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GENUINE SAVINGS MEASUREMENT AND ITS APPLICATION TO THE UNITED KINGDOM AND TAIWAN

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The genuine savings index (GSI) is a simple indicator that can be used to assess an economy's sustainability. It defines wealth more broadly than orthodox national accounts, and recalculates national savings figures based on this new definition. Genuine savings aim to represent the value of the net change in the whole range of assets that are important for development: produced assets, natural resources, environmental quality, and human resources. This paper takes the broad framework developed in previous studies and tests its application with respect to the United Kingdom and Taiwan between 1970 and 1998, with the goal of assessing the feasibility of using such measures quite broadly as indices of sustainable development. The paper shows that both the United Kingdom and Taiwan have positive genuine savings rates over the period in question, with the United Kingdom registering lower ones than Taiwan.

INTRODUCTION

THE concept of genuine savings (GS) is based on a measure of wealth that is expanded to include human and natural, as well as economic, wealth. It measures the net annual increase or decrease in a nation's wealth. According to previous definitions, development is considered to be sustainable if and only if the stock of capital (wealth) remains constant or rises over time. Thus, the rate of GS can be used to measure sustainability, in that if the genuine savings index (GSI) is positive we are leaving more for future generations; a negative rate of GS, on the other hand, indicates unsustainability.

The calculation of GS involves the itemization of a nation's stock of wealth, and an accounting of changes to that stock. The World Bank researchers have defined GS as follows:

Genuine Savings = Production – Consumption – Depreciation of Produced Assets – Depletion of Natural Assets,
= Gross Domestic Savings – Consumption of Fixed Capital (Depreciation) + Education Expenditure – Air Pollution Costs – Water Pollution Costs – Depletion of Nonrenewable Natural Resources – CO_2 Damage Costs.[1]

[1] This also equals [Gross Domestic Investment + Education Expenditure + Current Account Bal-

Table I presents a summary of the composition of the genuine savings index with the main rationale for each of the adjustments made.

Preliminary calculations from the World Bank (1997) suggest that GS measured in this way tends to depress the savings rates of resource-rich developing countries, meaning that current patterns of economic activity are diminishing national wealth. Depressed rates of GS for resource-rich countries represent lost opportunities for development—resources are being depleted, rather than transformed into assets.

In this case study, we chose the United Kingdom and Taiwan, using the GS framework and testing its application to both countries between 1970 and 1998, with the aim of assessing the feasibility of using such a measure as an index of national sustainable development. This paper does not include in its perspective the depreciation of assets caused by such issues as soil pollution, solid waste, and

TABLE I

SUMMARY OF THE GS CALCULATION METHODOLOGY

Item	Adjustment (Plus or Minus)	Rationale
Gross domestic savings		Basis for the index
Consumption of fixed capital	–	Accounting for replacement value of produced capital in the production process
Education expenditure	+	Adding in value of investments in human capital
Air pollution costs	–	Subtracting the environmental degradation costs
Water pollution costs	–	Subtracting the environmental degradation costs
CO_2 damage costs	–	Subtracting the environmental long-term damage costs
Nonrenewable natural resource depletion costs	–	Subtracting the declining costs of natural capital due to extraction or harvest
Genuine savings		Standing for how much a country truly saves for future

ance after Official Transfers – Consumption of Fixed Capital (Depreciation) – Air Pollution Costs – Water Pollution Costs – Depletion of Nonrenewable Natural Resources – CO_2 Damage Costs].

deforestation; it mainly focuses on the social costs of air and water pollution. The estimates reported in this paper were constructed independently of the Work Bank's 1997 estimates. Sources of data and methodological factors are discussed, comparability of the two countries is investigated, and the policy uses are indicated.

I. THE U.K.-GS AND TAIWAN-GS: ITEM BY ITEM

In this section, we will explain our calculations of the U.K.-GS and Taiwan-GS item by item. Our methods for calculating some components of the GS differ from those of the World Bank. Where possible, in what follows we will attempt to highlight important methodological issues and we will discuss significant effects on the overall shape of the GSI.

The World Bank's global GSI was presented for the years 1974 to 1994. For the U.K.-GS and Taiwan-GS that will be shown in the following sections, we have extended the survey period to run from 1970 to 1998.

Item A: Gross Domestic Savings

The starting point for the GS is gross domestic savings. According to standard national accounting, gross domestic savings are calculated as the difference between gross domestic product (GDP) and public and private consumption. Gross domestic savings also equal gross domestic investment plus current account balance after official transfers in national accounting terms.

For the United Kingdom, this information is published regularly in the *United Kingdom National Accounts* (Office for National Statistics) and time-series data are set out in detail in *Economic Trends: Annual Supplements* (Office for National Statistics), published for various years. The data of gross domestic savings were obtained from this source. For Taiwan, this information can be obtained from the national accounts information publicized by the Directorate-General of Budget, Accounting and Statistics (DGBAS), Executive Yuan: *National Income Account, National Statistics of Taiwan,* various years.

