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Abstract

Unprecedented industrial development in Indonesia during the last two decades, accompanied by a growing population, has increased the amount of environmental damage. One of the most important environmental problems is that the level of air pollution in several large cities has become alarming, particularly in the last few years. This high pollution level has stimulated the government to develop a national clean air program designed to control the quantity of pollutants in the air. However, the impact of this national clean air program on national economic performance and household incomes has not yet been analysed systematically. The main goal of this paper is to analyse the expected impact of the clean air program on national economic performance and household incomes for various socio-economic groups.

Key Words:

Environmental economics, computable general equilibrium model.

Introduction

Industrial development, coupled with an expanding population, has increased the amount of environmental damage in Indonesia. One of the most important environmental problems is that air pollution levels in several large cities have become alarming, particularly in the last few years (World Bank 1994, Resosudarmo and Thorbecke 1996, Soedomo *et al*. 1991). In parts of Jakarta, Surabaya and Bandung, for example, the air pollution concentration levels for suspended particulate matter (SPM), nitrogen dioxide (NO_2) and lead are far above the allowable World Health Organization (WHO) standards for air quality (Table 1).[1] Indeed, Jakarta is reported as having one of the worst urban air pollution conditions in the world (World Bank 1998).

Table 1 Air pollution levels in large cities

(micrograms per cubic metre: ? g/m^3)

	SPM	NO_2	Lead
Jakarta	290	250	2.9
Surabaya	190	120	2.7
Bandung	110	100	2.5
WHO standard	60	40	0.5

These alarming air pollution levels in large urban areas stimulated the government to develop a national clean air program, called the Blue Sky Program, to control the ambient level of air pollutants in urban areas. The government plans to start implementing this clean air program in the near future (Sutamihardja 1994).[2]

Studies analysing the potential benefits of this national clean air program are very limited. In 1994 Ostro argued that reducing the ambient level of air pollutants in Jakarta to the WHO standard for allowable air pollutants could substantially reduce certain health problems. The Indonesian Environmental Impact Management Agency (BAPEDAL) is currently analysing the benefits of improvement in air quality and the costs of imposing a national clean air program throughout large cities in the country.

[1] Below this standard undesirable human health effects do not occur.
[2] The economic crisis that started in 1997 has delayed the implementation of this program, however.

Both these studies have their limitations. They examine the partial impact of a national clean air program on the economy without taking into account the overall or the general equilibrium impact of the program. Furthermore, neither study analyses the impact of air quality improvement on national economic performance and household incomes for different socio-economic classes. For Indonesia, especially during the current economic crisis period, strong economic performance and protecting the incomes of poor households are major goals. The government wants only to implement environmental policies that are compatible with solid economic performance and maintaining or increasing the incomes of poor households; it would be reluctant to sacrifice growth and equity objectives in order to improve the environment.

This paper aims to determine the overall impact of air quality improvement that might be expected from the implementation of the clean air program on national economic performance, measured by Gross Domestic Product and by household income for various socio-economic groups. Furthermore, it searches for a strategy to implement air pollution policies so that air quality can be improved while maintaining relatively strong economic performance and inducing higher incomes for low-income households.

The Blue Sky Program

At the beginning of the 1980s, it was felt that air pollutants in urban areas had become intolerable. As a result, several government agencies undertook separate activities to monitor air pollution and to observe its impact on health in large cities. As of 1991, the Bureau of Meteorology and Geophysics had approximately 20 air pollutant monitoring stations in large cities throughout the country. Other agencies, such as the Health Ecology Division at the Ministry of Health, the Jakarta Municipal Government, and the Jakarta Research and Development Centre for Urban Areas and Environment, also operated air pollutant monitoring stations, although all of its stations are in Jakarta. The majority of these monitoring stations in large cities showed that the ambient level of air pollutants such as SPM, NO_2, lead, carbon monoxide (CO) and sulphur dioxide (SO_2) had increased during the 1980s (Sutamihardja, 1994). These stations also indicated that the concentrations of SPM, lead, CO and NO_2 in certain areas of large cities exceeded the WHO standards for air quality.

In 1991 the Bandung Institute of Technology (ITB) produced maps of levels of air pollutants such as SPM, NO_2, CO and SO_2 for the Java cities of Jakarta, Bandung and Surabaya for 1989 (Soedomo *et al*. 1991). These maps show the annual average ambient levels of air pollutants in different neighbourhoods in each city. In 1993 the Agency for the Assessment and Application of

Technology (BPPT), working together with the German Ministry of Technology, published average 1991 ambient levels of air pollutants for the entire island of Java (BPPT and KFA 1993).

Following these air pollution monitoring activities, researchers in the Health Ecology Division at the Ministry of Health and in the Department of Public Health at the University of Indonesia studied the impact of air pollutants on human health in large cities, particularly Jakarta. In 1987 Tri-Tugaswati *et al*. (1987) showed that the level of lead in the blood and urine of public transportation drivers was twice as high as its level in farmers living in the environs of Jakarta. In a study analysing the impact of CO and lead on human health, Achmadi (1989) found that public transportation drivers, street vendors, and people who live in high traffic areas have 12.8 times the risk of contracting health problems associated with CO and lead than people who live in suburban areas.

Results from air pollution monitoring activities and from studying health impacts of air pollutants in large cities stimulated government agencies to create programs to control these air pollutants in urban areas. In 1992 BAPEDAL started to develop the Blue Sky Program (BSP). The BSP has two components. The first is the BSP—Air Pollutants from Mobile Sources. The second is the BSP—Air Pollutants from Stationary Sources. The BSP is designed to serve as an umbrella for various government programs and activities to control air pollution.

BSP—Air Pollutants from Mobile Sources

The goal of the first component of the BSP is to control air pollutants from mobile sources (i.e. motor vehicles). Policies under consideration include:[3, 4]

?? **Reducing the Lead Content of Gasoline:** The lead content of gasoline is presently about 0.40 g/l (gram per liter). The government wants to reduce this to 0.04 g/l ('unleaded' gasoline). Since mid-997 unleaded gasoline has been available on the market, but annual sales are only 0.025 per cent of annual total oil-based fuel consumption in the transportation sector, since the price of unleaded gasoline is still approximately 30 per cent higher than that of leaded gasoline.

?? **Increasing Prices of Gasoline and HSDO:** The government plans gradually to increase prices of gasoline and high-speed diesel oil (HSDO) by reducing subsidies until they are at the same level as world gasoline and HSDO prices. In mid 1998 it increased prices of gasoline and

[3] Information on air pollutant abatement policies being considered by the Indonesian government was provided by the BAPEDAL, unless mentioned otherwise.

[4] This paper includes as much information as is currently available on each of the policies. Only limited information exists for certain policies; this lack is reflected in correspondingly brief descriptions in this section.

HSDO by approximately 40 and 45 percent, respectively. Even so, gasoline and HSDO prices are still approximately 25 and 45 percent, respectively, below the world market prices.

?? **Promoting the Recovery of Vapour Emissions:** The goal of this policy is to reduce the amount of gasoline vapour[5] emitted into the atmosphere when gasoline tanks are filled. The government will require gas station owners to adopt technologies to achieve this end.

?? **Introducing an Emission Standard for New Vehicles:** The government plans to implement a very strict emission standard for new vehicles. With the new standard, most likely new vehicles will need to be fitted with catalytic converters. This policy aims to limit the increase in air pollution levels as vehicle numbers rise.

