example, by taller chimneys.

17. The US GDP deflators are obtained from the website of the US Commerce Department. The basic year is 2005. (www.bea.gov/national/nipaweb/Tableview -asp?SelectedTable=4&ViewSeries=NO&Java=no&Request3Place=N&3Place=N&FromView=YES&Freq=Year&FirstYear=1960&LastYear1995, cited on 19 Aug 2010).

18. Most of the literature represented the income levels in terms of 1985PPP$, so we can not precisely compare our level with those in the literature. We translate the current-dollar income levels to those in dollars in 1985 prices in a rather loose way, since it would be difficult to obtain the exact income levels in Yokkaichi in 1985 U. S. PPP dollar terms. It should be noted that although the data in the most foregoing literature are panel data, we compare the time-series income levels in Yokkaichi with those in the literature.

19. Yoshida (2002) mentioned that the SO_X density in Isozu area had reached 2.5 ppm, while the safe level was said to be about 0.018 ppm/hour. The geographic and meteorological conditions might make the situation worse. Yokkaichi is a narrow area hemmed in by the Ise Bay from the west and the Suzuka mountains from the west. Ono (1971) mentioned that the

area is not a suitable site for petrochemical complexes. For the map of the complex area, see, for example, Yoshida et al. (1966).

20. According to ICETT (1994), anti-pollution facilities equipped in Yokkaichi by 1966 amounted to ¥6380 million (the cost of preventing air pollution including desulphurization was ¥2986 million). The total income in Yokkaichi in 1966 was ¥56991 million.

21. Twenty countries agreed on the First Sulphur Protocol in Helsinki in 1985, and 27 countries, including European countries, the US and Canada, participated in the Second Sulphur Protocol in Oslo in 1994.

22. It should be recalled that the relationship between fuel input and naphtha output was used in the calculation of SO_X emissions.

23. The close relationship between fuel inputs and output is already assumed in the calculation of fuel inputs.

24. According to Brock and Taylor (2010), the peak of the total flow of SO_X emissions in the United States was 1973, while the pollution intensity (:= total emissions of SO_X/output) had decreased from 25 years ago. Per capita GDP of the United States in 1973 is US$14739 at the 1985 world price (Penn World Table5.6, http://dc1.chass.utront.ca/cgi-bin/pwt/format/?s=USA/RGDPC).

25. The time path of the real amount of pollution investment has qualitative properties similar to those of a nominal one, although the real one was about half of the nominal one around 1990.

26. For calculation of investment in abatement, see the next section.

27. Brock and Taylor (2010) showed that investment in abatement increased largely around the peak of the total emissions around 1973, asserting that the return rate on capital exceeded the rate of environmental technology progress, resulting in the inverted U-shape environmental Kuznets curve and that the same situations could also be observed in Europe.

28. Whether or not the so-called Porter Hypothesis holds requires more analysis. For the Porter Hypothesis, see, for example, Porter and Linde (1995).

Appendix: Environmental Kuznets Curve in Yokkaichi

Year	Real per capita income in 1985 US$	SOx emissions per capita (tons)
1964	1452.50	0.945
1965	1500.79	0.819
1966	2050.08	0.687
1967	2729.28	0.983
1968	3374.22	0.591
1969	4015.28	0.569
1970	4978.18	0.437
1971	5837.22	0.538
1972	6104.14	0.303
1973	8255.00	0.208
1974	8542.34	0.119
1975	7392.88	0.084
1976	8007.71	0.071
1977	9816.86	0.057
1978	12276.26	0.048
1979	10337.11	0.043
1980	12364.53	0.039
1981	10187.21	0.033
1982	9218.38	0.030
1983	9532.16	0.024
1984	8912.89	0.024
1985	11678.61	0.017
1986	14811.26	0.016
1987	19993.79	0.013
1988	21162.98	0.012
1989	19047.46	0.012
1990	20919.67	0.012
1991	226.03.68	0.012
1992	21772.06	0.008
1993	23409.05	0.008