Item B: Consumption of Fixed Capital

Consumption of fixed capital represents the replacement value of capital used up in the process of production. Net domestic savings are equal to gross domestic savings less the value of consumption of fixed capital. For the United Kingdom, the data were taken from the United Nations Statistics Division's *Statistical Yearbook*, various years. For Taiwan, this information was derived from *National Income Account, National Statistics of Taiwan* (DGBAS), various years.

Item C: Education Expenditure

In national accounts, education expenditure refers to the current operating expenditures in education, including wages and salaries and excluding capital investments in buildings and equipment. In the GS model, current expenditures on education are added to net domestic savings as an approximate value of investments in human capital (in standard national accounting, these expenditures are treated as consumption). For the United Kingdom, the data were from *Economic Trends: Annual Supplement,* various years. For Taiwan, they were taken from *Data Statistics,* Ministry of Education, various years.

Item D: Air Pollution Costs

The World Bank's global GS calculation table does not include an item for air pollution costs. We therefore carried out an exercise for valuing air pollution for the years concerned, so as to include these costs in our GS calculation.

For the United Kingdom, the key local air pollutants include sulphur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM_{10}). These three main pollutants are acknowledged and publicized by the British government's Department of Environment, Transport and Regions (DETR). We have then multiplied emissions of each pollutant by an estimate of the marginal social costs of that pollutant to obtain the costs of each kind of air pollution in each year. The total negative costs flowing from all the air pollutants in a given year are taken to be the annual air pollution costs.

The data for varied pollutant emissions for various years were derived from DETR sources. The estimates of unit social/damage cost of air pollutants are from the most up-to-date version of the ExternE Project.[2] The fuel cycle was assessed in the first phase of the ExternE Project. It has now been updated to take account of more recent methodological developments[3] and new sources of data that have become available.

The major emissions from power generation are the atmospheric emissions of SO_2, NO_x, and PM_{10}, and their impacts on public health, materials, and crops have been quantified. The summary of the externalities assessed for the coal fuel cycle is shown in Table II.

These pollutants have long-range transboundary effects, and they have accord-

[2] The ExternE (Externalities of Energy) Project is the first comprehensive attempt to use a consistent "bottom-up" methodology to evaluate the external costs associated with a range of different fuel cycles. The European Commission launched the project in collaboration with the U.S. Department of Energy in 1991. The EC and U.S. teams jointly developed the conceptual approach and methodology and shared scientific information for its application to a range of fuel cycles.

[3] The ExternE Project uses the "impact pathway" approach for the assessment of the external impacts and associated costs resulting from the supply and use of energy. This method of analysis has only recently become possible, as a result of developments in environmental science and economics, and improvements in computing power. The analysis typically proceeds as: (1) prioritization of impacts, (2) description of priority impact pathways, (3) quantification of burdens, (4) description of the receiving environment, (5) quantification of impacts, (6) economic valuation, and (7) description of uncertainties.

TABLE II

UNITED KINGDOM: DAMAGE (SOCIAL) COSTS BY AIR POLLUTANTS

(ECU per tonne of pollutant)

Air Pollutant	Damage (Social) Costs
SO_2	6,818.2
NO_x	5,736
PM_{10}	14,062.5

Source: Berry et al. (1998).

TABLE III

EU COUNTRIES: DAMAGE (SOCIAL) COSTS BY AIR POLLUTANTS

(ECU per tonne of pollutant emitted)

Country	SO_2	NO_x	PM_{10}
Austria	9,000	9,000–16,800	16,800
Belgium	11,388–12,141	11,536–12,296	24,536–24,537
Denmark	2,990–4,216	3,280–4,728	3,390–6,666
Finland	1,027–1,486	852–1,388	1,340–2,611
France	7,500–15,300	10,800–18,000	6,100–57,000
Germany	1,800–13,688	10,945–15,100	19,500–23,415
Greece	1,978–7,832	1,240–7,798	2,014–8,278
Ireland	2,800–5,300	2,750–3,000	2,800–5,415
Italy	5,700–12,000	4,600–13,567	5,700–20,700
Netherlands	6,205–7,581	5,480–6,085	15,006–16,830
Norway	n.a.	n.a.	n.a.
Portugal	4,960–5,424	5,975–6,562	5,565–6,955
Spain	4,219–9,583	4,651–12,056	4,418–20,250
Sweden	2,357–2,810	1,957–2,340	2,732–3,840
United Kingdom	6,027–10,025	5,736–9,612	8,000–22,917

Source: CIEMAT (1998).

ingly become a major concern for most European countries. The Geneva Convention on Long-Range Transboundary Air Pollution, sponsored by the United Nations, and in which the European Union participates, is the international body attempting a reduction of these pollutants.