?? **Establishing a Roadside Inspection Program:** This policy is designed to control air pollutants from vehicles in use. It is suspected that the worst 10 per cent of polluting vehicles generate about half of total pollution (World Bank 1993). To implement this policy, the government plans to build vehicle emission testing centres in several large cities. An emission standard for existing vehicles will also be introduced.

?? **Phasing Out Two-Stroke Engines:** The reason for phasing out two-stroke engines is that they generate approximately 40 per cent more pollution than four-stroke engines of the same size (World Bank 1993). Currently, approximately 50 per cent of motorcycles in Indonesia have two-stroke engines. These engines contribute approximately 20 per cent of the SPM, NO_2, and lead pollutants in the air.[6]

?? **Substituting Compressed Natural Gas (CNG) for Other Fuels:** Substituting CNG for gasoline could reduce SPM and CO emissions by up to 90 percent. The reduction will be even greater when substituting CNG for HSDO. Several types of public transportation will be required to undertake this substitution. Vehicle owners will be given an incentive to install conversion kits that enable their vehicles to switch from gasoline and HSDO to CNG.

BSP—Air Pollutants from Stationary Sources

The second component of the BSP will attempt to control air pollution from stationary sources such as factories and open burning municipal wastes. This program is still in its very preliminary planning stages, and no detailed studies have yet been conducted to estimate the investment costs of the different components of this program.

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[5] Gasoline vapour contains, among others, nitric oxide, nitrogen dioxide, and volatile organic compounds (VOC).

To control air pollutants from factories, the government plans to (1) introduce industrial emission standards; (2) promote energy-efficient technologies; (3) require every factory to conduct a detailed environmental impact analysis; and (4) increase public pressure by announcing to the general public companies' environmental performance according to their success in reducing pollution. For the open burning of municipal wastes the government plans to improve existing municipal waste management, including building incinerators.

The Model

This paper utilizes a Computable General Equilibrium (CGE) model.[7] In the model, links between air pollution and the economy focus on the relationships between urban production activities, urban air quality, and health problems in urban areas, as shown in Figure 1. The use of oil-based fuels in production activities contributes to air pollution in urban areas. A high level of ambient air pollutants in these areas causes a correspondingly high number of air pollutant-related illnesses. These illnesses cause urban households to spend money on medical care and also reduce the productivity of labour in urban production activities. It is assumed that urban production activities are non-agricultural.

Facts and relationships important to understanding the impact of implementing a national clean air program on air quality and the economy simulated in this paper are as follows. First, a national clean air program might require the government and/or private sector to spend money to adopt different technologies and implement services to reduce the quantity of pollutants released in the air. In this paper, the government and the private sector use their savings to finance these technologies and services. These savings also provide the budgets for all new capital investments throughout the economy. To finance air pollution abatement technologies, the government and private sector must therefore reallocate these capital budgets. Second, implementation of a clean air program reduces the quantity of pollutants released into the air by various economic activities and thus improves ambient air quality in urban areas. The improvement in urban air quality reduces the number of air pollutant-related illnesses. Third, reduction in the number of air pollutant-related illnesses improves the productivity of labour in urban production activities. This improvement in labour productivity ultimately increases the overall effectiveness of all other factor inputs in urban production activities. Fourth, reductions in the number of air pollutant-related illnesses also lowers

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[6] Motorcycles include the *bajaj* and the *bemo* (three-wheeled vehicles used for public transportation).

[7] See Resosudarmo (1996) for the full CGE program utilized in this paper.

the amount spent by urban households on health treatments. These lower health costs enable urban households to consume more of other goods and services.

National Economic and Air Pollutant Health Problem Data

The main data source used in this paper is the 1990 Social Accounting Matrix (SAM) from the Central Statistics Agency.[8] This paper modifies the SAM so that the new classification of commodities includes five different types of oil-based fuel: gasoline, HSDO, industrial diesel oil, kerosene and fuel oil.[9] Furthermore, in the new classification, the Air Pollutant-Health Service sector (health service activities associated with air pollutants) is separated from the Public Service sector.

The procedure to estimate the number of occurrences of health problems associated with air pollutants utilizes dose-response functions collected by Ostro (1994) from epidemiological literature. Dose response functions estimate the number of people who contract certain kinds of air pollutant health problems given the number exposed to a pollution level above the WHO standard. The same approach can also be used to determine the number of restricted activity days (i.e. time away from work) associated with air pollutants.

This paper limits itself to estimating the health problems associated with SPM, NO_2 and lead, for which relevant data are available, in contrast with the paucity of data for other air pollutants.

The maps published by BPPT focus on Java and indicate that three cities have air pollution levels above the WHO standard for air quality—Jakarta, Bandung and Surabaya. To estimate the health effects of air pollutants in these three cities the detailed city maps of air pollution developed by ITB are utilized. Based on these maps, population distribution data, and the dose-response functions, the total number of health cases associated with air pollution in Jakarta, Bandung and Surabaya can be estimated.[10] In 1990, these health problems included 40 million cases of respiratory symptoms, 560 thousand cases of asthma attacks, and 190 thousand cases of hypertension.

Since no air pollution map is available for regions outside Java, an approximation must suffice. Note that all cities outside Java other than Medan have populations much lower than

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8 A more recent SAM cannot be used in this paper, since no more recent map of air pollution is available.

9 See Lewis (1993) on how to disaggregate the oil refinery sector to the gasoline, HSDO, industrial diesel oil, kerosene and fuel oil sectors.

10 See Resosudarmo (1996) for the detailed methodology for estimating the number of health problems related to air pollution.

Jakarta, Bandung and Surabaya. Since the population of Medan is close to that of Bandung, Medan is assumed to have as many cases of health problems associated with air pollution as Bandung. Other cities outside Java are assumed to have no serious health problems associated with air pollution.

Information on the costs of medical treatment (including information on government subsidies) is derived from interviews with medical doctors working in public hospitals and public health centres in Jakarta. The total treatment cost for health problems associated with air pollutants in 1990 is estimated to be approximately Rp 45.5 billion.

Simulation Scenarios

This section describes the simulation scenarios that show the impact of selected BSP air pollution abatement policies on the national economy. The policies simulated below are those that the government will most likely implement in the near future and for which data are available on their implementation cost and on the air pollution reductions that they would achieve. The policies are only from the BSP—Air Pollutants from Mobile Sources program.

As mentioned before, the main data source for the CGE in this paper is the 1990 SAM. So, before running the simulation scenarios, the model is calibrated so as to mimic performance of the economy from 1990 until 2000. Then the model is run to simulate several scenarios for a 20-year time horizon, from 2001 until 2020.[11] The scenarios simulated are as follows:

?? **Base Case:** This scenario assumes that the government does not introduce any air pollution abatement policies during the 2001-2020 time horizon.

?? **Unleaded Gasoline Policy:** As mentioned above, unleaded gasoline is already available, but its price is higher than that of leaded gasoline. This scenario assumes that the government equates the prices of leaded and unleaded gasoline, and requires the national oil company to reduce the supply of leaded gasoline while increasing the supply of unleaded gasoline. In the first year, only 25 per cent of the total gasoline consumed is unleaded. In the second, third and fourth years, the percentages become 50, 75 and 100 percent, respectively, of total gasoline consumed. The national oil company needs to invest as much as Rp 60 billion in 1990 prices to be able to produce unleaded gasoline for the whole country.[12]

[11] Prices in any year of the simulation are in real terms.