The European Union, by itself, is also attempting to reduce the emission of these pollutants through different strategies such as emissions standards and economic instruments. In all cases, it is important to determine the benefits achieved by these reductions, so as to assess the efficiency of the policies being implemented. In other words, it is necessary to determine the damages avoided with the reduction of the air emissions ("ExternE" 1997). This has also been carried out within the ExternE National Implementation Project.[4] Table III lists the damage

[4] The ExternE Project commenced in 1991. In December 1997, Phase III of the project finished. The project has been split into three major project areas: ExternE Core Project, ExternE National Implementation, and ExternE Transport.

costs of main air pollutants for different EU countries.

After compilation, the result shows that the air pollution costs as a percentage of the GDP for the United Kingdom decreased each year. For details see the next section of this study.

For Taiwan, official data do not provide direct estimates of the marginal social costs per tonne of air pollutant emitted, but give estimates of "air pollution marginal social costs per unit of energy consumed."[5] We therefore calculated the air pollution costs per year as the sum of air pollution marginal social costs associated with a unit of energy consumed multiplied by the energy consumption for that year. Table IV shows the estimate of air pollution marginal social costs per unit of energy consumed. The energy consumption data were obtained from the Energy Commission, Ministry of Economic Affairs, for various years.

TABLE IV
TAIWAN: AIR POLLUTION SOCIAL COSTS OF ENERGY CONSUMED

Energy	Social Costs
Fuel oil	8.57 (NT$/liter)
Motor gasoline	0.61 (NT$/liter)
Diesel oil	2.88 (NT$/liter)
LPG	0.17 (NT$/liter)
Natural gas	0.10 (NT$/$m^3$)
Coal	7.79 (NT$/kg)

Source: Liang (1993).
Note: In 1991 prices: 1 U.S. dollar equaled about 25.75 NT dollar (*Monthly Bulletin of Statistics* [DGBAS], various issues).

Item E: Water Pollution Costs

The World Bank's global GS table also does not have this item included. We have therefore tried to locate the data and have estimated this sort of cost by ourselves.

Up to now, methods of evaluating costs of water pollution in many countries have remained uncertain. However, if we understand that the key pollution adjustment to the genuine savings is for deriving the changes in welfare effects (as environmental pollution essentially causes social welfare loss), valuing the "willingness to pay" (WTP) to avoid excess suffering from pollution-linked morbidity or to improve certain kinds of environmental quality can serve as the base for measuring environmental costs. By so doing we can compare the values attached by consumers to goods and services traded on the market with the values they attach to nonmarketed environmental resources.

5 See Appendix B for the derivation of these unit social costs.

In this study, we adopted the WTP estimates based on the Resource for the Future (RFF) water quality index taken from Georgiou et al. (2000), and then calculated the total water pollution costs for each year.

The WTP values are obtained by a combined contingent ranking and contingent valuation study on inner city river water quality improvements in the United Kingdom. Contingent ranking (Smith and Desvousges 1986) is a survey-based technique designed to isolate the value of individual product characteristics (attributes), which are typically supplied in combination with one another. Such ranking activities are especially useful for valuing environmental programs, which often have several features, such as cleaner water, and so on. Respondents are usually asked in this exercise to rank, for example, three potential water quality schemes along with the current status quo.

The RFF water quality index (Vaughan 1986) is a ten-point index of technical U.K. water quality measures combined with informed judgment linking recreational activities with water quality (Georgiou et al. 2000). Alternatively, one might use technical water quality measures such as levels of dissolved oxygen, biological oxygen demand (BOD), and total ammonia.[6] Table V shows the water quality level improvements used in the survey along with their associated RFF water quality index values and other technical measure values.

TABLE V
WATER QUALITY IMPROVEMENTS AND RFF WATER QUALITY INDEX

Water Quality Level	RFF Water Quality Index	Dissolved Oxygen (% Saturation)	BOD (mg/liter)	Total Ammonia (mg N/liter)
Large improvement (L)	7.0	80	2.5	0.25
Medium improvement (M)	5.0	65	5	0.95
Small improvement (S)	2.5	50	8	2.5
Current situation (C)	0.8	20	15	9

Source: Georgiou et al. (2000).

Georgiou et al.'s valuation modeling involves the marginal rate of substitution between the water quality and payment attributes (ratio of marginal utilities). Calculating this for the specification shown in Table VI gives an estimated WTP trade-off of £5.08 (in year 2000 value) per household per annum for a unit increase in RFF water quality index.

[6] The correspondence of these technical measures to the RFF index scores and water quality improvement levels considered is derived from the U.K. Environment Agency's River Ecosystem Classification scheme, which has been used to describe rivers according to their suitability for fish in terms of these technical measures.

TABLE VI

WILLINGNESS TO PAY (WTP) PER UNIT CHANGE IN WATER QUALITY INDICES

(£)

Unit Change in Water Quality Index	WTP per Household per Annum
Unit increase in RFF index	5.08
1% saturation increase in dissolved oxygen	0.61
1 mg/liter decrease in biological oxygen demand (BOD)	3.06
1 mg N/liter decrease in total ammonia	5.05

Source: Georgiou et al. (2000).

In view of the above information, it is reasonable to propose a formula as [$p \times \Delta x \times$ Yearly Household Population × Water Pollution Trend Index × Consumer Price Index], to compute the annual (different) water pollution costs for the United Kingdom. Here, p denotes the marginal household WTP for improving river water quality and Δx is the change in water quality (from "current situation" to "large improvement") as a result of pollution (see Table V). The water pollution trend index then adjusts the product of the previous three items. This product equals the total WTP for largely improving water quality in the light of the current situation. However, the "current situation" varies from year to year. That is to say, river water pollution costs are essentially different each year. As the survey for water quality improvement and RFF water quality index was completed in year 2000, that year would be treated as the base year for the further calculation of water pollution costs, and the "current situation" at that time refers to level 0.8 (also see Table V). So, for any certain year, if the pollution condition is relatively more serious than year 2000, the total WTP for that year should be counted as higher than that of year 2000 accordingly. Finally, the costs should be adjusted again based on the consumer price index to reflect computational consistency of the cost.

As a result, the yearly water pollution cost for the United Kingdom would be measured as [£5.08 × (7 − 0.8)[7] ×Water Pollution Expenditure Index[8] × Yearly Household Population × Consumer Price Index = £31.5 × Water Pollution Expenditure Index × Yearly Household Population × Consumer Price Index]. The information for the U.K. population as well as government and industrial defen-

[7] The empirical analysis on which the unit values are based did not consider improvements beyond level 7 and hence it is not appropriate that the unit value applies beyond this level, say, level 8, 9, or 10.

[8] There are no yearly RFF water quality indices or other numerical water quality indices existing in the United Kingdom. The related government statistics only include simple description of the water quality from 1990 to 2000—good, fair, and poor. In order to determine the quantitative water pollution degree and trend over time, we used the publicized data "yearly public expenditures on water pollution control and defense" (i.e., sewage collection, treatment, and disposal) and then transferred the expenditure amounts to normalized ratio (index) (the base year = year 2000): the more the ratio (index), the more expenditures on pollution control and defense have been spent and therefore the more serious water pollution is for that year (see Table VII).

TABLE VII

UNITED KINGDOM: WATER POLLUTION EXPENDITURE INDEX, 1970–98

Year	Index	Year	Index
1970	0.827	1985	0.526
1971	0.850	1986	0.554
1972	0.841	1987	0.553
1973	0.887	1988	0.754
1974	0.912	1989	0.962
1975	0.892	1990	1.065
1976	0.819	1991	0.977
1977	0.754	1992	0.909
1978	0.775	1993	0.867
1979	0.785	1994	0.845
1980	0.775	1995	0.820
1981	0.538	1996	0.886
1982	0.538	1997	0.962
1983	0.540	1998	0.993
1984	0.515		

Source: Prepared by the authors.

sive expenditures on water pollution was taken from the U.K. *National Statistics Annual Report,* various years.

To calculate annual water pollution costs for Taiwan, we used the values of WTP estimated by Wu and Yeah (1996), and then further measured the total water pollution costs for each year. The computation methodology used is the same as the United Kingdom's.

According to Wu and Yeah's contingent survey and estimate for 1993, the WTP for large water quality improvements per person per year amounts to NT$509 in 1993 prices (about U.S.$19.29 in 1993 prices). The annual water pollution cost for Taiwan would therefore be measured as [NT$509 × Water Pollution Index× Yearly Population × Consumer Price Index]. For water pollution index, in this case, we used Taiwan's published data "main river serious pollution percentage" as a base (see Table VIII). The information for Taiwan's yearly population was taken from *National Statistics of Taiwan* (DGBAS), various years.

Item F: CO_2 Damage Costs

In the World Bank's global GS calculation, the CO_2[9] cost item is essential, but the data collected by the World Bank are incomplete, and are missing for several countries. The World Bank does not have the data for Taiwan, for instance.

Similar to the method of evaluating air pollution costs, the method of measur-

[9] Carbon dioxide (CO_2)—a naturally occurring gas, also a by-product of burning fossil fuels and biomass as well as from land-use changes and other industrial processes. It is the principal greenhouse gas that affects the Earth's radiative balance.