[12] This cost is based on information from a consultant firm hired by BAPEDAL.

Note that it is common for the switch to unleaded gasoline to be followed by a requirement to install catalytic converters in new vehicles.[13] This paper hence adopts two variants of the Unleaded Gasoline Policy:

1. **With Catalytic Converters:** Along with the unleaded gasoline policy, from 2001 the government requires new vehicles to be installed with catalytic converters. Using private sector funds, automotive factories modify their assembly lines so that they can produce catalytic converters and install them in new vehicles.[14]
2. **Without Catalytic Converters:** During the simulation horizon, there is no requirement to install catalytic converters.

?? **Phasing Out Two-Stroke Engines Policy:** This scenario assumes that, from 2001, the government bans the use of two-stroke engines in large cities and requires factories to stop producing two-stroke engines. Existing two-stroke engines are assumed to be sold to users in rural areas. Using private sector funds, automotive factories modify their assembly lines so that they do not produce two-stroke vehicles after 2003. It is estimated that the total investment required is approximately Rp 15 billion. This policy is expected to reduce SPM, NO_2 and lead emissions from gasoline by approximately eight per cent.

?? **Vehicle Emission Standard Policy:** This scenario assumes that, from 2001, the government requires vehicle owners to comply with the Indonesian Vehicle Emission Standard for new and existing vehicles. It is further assumed that in 2001 the government builds eight emission testing stations—five in Jakarta and one each in the cities of Bandung, Surabaya and Medan. Then, every year starting in 2002, the government builds two more emission-testing stations and locates them in various large cities.[15] Vehicle owners have to test their vehicles' emissions once every year at these testing stations. Roadside inspection on a random basis is also conducted to help ensure that all functioning vehicles in these cities comply with the emission standard.[16] This scenario assumes that no significant investment is needed for vehicle factories to improve the performance of new vehicles. Another assumption is that owners of existing vehicles either

[13] Catalytic converters work effectively with unleaded gasoline.

[14] To avoid any vehicle price increase caused by this requirement, the government subsidises the cost of producing new cars with catalytic converters for the first three years. It is estimated that the subsidy needed is approximately 0.5 per cent of the total cost of producing new cars.

[15] More emission-testing stations will be built in Jakarta, Surabaya, Bandung and Medan. If there are enough stations in these four cities, stations will be built also in other large cities, such as Semarang, Solo and Yogyakarta. The cost of one monitoring station is assumed to be approximately Rp 1 billion.

[16] Vehicles from other areas have to comply with the emission standard if they enter Jakarta, Bandung, Surabaya or Medan.

improve vehicle maintenance so that the vehicle complies with the emission standard,[17] or they move the vehicle to a rural area. Well-maintained vehicles are assumed to be five per cent more efficient in gasoline and HSDO use than poorly maintained vehicles. Air pollutant emissions from vehicles is expected to decrease by approximately 15 per cent.

?? **Gasoline and HSDO Pricing Policy:** Government subsidies on gasoline and HSDO were approximately 40 and 70 per cent of total production costs, respectively, in 2000. This scenario assumes that, in 2001, the government reduces subsidies on gasoline by five per cent (so that the total government subsidy is approximately 35 per cent of the total production cost) and on HSDO by ten per cent (so that the total government subsidy is approximately 60 per cent of the total production cost). In 2003, the government again reduces the subsidies on gasoline and HSDO by five and ten percent, respectively (so that the subsidies are approximately 30 and 50 per cent of total production costs). In 2005, the government once more reduces these subsidies by the same percentages. It is believed that when subsidies are reduced and the prices of these fuels increase, people will improve their efficiency in using gasoline and HSDO. It is not clear, though, by how much they will do so. Hence this paper focuses on two extreme outcomes, with the actual outcome falling somewhere in between. These extremes are as follows:

1. **Pessimistic:** This scenario assumes that people are not able to improve their gasoline and HSDO efficiency, even though prices increase.
2. **Optimistic:** This scenario assumes that people are capable of increasing their efficiency in using gasoline and HSDO by as much as the percentage increases in prices, so their net cost of fuel is not changed.

?? **Combined Policy:** This scenario simulates a scenario in which the government implements all of the above policies together, starting in 2001. This Combined Policy will have two possible outcomes, reflecting the Pessimistic and Optimistic Outcomes of the Gasoline and HSDO Policy.

Results and Discussion

This section presents and discusses results of the simulation scenarios. Note that all policies are assumed to be implemented starting in 2001, after establishing the initial conditions in 2000. In this

[17] Improving maintenance of existing vehicles in this scenario is assumed to be not costly. Existing vehicles should be tuned-up two or three times a year. If this regular tune-up doesn't work, then owners will sell their vehicles to rural areas.

section the simulation results from the various air pollution abatement policy scenarios are compared with the Base Case.

Table 1 exhibits indicators of urban air pollution levels under all scenarios, including the Base Case, in 2020. Table 2 shows numbers of cases of various health problems caused by air pollutants in urban areas, the estimated total cost associated with these health problems, and the expected impact of air pollution abatement policies on these health problems and their costs. Table 3 presents the estimated impact of various air pollution abatement policies on the total present value of GDP and household income gains during the 20 year time horizon for implementation years of these policies (as depicted in Figure 2).

Impact on Ambient Levels of Air Pollutants

Columns (3) and (4) in Table 1 show that the introduction of the Unleaded Gasoline Policy, with or without catalytic converters, will effectively reduce the ambient concentration of lead in urban air to approximately zero, thus more than fulfilling the WHO air quality standard for lead. The Unleaded Gasoline Policy with catalytic converters is also the most effective single policy for countering the increasing trend of SPM and NO_2 air pollution,[18] although it is not able to reduce their levels to below their 2000 levels, for the following reasons.

First, in the case of SPM, the transportation sector only contributes about 30 per cent of SPM pollution in urban areas. Hence, although catalytic converters reduce SPM emitted by cars by up to 90 per cent, this policy is only able to reduce the SPM level in 2020 such that in 2020 it is still 2.05 times its level in 2000. Second, in the case of NO_2, the transportation sector contributes only about 60 per cent of NO_2 pollution in urban areas. Catalytic converters are only able to reduce NO_2 emitted from cars by approximately 40 per cent. Therefore, this policy fails to reduce the 2020 level of NO_2 in urban air below its level in 2000.

Indeed, columns (9) and (10) show that, even after implementing all four pollution abatement policies together (including introducing catalytic converters and focusing on the most optimistic outcome), concentrations of SPM and NO_2 in 2020 remain significantly higher than those in 2000. Recall that the 2000 ambient levels of SPM and NO_2 in many parts of Jakarta, Bandung and Surabaya were higher than the WHO air quality standard.

One can conclude, then, that implementing air pollution abatement policies in the transportation sector (i.e. focusing on mobile sources) can reduce lead concentration in urban areas

[18] The oil-based pricing policy has a similar impact on NO_2 levels, but only assuming a highly optimistic outcome.

to meet the WHO air quality standard for lead, but it cannot reduce SPM and NO_2 concentrations sufficiently to meet the WHO standards for these pollutants. To do so, air pollution abatement policies will also need to focus on stationary sources such as manufacturing, burning of waste, and construction activities.

Impact on Air Pollution Health Problems and Costs

From Table 2 it can be seen that by far the most effective single policy to reduce health problems and costs associated with air pollution is the shift to unleaded gasoline with catalytic converters. Clearly this policy is important to air pollution abatement.

It is interesting to observe is the simulated results of the gasoline and HSDO pricing policy. Table 2 shows that the impacts on air pollution health costs are quite different under the pessimistic and optimistic assumptions. Under the pessimistic assumption, this policy is only able to reduce the total present value of health costs by about Rp 12 billion. With the optimistic outcome, however, the reduction is as much as Rp 287 billion—i.e. approximately 24 times higher—making it the second most effective air pollution abatement policy for reducing total air pollution health costs. From this one may conclude that in implementing this policy it is very important to make sure that the optimistic outcome will obtain.

To ensure the optimistic outcome, the government needs to socialize this policy and conduct an effective educational campaign on how to improve the efficiency of fuel consumption long enough so that vehicle owners will be able to increase their efficiency in consuming gasoline and HSDO by, among others, better and regularly tune up their vehicles, better planning in using their vehicles, and drive/ride more efficient. Another strategy that the government needs to consider is to increase the prices gradually, so that vehicle owners have enough time to keep improving the efficiency of their fuel consumptions.[19]

Column (2) in Table 1 shows that urban air quality in 2020 will be approximately 3 times worse than in 2000, while column (2) in Table 2 shows that the number of air pollution-health problems in 2020 will be more than six times higher than in 2000. The reason why the number of health problems increases much more rapidly than the worsening of urban air quality is that more and more people each year will be living in urban areas. Thus the number of people who contract air

[19] If price increases come in small steps, people might just get used to each increase without changing behaviour. If the prices are adjusted in large steps, the impact will be greater so people will have a strong incentive to become more efficient. Hence, the gradual price changes should be significant enough so that there is enough incentive for people to change their behaviours.

pollutant related illnesses will grow faster than the concentration level of air pollutants in urban areas. Hence, in order to avoid more air pollutant related illnesses in urban areas, the implementation of air pollution abatement policies should begin as soon as possible.

Impact on GDP

Table 3 shows that the impact of all the pollution abatement policies on GDP is small.[20] Amongst all the policies considered here, the only one that induces a reduction in total present value of GDP during the 20 year simulation period is the unleaded gasoline policy without catalytic converters. The explanation is as follows. From 2001 to 2004, the government has to invest relatively heavily in the national oil company so that it can increase the supply of unleaded gasoline.[21] This investment involves foregoing opportunities to invest in other sectors. This has a negative impact on the economy, which can be thought of as the societal cost of shifting to unleaded gasoline.

During this investment period (2001–04) there are, nevertheless, some benefits from the implementation of this policy. Using unleaded gasoline significantly reduces the level of lead in air, and this decreases the number of urban residents who contract air pollution illnesses, in particular, hypertension and non-fatal heart attacks. With fewer health problems, urban workers—who are mostly members of the urban low income household group—are able to work more productively and to enjoy additional incomes net of health expenditures by virtue of spending less on health treatments. More productive workers and higher incomes of urban low income households affect the economy positively. This can be thought of as the societal benefit of shifting to unleaded gasoline.

During the investment phase it turns out that the benefit from having unleaded gasoline is smaller than the cost. Figure 3 shows that GDP under this policy is lower than under the Base Case during the 2001–05 period, with the gap increasing steadily. From 2006 the gap decreases, because there is virtually no further societal cost from switching to unleaded gasoline, while the societal benefit remains; GDP thus begins to increase faster than under the Base Case. Nevertheless it increases relatively slowly, such that up until 2020 it is still lower. On the other hand, if the shift to unleaded gasoline is accompanied by a requirement to install catalytic converters, it can be seen that the societal benefit is greater, since this policy also reduces SPM and NO_2 pollutants. Table 3 shows that the total present value gain of GDP over the 20 year period is positive. Thus it is apparent that the implementation of unleaded gasoline policy should be accompanied by a

[20] Note that GDP discussed here is GDP excluding air pollution health treatment. This enables us to see clearly the impact of air pollution policies on economic output other than air pollution related health service provision.
[21] The impact of this investment occurs after a one year lag.

requirement to install catalytic converters in cars, in order that the total present value of GDP gains is positive.

Impact on Household Incomes

Table 3 shows that the impact of each pollution abatement policy on household income for each group is small.[22] Even so, ensuring that the implementation of such policies does not negatively affect the incomes of households, particularly the poor-households, is important. Poor households are typically found in the Agricultural Employees, Small and Medium Farmers, Rural Low Income, Rural Non-Labour and Urban Low Income household categories. Agricultural Employee households are, on average, the poorest in the country (Thorbecke 1992; Resosudarmo 1996).

Two policies need to be observed carefully. First is the unleaded gasoline policy without catalytic converters. Under this policy, most households, except the Rural Non-labour, Urban Low Income and Urban Non-labour household groups, experience reductions in the total present value of income relative to the Base Case. On the other hand, under this policy with catalytic converters, only Rural High Income households suffer such a reduction. Second is the Gasoline and HSDO Pricing Policy under the pessimistic assumption, under which all households other than Rural Non-labour and Rural High Income households experience a decline in the present value of income. By contrast, if the optimistic outcome obtains, only Urban Non-labour households are negatively affected.

Impacts on Sectoral Value Added

Switching to unleaded gasoline without catalytic converters lowers the value-added of many production sectors compared to the Base Case (Table 4). Hence the income of most households is lower under this policy is reduced. Note that switching to unleaded gasoline with catalytic converters results in a much greater reduction of the number of most air pollution related illnesses than the reduction under the unleaded gasoline policy without catalytic converters. Thus urban Low Income households will have more income with which to purchase goods and services other than air pollution-health services. In particular, they will consume more food,[23] increasing value-added of the Food Processing and Food Crop sectors relative to the Base Case. These increases induce higher incomes for all households, particularly agricultural and rural households, compared to the Base

[22] Note that household 'incomes' discussed in this paper are incomes *net of air pollution health costs*. This enables us to see clearly the impact of pollution abatement policies on households' command over consumption other than treatment for pollution-related illnesses.

[23] Low income households' income elasticities for food are typically larger than for other goods and services.

Case. Thus most households benefit from the introduction of unleaded gasoline along with catalytic converters, although only to a very small extent.

Under the pessimistic assumption the implementation of gasoline and HSDO pricing policy lowers value added in many production sectors compared to their value added under the Base Case. On the other hand, if the optimistic outcome obtains, the value-added of most production sectors is higher (Table 5). Therefore, most household incomes are lower under this policy with the pessimistic assumption, while most are higher under optimistic assumption, compared with the Base Case.

It is important to note that, under the policy of switching to unleaded gasoline without catalytic converters, and under the pessimistic assumption of the gasoline and HSDO Pricing Policy, most poor households suffer lower income compared to the Base Case. Hence, it would seem advisable to require catalytic converters and to find ways to ensure that the impact of implementing the gasoline and HSDO pricing policy is as close to the optimistic outcome as possible. Overall, the simulation results would appear to support introducing unleaded gasoline along with catalytic converters, banning two-stroke engines, imposing vehicle emission standards, and adjusting gasoline and HSDO prices to world parity levels.

Conclusion

Bearing in mind the relatively small size of changes in many of the variables discussed above, it is important to note that these results need to be qualified. Since data are limited, the CGE model in this paper cannot capture perfectly all relationships within the economy, within the environment, and between the economy and the environment. The underlying assumptions and structure of the CGE model and the simulation scenarios also should be carefully examined (Resosudarmo 1996).