TABLE VIII

TAIWAN: MAIN RIVER SERIOUS POLLUTION PERCENTAGE, 1970–98

(%)

Year	Main River Pollution	Year	Main River Pollution
1970	2.70	1985	4.70
1971	2.98	1986	10.20
1972	3.66	1987	13.50
1973	3.78	1988	13.00
1974	4.53	1989	13.10
1975	5.31	1990	11.30
1976	4.89	1991	14.20
1977	5.09	1992	11.30
1978	5.18	1993	14.40
1979	4.58	1994	16.10
1980	3.88	1995	15.50
1981	4.30	1996	16.24
1982	7.75	1997	16.83
1983	5.70	1998	17.11
1984	5.60		

Source: Environmental Protection Administration, Taiwan.
Note: The values show percentages of main rivers polluted.

ing annual CO_2 damage cost is to multiply annual total carbon emissions by an estimate of marginal social cost in this regard. We view this method as a more straightforward calculation. For this, we needed the estimation of CO_2 marginal social cost per unit as well as the annual total carbon emissions. For each year, the CO_2 damage cost is therefore the product of the two numbers. For the U.K.-GS, the data on annual carbon emissions were from the U.K. National Air Quality Information Archive. And the estimation of marginal social cost was taken from PAGE 95[10] (= 21 in 1990 dollar per tonne of carbon).

The range of CO_2 marginal social cost estimates is large; most values lie between U.S.\$5 and U.S.\$25/tC (Fankhauser and Pearce 1993). Hope and Maul (1996) demonstrated that much of this disparity can be explained by different assumptions concerning the effectiveness of adaptation to climate change,[11] the background level of CO_2 emissions, economic growth rates, and the discount rate. Another key factor is the treatment of uncertainty.

10 The PAGE (Policy Analysis for the Greenhouse Effect) integrated assessment model was developed in 1991 for use by European Union decision makers (Hope et al. 1993). Its updated model version, PAGE 95, accounts for recent developments in the science and economics of global warming (Plambeck and Hope 1996).

11 According to the United Nations Framework Convention on Climate Change (UNFCCC), "climate change" is a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

One of the two models used by Hope and Maul, PAGE, was developed in 1991. Since then, scientific knowledge of the global warming problem and methods for impact valuation have developed greatly. For example, the sulphate aerosols produced by fossil fuel burning have been found to exert a significant cooling effect. Chlorofluorocarbons or CFCs, once thought to be the most potent greenhouse gases,[12] are now believed to have only a slight effect because they destroy ozone, itself a strong greenhouse gas (Plambeck and Hope 1996).

The updated PAGE 95 model has examined the effect of new scientific and economic knowledge on the predicted marginal impact per tonne of carbon, and reconsiders the role of assumptions about the discount rate, the economic growth rate, and the effectiveness of adaptation to climate change (Plambeck and Hope 1996). Their estimate of the CO_2 marginal social cost is accordingly a moderate one.

The PAGE model calculates a single global figure for the marginal damage from CO_2. As CO_2 rapidly mixes into the global atmosphere, no matter where in the world a tonne of CO_2 is emitted, it will cause the same damage. So we have used the same unit social cost value to compute the CO_2 damage costs for Taiwan during the study period. The data on annual carbon emissions of Taiwan were taken from the Environmental Protection Administration (EPA).

Item G: Nonrenewable Resource Depletion Costs

For the nonrenewable natural resource depletion evaluation, the user-cost method,[13] compared to other ways, is theoretically preferable to other methods, but is not practically feasible, especially if applied to the empirical calculation. The main reason concerns the calculation of n, the number of years to exhaustion of a resource, which poses some conceptual problems. The longevity of a mineral/natural resource deposit at a specified rate of extraction is not a simple physical fact. The availability of the resource is a function not only of how much is "out there" but also of the intensity of the effort (in labor, capital, and energy) used to extract it. In other words, in El Serafy's equation, n is dependent on an exogenous variable, extraction costs, which are nearly impossible to define and measure practically.

12 Greenhouse gases effectively absorb infrared radiation emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus greenhouse gases trap heat within the surface-troposphere system. This is called the "natural greenhouse effect."

13 The basic idea of the "user-cost valuation" is to convert a time-bound stream of (net) receipts R from the sales of an exhaustible resource into a permanent income stream X by investing a part of the receipts, i.e., the user-cost allowance $R - X$ over the lifetime of the resource. Only the remaining amount X of the receipts should be considered "true income." It can be shown (El Serafy 1989) that the user-cost allowance at the interest rate r and the lifetime of the resource of n years amounts to: $R - X = R/(1 + r)^{n+1}$.

Another ISEW (Index of Sustainable Economic Welfare)[14] method for estimating this nonrenewable resource depletion—setting certain replacement costs reflecting the costs of replacing each barrel of oil equivalent of energy consumed with renewable resource—is also arbitrary and cannot be justified in theoretical terms.

We, therefore, followed the method that has been used by the World Bank for estimating the resource depletion cost, namely, the "rental depletion" method, which is theoretically and practically acceptable under such a circumstance. The calculation is: [Unit Resource Rent = Market Price − Cost of Extraction]. In this study, for both the United Kingdom and Taiwan, the resources refer to coal, natural gas, and oil.