Given these caveats, several important conclusions can be drawn from the simulations described above. First, to be able to reduce all air pollution levels in urban areas below WHO standard levels of air pollution, abatement policies should be applied not only to mobile sources, but also to stationary sources of air pollution.

Second, to reduce the occurrence of air pollution illnesses, abatement policies should be implemented as soon as possible. From the simulation one learns that, even if the concentration of air pollutants in urban areas is relatively constant, more air pollutant-related health problems will occur over time since the rate of urbanisation is relatively rapid. The sooner the concentration of air pollutants can be lowered, the more health problems that might otherwise occur can be avoided.

Third, the decision to produce unleaded gasoline should be accompanied by a requirement to install catalytic converters on new cars. Results of the simulation show that introducing unleaded gasoline alone lowers total GDP and incomes of poor households compared with the Base Case during the 20 year simulation horizon. On the other hand, if unleaded gasoline is accompanied by catalytic converters, total GDP and incomes of all households other than Rural High Income households can be increased.

Fourth, phasing out two-stroke engines and implementing vehicle emission standards are good for the economy and household incomes, although their impacts on the economy and on air pollution are small. From Table 3 it can be seen that the implementation of these policies, whose costs are relatively small, induces higher GDP and household incomes for all groups than under the Base Case.

Fifth, when adjusting gasoline and HSDO price upwards, it will be important to find ways to ensure that the actual outcome is closer to the assumed optimistic outcome than to the pessimistic one. If the optimistic outcome occurs, total present value of GDP and incomes of most household groups will be higher than those under the Base Case during the 20 year of the simulation horizon. If the pessimistic outcome occurs, the total present value of GDP during the simulation horizon will still be higher than that under the Base Case, but not that of the income of most household groups. In particular, poor households will have lower total incomes under this outcome.

Finally, the government should consider producing only unleaded gasoline, requiring cars to have catalytic converters installed, phasing out two-stroke engines from urban areas, and imposing vehicle emission standards, as soon as possible. Gasoline and HSDO prices should be allowed to increase gradually and there are enough activities in socializing information on how to improve efficiency in fuel consumption, so that society can increase the efficiency of using gasoline and HSDO.[24] By implementing these policies, the government may expect to achieve an improvement of urban air quality as well as higher GDP and incomes of poor households.

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[24] See footnote number 19.

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Appendix

This appendix explains the features of the CGE model for analysing the impact of air pollution abatement policies on related health problems and the economy.

The model consists of six equation blocks, as follows:

- **Production Block**: This block represents the structure of production activities and producers' behaviour.
- **Consumption Block**: This block represents the behaviour of households and government.
- **Export-Import Block**: This block models exports and imports of goods and services (Armington 1969).
- **Investment Block**: This block simulates decisions to invest as well as the demand for goods and services used in the construction of the new capital.
- **Market Clearing Block**: This block contains market clearing conditions for labour, goods and services, and foreign exchange.
- **Intertemporal Block**: This block consists of dynamic equations that link future economic conditions to economic activities in the current year (Dervis *et al.*, 1982).

In the production block, a nested Constant Elasticity of Substitution (CES) function represents the production technology. At the upper level of this production function, output is defined as a CES function of composite intermediate input and value added. At the lower level, intermediate input is a Leontief function of several material inputs (see also Devarajan and Lewis 1991; Lewis 1991; and Resosudarmo 1996). Value added is a function of air pollution-related illnesses and factor inputs, in which factor inputs are expressed in a CES function. The value-added function is:

$$VA_i = HE_i \cdot \alpha_i \cdot \left[\sum_f \delta^v_{i,f} \cdot FD_{i,f}^{-\rho^v_i} \right]^{-\frac{1}{\rho^v_i}} \qquad \text{(A1)}$$

where:

i	is the production sector index
f	is the factor of production index (agricultural labourers, manual-clerical workers, professional personnel, land and capital)
VA	is composite value-added
HE	is the impact of human air pollutant-related illnesses on value added
FD	is factor input.

The impact of air pollutant-related illnesses on the value-added production activity (*HE*) is assumed to be a function of the number of restricted activity days caused by illness. It deserves mention again that this paper limits its analysis to air pollutant-related illnesses in urban areas and the impact of these illnesses on urban (non-agricultural) production sectors. The impact of air pollutant-related illnesses on the value added function is then as follows:

$$HE_i = \left(1 - \frac{RAD_i}{DA_i}\right) \qquad \forall\, i \notin \text{ agricultural sector} \qquad \text{(A2)}$$

and

$$HE_i = 1 \qquad \forall\, i \in \text{ agricultural sector} \qquad \text{(A3)}$$

where:

RAD is the number of restricted activity days caused by air pollutant-related illnesses

DA is the number of workdays that are available if no air pollutant-related illnesses occur.

From the relationships (A2) and (A3), one can see that an increase in the number of restricted activity days caused by air pollutant-related illnesses reduces the productivity of all factor inputs.

Production activities are linked to ambient air quality via the fixed proportion coefficients (input-output coefficients) of oil-based fuels. Ambient air quality is thus a function of the amount of oil-based fuels utilized in production activities. The input-output coefficients are a function of government and/or private sector spending on technologies and services that lead to more efficient use of oil-based fuels; i.e. the higher such spending, the lower the coefficients. For example, if vehicle owners spend more to make the use of gasoline more efficient, the gasoline input-output coefficient in the transportation sector decreases.

In the consumption block, ten different types of household group are distinguished. The expenditures of each household group on goods and services, except for necessary health treatments for air pollutant-related illnesses, are a function of prices and income. Each household group determines its expenditures by maximizing utility according to a simplified version of the Linear Expenditure System, subject to the group's budget constraint (Lewis, 1991). The budget constraint of each household group equals household income minus taxes, savings, necessary health expenditures associated with air pollutant-related illnesses, and net transfers among households. The following equation represents the budget constraint of each household group:

$$\sum_{i \in m} P_i \cdot C_{i,h} = Y_h - T_h - S_h - CH_h - TR_h \qquad \text{(A4)}$$

where:

h	is the household group index
m	is the index for health services consumed by households that experience air pollutant-related illnesses
P	is the price of commodities
C	is household consumption of commodities
Y	is household income
T	is income taxes
S	is household savings
CH	is household health costs associated with air pollutant-related illnesses
TR	is net household transfers.

Since this paper limits its analysis to air pollutant-related illnesses in urban areas, the health costs associated with these illnesses (*CH*) in relationship (A4) only appear in the budget constraints of urban household groups, i.e. for a non-urban household, *CH* is assumed to be zero. From the relationship (A4), one can see that a reduction in health costs associated with air pollutant-related illnesses effectively creates extra income for urban households to spend on goods and services other than air pollution related health treatment.

Household spending on health treatment associated with air pollutant-related illnesses depends on the number of these illnesses that occur. The quantity of air pollutant-related illnesses is a function of the ambient level of air pollutants. The ambient level of air pollutants is a function of the quantity of oil-based fuels used in economic activities. The following equation represents the number of air pollutant-related illnesses (see also Garbaccio *et al.*, 1999):

$$N_{p,k} \; ? \; ?_{p,k} ? ?_{an} \; ?_{l} \; ?_{l,p,an} ?? _{l,an} ? IN_{an} ? POP \qquad \text{(A5)}$$

where:

p	is the air pollutant index (SPM, NO_2 and lead)
k	is the air pollutant-related illnesses index (lower respiratory illnesses, asthma attacks, respiratory symptoms, chronic bronchitis, hypertension and non-fatal heart attacks)
l	is the oil-based fuels index (coal, natural gas, gasoline, HSDO, industrial diesel oil, kerosene and fuel oil)
an	is the index for non-agricultural sectors

N	is the number of people who contract health problems
d	is the air pollutant dose-response coefficient
μ	is the air pollutant emission coefficient
$?$	is the input-output coefficient
IN	is the composite intermediate input
POP	is the total population at risk of air pollutant-related illnesses, i.e. the number of people in urban areas exposed to the air pollutants under consideration.

Equation (A5) is known as the dose-response function. It defines the number of people who contract health effect k, given that a total population POP is exposed to a certain level of air pollutant p.[25] The part $?_{l,p,an} ??_{l,an} ?IN_{an}$ in relationship (A5) determines the amount of air pollutant p emitted from the oil-based fuel l used in production sector an. The part

$$??_{an} ?_{l} ?_{l,p,an} ??_{l,an} ?IN_{an} ?$$

defines the ambient level of air pollutant p. The air pollutant emission coefficient ($\mu_{l,p,an}$) is a function of government and private sector investment in air pollutant abatement technologies and services. For example, if the national oil company decides to reduce the lead level in gasoline, the lead emission coefficient from gasoline ($\mu_{GASOLINE,LEAD,an}$) declines.

Finally, the closure rules of this CGE model are as follows:

- Current account balance is fixed exogenously and the exchange rate is the equilibrating variable (see also Thorbecke 1992).
- Real government expenditure is fixed exogenously and government saving is determined residually.
- Land and capital are determined exogenously. The markets for agricultural, manual-clerical, and professional labour are assumed to be always in a full-employment equilibrium (Lewis 1991).

[25] The same form of equation as relationship (A5) is also used to determine the number of restricted activity days (RAD) associated with air pollutants.

Figure 1. Links Between the Economy and Air Pollutants

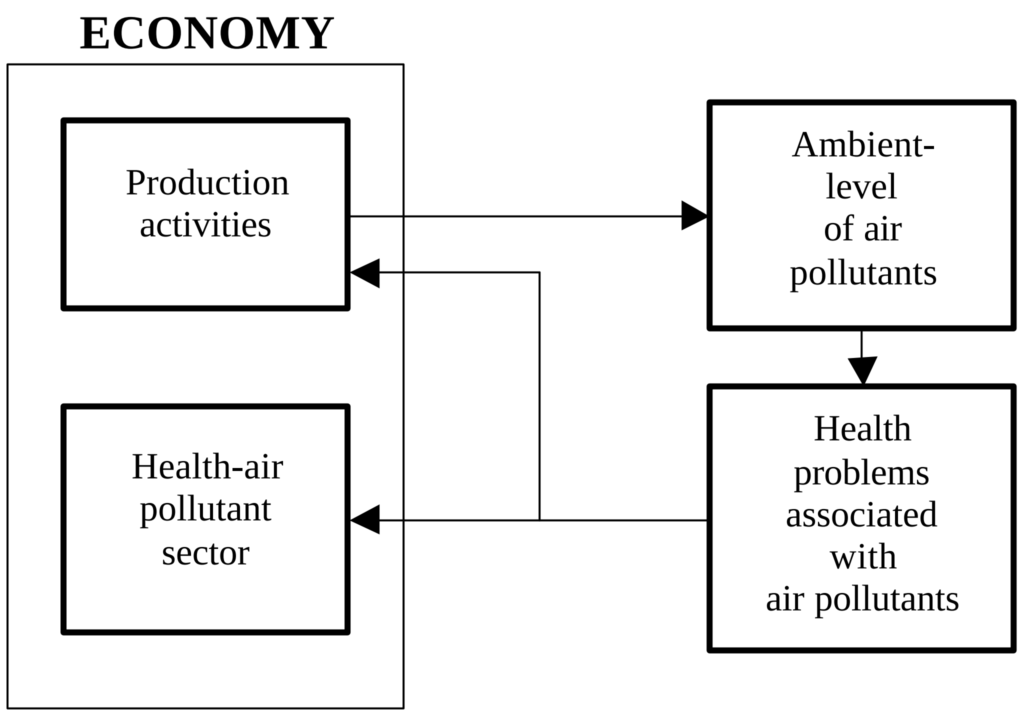
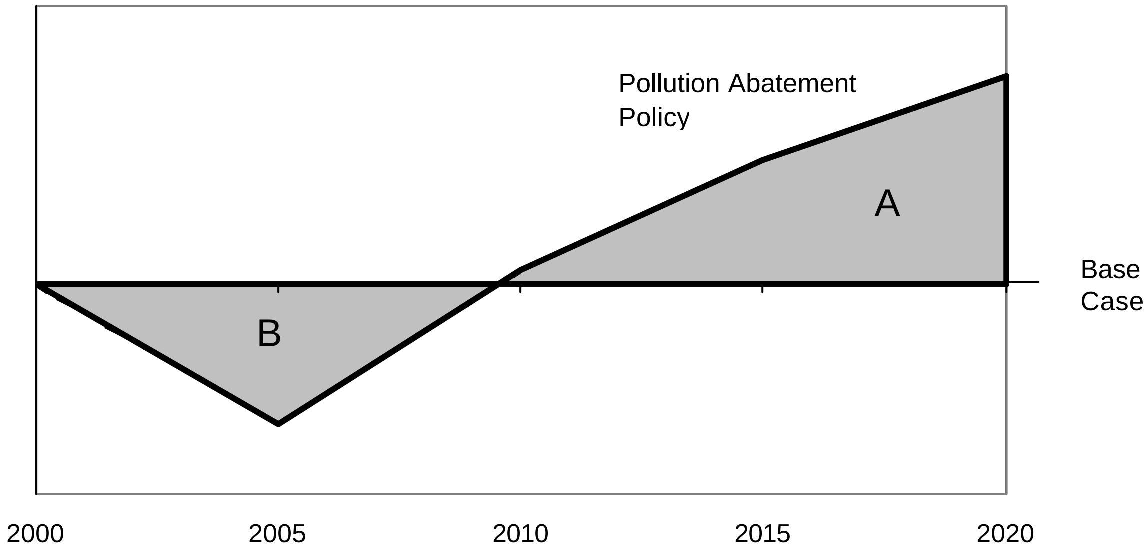


Figure 2. GDP Gains under an Air Pollution Abatement Policy



Note: The shaded area is the gain in present value of GDP for each year shown (which may be negative). Hence, the total gain in present value of GDP for 20 years is area A minus area B.