For the U.K.-GS, the natural resource depletion costs data were from the World Bank working paper "Estimating National Wealth" (Kunte et al. 1998) and the World Bank's *World Development Indicators*. For the Taiwan-GS, the data were also from the World Bank working paper "Estimating National Wealth" (Kunte et al. 1998) and the World Bank's *World Development Indicators*, as well as Environmental Protection Administration's "Taiwan Green Accounting Trial Compilation," 1999.

II. RESULTS AND DISCUSSION: TAIWAN-GS AND U.K.-GS

A. *GDP versus GS*

National economic performance is commonly measured through the indicator known as gross domestic product. According to conventional wisdom, rising GDP is desirable. The use of GDP as an indicator of economic success has a strong political effect. For example, when GDP falls, businesses go bankrupt, jobs are lost, homes are repossessed, consumer spending falls, personal savings are reduced, public sector borrowing and trade deficits rise, and so on. It is also now well known that the path of national economic success is not the same as that of national sustainable development (see, for example, Nordhaus and Tobin 1973; Moffatt 1996). That is why we have chosen the GSI as a more appropriate indicator of national sustainable development, since GSI shows whether or not a nation saves enough in terms of its multiplied capital for the future to sustain its social and economic development and related achievements.

The results of our compilation are shown in Table IX with regard to the average GDP growth rates and average GS ratios to GDP during the years from 1970 to 1998. Figure 1 presents the changes in the amounts of Taiwan's GDP and GS over those years.

14 Cobb and Cobb (1994) and Daly and Cobb (1989) published benchmark studies in the early 1990s which showed how indices of sustainable economic welfare could be calculated for the United States.

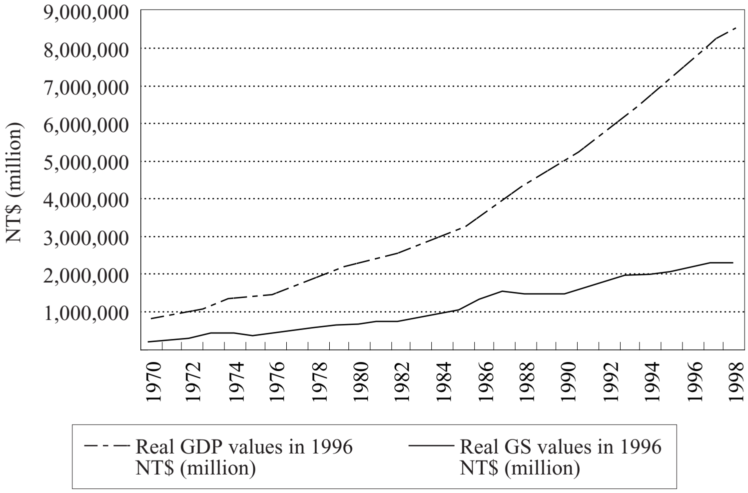
TABLE IX

TAIWAN: AVERAGE ANNUAL REAL GDP GROWTH RATES AND AVERAGE ANNUAL GS RATIOS TO GDP

(%)

	1970s	1980s	1990s
Average annual real GDP growth rates	9.8	8.0	5.9
Average annual GS ratios to GDP	18.5	28.2	27.6

Fig. 1. Taiwan: GDP versus GS, 1970–98



As stated above, GDP rates give a description of a country's economic performance. During the 1970s, as a result of the national economic development policy, Taiwan's average economic growth was somewhat faster than in the 1980s and 1990s. In the process of economic development, whether a country is going toward a sustainable path, can be judged by its GS rates. Negative GS rates are a serious warning of unsustainability.

According to our investigation and calculation of the Taiwan-GS, the annual Taiwan-GS has been positive during the past thirty years. This means that when associated with its economic activities, the country's overall capital wealth can still be sustained for future use and development. Moreover, from Table IX we can see that the average GS ratios to GDP were higher in the 1980s and 1990s than in the 1970s. That is probably because of the government's environmental policy performance especially in pollution control, as well as a slowing down economic growth during the 1980s and 1990s—with fewer economic activities, the national capital would not fall (be depleted) so much, and the pollution caused