Figure 3. Change in Present Value of GDP Relative to Base Case with Unleaded Gasoline Policy
(Rp billion)

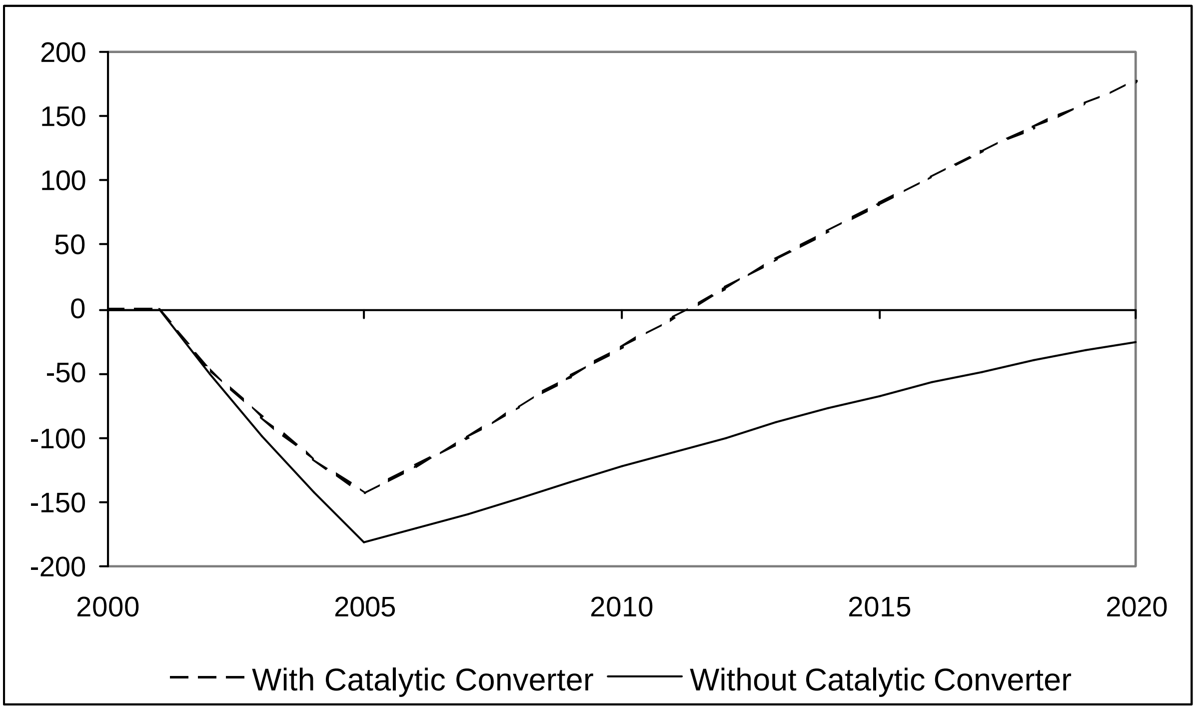


Figure 4. Differences between Present Values of GDP under the Gasoline and HSDO Pricing Policy Relative to Base Case

(Rp billion)

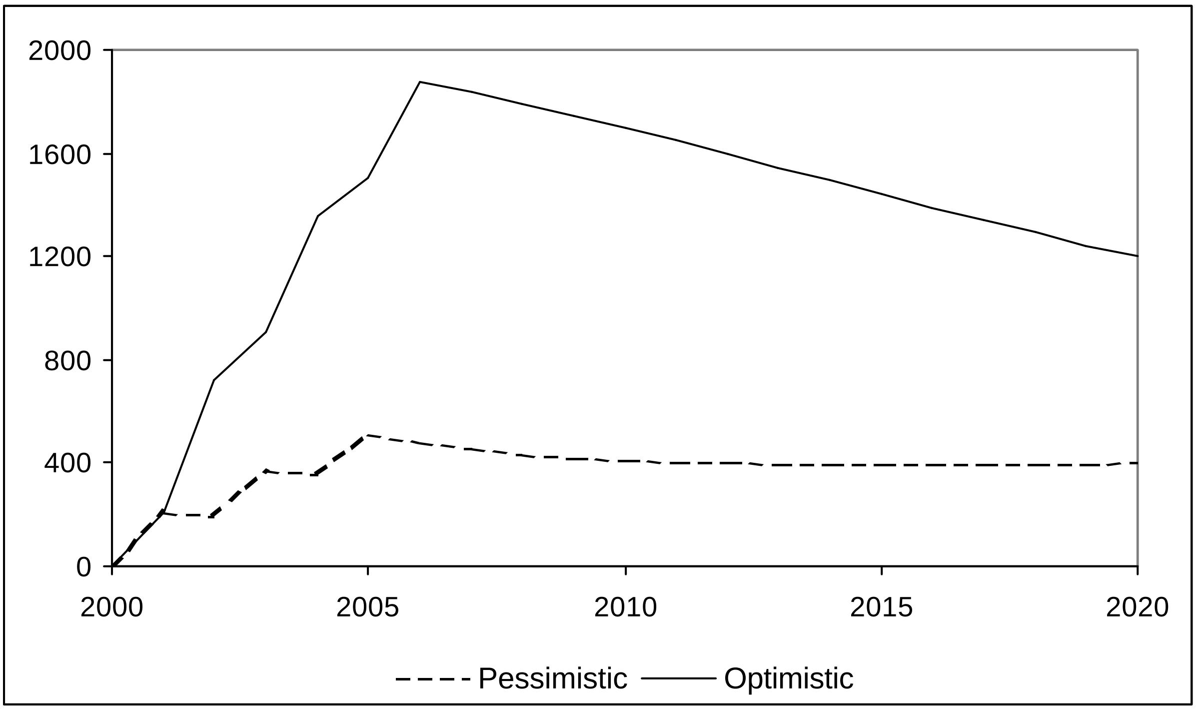


Table 1. Urban Air Pollutant Levels under Various Abatement Policies

	Base Case: No Air Pollution Program		Air Pollution Indicators in 2020 (and percentage changes compared to the Base Case in 2020)							
	2000	2020	Unleaded Gasoline		Ban Two-	Emission	Gas. and HSDO Pricing		Combined Policies	
			no cat. con.	cat. con.	Strokes	Standard	Pessimistic	Optimistic	Pessimistic	Optimistic
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
SPM	1.00	2.91	2.91	2.05	2.88	2.72	2.90	2.62	2.03	1.96
			0.0%	-29.4%	-1.1%	-6.5%	-0.4%	-9.8%	-30.3%	-32.5%
NO2	1.00	2.88	2.88	2.16	2.86	2.55	2.87	2.13	2.11	1.61
			0.0%	-24.8%	-0.5%	-11.5%	-0.2%	-26.1%	-26.8%	-44.0%
Lead	1.00	3.02	0.00	0.00	2.78	2.44	3.01	2.59	0.00	0.00
			-100.0%	-100.0%	-8.0%	-19.1%	-0.5%	-14.5%	-100.0%	-100.0%

Notes:
Column (2) indicates how many times higher are average ambient levels of SPM, NO_2, and Lead in 2020 than their levels in 2000. Columns (3-10) show expected levels of urban air pollutants in 2020 under various abatement policy scenarios compared to their levels in 2000. Columns (3-10) also present percentage reductions in pollution levels under various abatement policies relative to the Base Case in 2020.