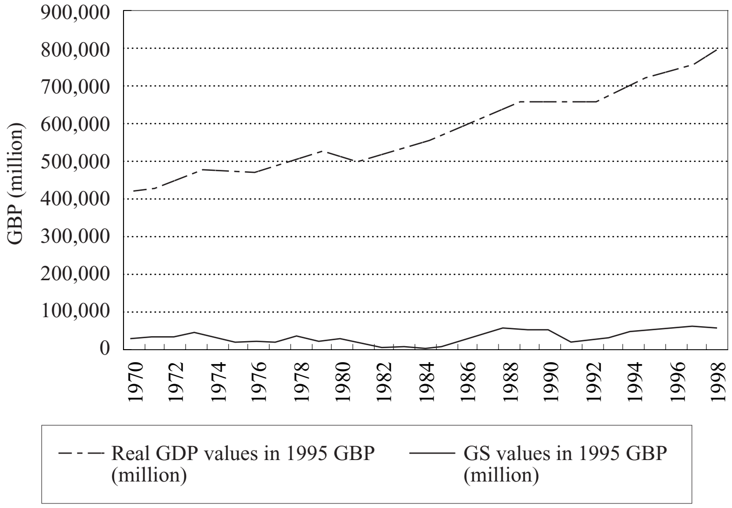
TABLE X

UNITED KINGDOM: AVERAGE ANNUAL REAL GDP GROWTH RATES AND AVERAGE ANNUAL GS RATIOS TO GDP

(%)

	1970s	1980s	1990s
Average annual real GDP growth rates	2.0	2.7	1.9
Average annual GS ratios to GDP	6.6	4.6	6.8

Fig. 2. United Kingdom: GDP versus GS, 1970–98



by the activities would not be so bad, either.

Table X shows the United Kingdom's average annual GDP growth rates and average annual GS ratios to GDP between 1970 and 1998. Figure 2 presents the changes in the value of the United Kingdom's GDP and GS over those years. The table shows that, as a developed country, the United Kingdom had lower average annual GDP growth rates than Taiwan throughout the 1970s, 1980s, and 1990s. Moreover, along with economic activities, the United Kingdom also exhibited somewhat lower average GS ratios to GDP than Taiwan between 1970 and 1998.

From the 1970s to the 1980s, the average annual GDP growth rate of the United Kingdom lifted slightly (from 2.0 per cent to 2.7 per cent), which means that economic development as well as economic growth were being boosted. However, the average annual GS ratio to GDP went down (from 6.6 per cent to 4.6 per cent) during the same period. As noted above, this suggests that a high degree of economic development has most likely led to more natural resource depletion and greater environmental degradation, which then results in a lower GS rate. From the 1980s to the 1990s, however, the average annual GDP growth rate fell (from 2.7 per cent to 1.9 per cent), while the average annual GS ratio to GDP increased (from 4.6 per cent to 6.8 per cent). Likewise, when economic activities are not proceeding very aggressively, depletion and pollution are lessened, and the GS rates are heightened. In sum, during the past thirty years, the U.K.-GS were also all positive, which means that in the first place, the country did not move toward an unsustainable path when using its man-made, natural, and human capital to promote the current economic development.

Our calculations illustrate the differences between these two countries as regards the conditions of economic development during the study period. More particularly, as is clear in Table IX and Table X, the average annual ratios of GS to GDP for Taiwan show a large increase from the 1970s to the 1980s/90s in contrast to those of the United Kingdom which show only moderate fluctuations. Therefore, the comparison between the two economies shows that United Kingdom represents a matured developed economy with stable economic conditions, whereas Taiwan is an emerging economy undergoing rapid economic growth.

B. *Components of Genuine Savings*

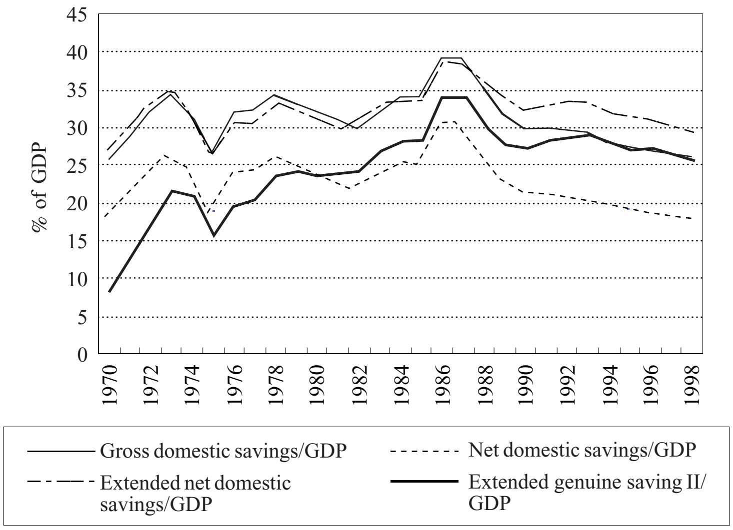
The traditional measure of a nation's rate of accumulation of wealth, as reported in the World Bank's *World Development Indicators,* is gross savings. This is calculated as a residual: GNP minus public and private consumption. Net savings (or total gross savings less the value of depreciation of produced assets) is a first step toward a sustainability indicator. Measures of GS address a much broader concept of sustainability, by valuing changes in the natural resource base and environmental quality in addition to produced assets.