Table 2. Impact of Pollution Abatement Policies on Pollutant-Related Illnesses and Health Costs

	Annual Cases of Health Problems		Total Reduction in Health Cases and Costs from 2001 until 2020 (number of cases and percentages)							
	Base Case		Unleaded Gasoline		Ban Two-Strokes	Emission Standard	Gas. and HSDO Pricing		Combined Policy	
(Number of cases, except as mentioned otherwise)	2000	2020	no cat. con.	cat. con.			Pessimistic	Optimistic	Pessimistic	Optimistic
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Health Problems										
Hospital Admission	4,963	30,358	51	67,761	3,103	19,574	1,226	27,638	75,980	84,499
		512%	0.02%	21.83%	1.00%	6.31%	0.40%	8.91%	24.48%	27.23%
Non-fatal Heart Attack	591	3,754	35,750	35,749	2,897	7,071	195	5,034	35,814	35,820
		536%	94.85%	94.85%	7.69%	18.76%	0.52%	13.36%	95.02%	95.03%
Emergency Room Visit	97	594	1	1,327	61	383	24	541	1,487	1,654
(thousand)		512%	0.02%	21.83%	1.00%	6.31%	0.40%	8.91%	24.48%	27.23%
Lower Respiratory Illness	249	1,526	3	3,406	156	984	62	1,389	3,819	4,247
(thousand)		512%	0.02%	21.83%	1.00%	6.31%	0.40%	8.91%	24.48%	27.23%
Asthma Attack	1,111	6,794	11	15,166	694	4,381	275	6,186	17,005	18,912
(thousand)		512%	0.02%	21.83%	1.00%	6.31%	0.40%	8.91%	24.48%	27.23%
Respiratory Symptom	79,530	486,175	877	1,101,733	48,490	324,966	19,383	479,477	1,229,916	1,396,298
(thousand)		511%	0.02%	22.17%	0.98%	6.54%	0.39%	9.65%	24.75%	28.09%
Chronic Bronchitis	24	151	0.3	338	15	98	6	138	379	422
(thousand)		512%	0.02%	21.83%	1.00%	6.31%	0.40%	8.91%	24.48%	27.23%
Hypertension	438	2,786	26,528	26,528	2,150	5,247	144	3,736	26,576	26,581
(thousand)		536%	94.85%	94.85%	7.69%	18.76%	0.52%	13.36%	95.02%	95.03%
Res. Activity Days	15,279	93,453	158	208,593	9,551	60,255	3,776	85,078	233,893	260,115
(thousands of days)		512%	0.02%	21.83%	1.00%	6.31%	0.40%	8.91%	24.48%	27.23%
Health Costs										
Air Pollutant-Health Cost	90	551	223	788	45	225	12	287	874	965
(Rp billion)		513%	7.27%	25.68%	1.47%	7.34%	0.39%	9.35%	28.49%	31.45%

Note: Percentages in column (2) are increases in numbers of health problems (upper block) and air pollution-related health costs (lower block) from 2000 to 2020. Columns (3–10) show total reductions in health problems (upper block) and in total present values of air pollution-related health costs associated with the various abatement policies (lower block) during the 2001–2020 time horizon, relative to the Base Case. Present values are calculated using a 5 percent discount rate. All changes in cases and costs are also shown as percentages.

Table 3. Impact of Pollution Abatement Policies on GDP and Household Incomes*

	Base Case No Air Pollution Program		Total Changes in Present Value of GDP and Household Incomes Resulting from Abatement Policies from 2001 until 2020							
	2000	2020	Unleaded Gasoline		Ban Two-	Emission	Gas. and HSDO Pricing		Combined Policy	
(Rp billion, except as			no cat. con.	cat. con.	Strokes	Standard	Pessimistic	Optimistic	Pessimistic	Optimistic
mentioned otherwise)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
GDP	313,304	969,627	-1,853	128	123	1,169	7,837	27,839	9,671	28,533
		209%	-0.03%	0.002%	0.002%	0.02%	0.12%	0.42%	0.14%	0.43%
Household Incomes										
Ag. Employee	10,123	32,796	-44	57	6	49	-181	607	-74	666
		224%	-0.02%	0.03%	0.003%	0.02%	-0.08%	0.27%	-0.03%	0.30%
Small-scale Farmer	53,784	190,555	-380	201	38	289	-795	4,275	-259	4,518
		254%	-0.03%	0.02%	0.003%	0.02%	-0.06%	0.34%	-0.02%	0.36%
Medium-scale Farmer	12,567	45,199	-90	49	9	69	-598	657	-480	704
		260%	-0.03%	0.02%	0.003%	0.02%	-0.20%	0.22%	-0.16%	0.24%
Large-scale Farmer	16,653	59,141	-116	65	12	90	-799	839	-644	901
		255%	-0.03%	0.02%	0.003%	0.02%	-0.21%	0.22%	-0.17%	0.23%
Rural Low Income	14,801	46,102	-45	32	6	50	-437	580	-344	621
		211%	-0.01%	0.01%	0.002%	0.02%	-0.14%	0.18%	-0.11%	0.20%
Rural Non-labour	3,853	9,926	38	57	1	6	424	344	490	407
		158%	0.05%	0.08%	0.001%	0.01%	0.57%	0.46%	0.66%	0.55%
Rural High Income	44,625	144,692	-249	-34	17	159	368	3,869	600	3,936
		224%	-0.03%	-0.004%	0.002%	0.02%	0.04%	0.40%	0.06%	0.41%
Urban Low Income	32,801	94,320	145	587	35	213	-368	1,287	363	1,831
		188%	0.02%	0.09%	0.005%	0.03%	-0.06%	0.19%	0.05%	0.28%
Urban Non-labour	10,152	31,568	47	138	6	42	-721	-271	-571	-161
		211%	0.02%	0.06%	0.003%	0.02%	-0.33%	-0.13%	-0.26%	-0.07%
Urban High Income	67,759	201,478	-5	124	11	146	-2,164	1,387	-1,850	1,546
		197%	0.00%	0.01%	0.001%	0.01%	-0.15%	0.10%	-0.13%	0.11%

Note: * GDP and household incomes in this table are calculated net of the costs of treating health problems caused by air pollution. Columns (3–10) show total present value gains in GDP and in incomes for each household group during the 20-year time horizon under consideration, relative to the Base Case. Present values are calculated using a 5 percent discount rate. The gains are also shown as percentages.

Table 4. Impact on Sectoral Value-Added of Switching to Unleaded Gasoline

Without Catalytic Converter		With Catalytic Converter	
Negative	**Positive**	**Negative**	**Positive**
Food Crop	Other Mining	Estate Crop	Food Crop
Estate Crop	Gasoline	Other Crops	Other Mining
Other Crops	HSDO	Coal	Food Processing
Coal	Electricity & Gas	Natural Gas	Gasoline
Natural Gas	Services	Industrial Diesel Oil	HSDO
Food Processing		Kerosene	Electricity & Gas
Industrial Diesel Oil		Fuel Oil	Services
Kerosene		Other Manufactures	
Fuel Oil		Trade & Storage	
Other Manufactures		Land Transportation	
Trade & Storage		Air Pollution-Health	
Land Transportation			
Air Pollution-Health			

Note: The ‘Negative’ and ‘Positive’ columns indicate sectors in which value added falls or rises relative to the Base Case, depending on whether catalytic converters are introduced along with unleaded gasoline.

Table 5. Impact on Sectoral Value-Added of Gasoline and HSDO Pricing Policy

Pessimistic Outcome		Optimistic Outcome	
Negative	**Positive**	**Negative**	**Positive**
Food Crop	HSDO	Other Mining	Food Crop
Non-Food Crop	Industrial Diesel Oil	Gasoline	Estate Crop
Other Crops	Kerosene	HSDO	Other Crops
Coal	Fuel Oil	Other Manufactures	Coal
Natural Gas	Electricity & Gas	Air Pollution-Health	Natural Gas
Other Mining	Land Transportation		Food Processing
Food Processing	Services		Industrial Diesel Oil
Gasoline			Kerosene
IDO			Fuel Oil
Other Manufactures			Electricity & Gas
Trade & Storage			Trade & Storage
Air Pollution-Health			Land Transportation
			Services

Note: The 'Negative' and 'Positive' columns indicate sectors in which value added falls or rises relative to the Base Case, under the pessimistic and optimistic assumptions**.**