Figure 3 presents the components of the Taiwan-GS as shares of GDP. The starting point in the calculation of GS is standard accounting. The top curve in Figure 3 is gross domestic savings of Taiwan. Next, the depreciation of produced assets is subtracted from the top curve to give net domestic savings. Next, the education expenditures are added, yielding the curve of "extended net domestic savings." Finally, the bottom line is the GS ("extended genuine saving II"[15]), which is obtained by subtracting the value of resource depletions and pollution damages from extended net domestic savings.

The key contributions of the environmentalist national accounting literature are its recognition of natural resources as factors of production and environmental amenities as sources of welfare. A first question to be answered, therefore,

[15] In here, we define "extended genuine saving I" as [Extended Net Domestic Savings – Depletion Costs of Natural Resources], and "extended genuine saving II" as [Extended Genuine Saving I – Air and Water Pollution Costs – CO_2 Damage Costs].

Fig. 3. Taiwan: Components of GS as Percentage of GDP, 1970–98

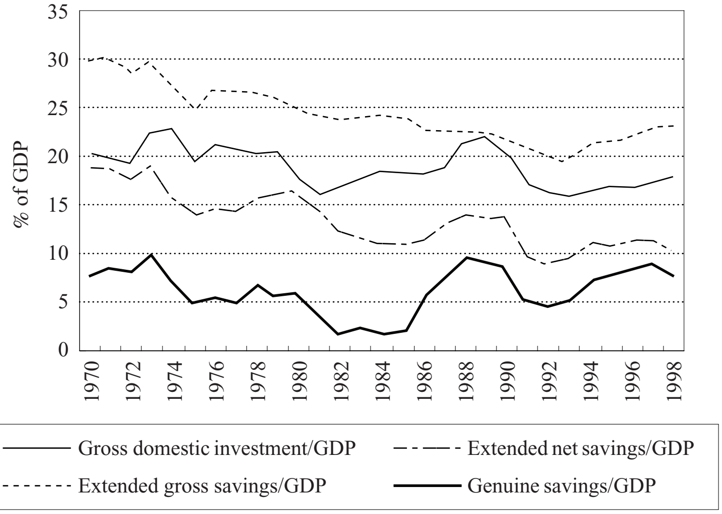


is whether the calculation of depletion and degradation adds substantially to the picture of whether countries are on a path to sustainability. This can be further refined to the question of whether there are countries whose net savings rates are positive but whose genuine savings rates are negative, or vice versa.

For Taiwan, both net domestic savings and genuine savings were positive from 1970 to 1998. However, before 1978, most of the yearly GS rates were below 20 per cent of GDP. During the 1980s, average GS rates rose and represented around 28 per cent of GDP. Since 1990, however, average GS rates dropped to under 28 per cent of GDP (see Figure 3).

In Taiwan, the trends in net domestic savings and genuine savings are similar throughout the study period. But whereas before 1982, the net domestic savings rates were higher than the GS rates, after 1982, the GS rates consistently exceeded the net domestic savings rates. From the previous illustration, we know that the factors affecting these two savings items are education expenditures which stand for national human capital investments, as well as resource depletion and environmental degradation costs. Thus this situation indicates that, before 1982, the total value of Taiwan's natural resource depletion and environmental degradation was larger than that of its human capital investments, so the GS rates were lower than net domestic savings rates. Conversely, after 1982, the whole value of Taiwan's human capital investments was greater than that of its natural resource depletion and environmental degradation, so the GS rates began to exceed net domestic savings rates.

Fig. 4. United Kingdom: Components of GS as Percentage of GDP, 1970–98



For the United Kingdom, the formula for calculating its annual GS is:

GS = Gross Domestic Investment + Education Expenditure + Current Account Balance after Official Transfers – Consumption of Fixed Capital (Depreciation) – Air Pollution Costs – Water Pollution Costs – Depletion of Nonrenewable Natural Resources – CO_2 Damage Costs.

In the case of Taiwan, we calculated the annual GS as follows:

GS = Gross Domestic Savings – Consumption of Fixed Capital (Depreciation) + Education Expenditure – Air Pollution Costs – Water Pollution Costs – Depletion of Nonrenewable Natural Resources – CO_2 Damage Costs.

In fact, either of the two formulas will do, since Gross Domestic Savings = Gross Domestic Investment + Current Account Balance after Official Transfers, as noted before.

Results for the United Kingdom, obtained on the basis of the above calculations, are shown in Figure 4, which refers to the components of U.K.-GS as shares of its GDP. The curve second from the top in Figure 4 is gross domestic investment. Adding both education expenditure and current account balance after official transfers to gross domestic investment, we get the top curve—extended gross savings. Next, the depreciation of produced assets is subtracted from the top curve to give extended net savings. Finally, the bottom line is the GS, which is obtained by subtracting the value of resource depletion and pollution damages from extended net savings.

In the United Kingdom, both extended net savings and genuine savings were

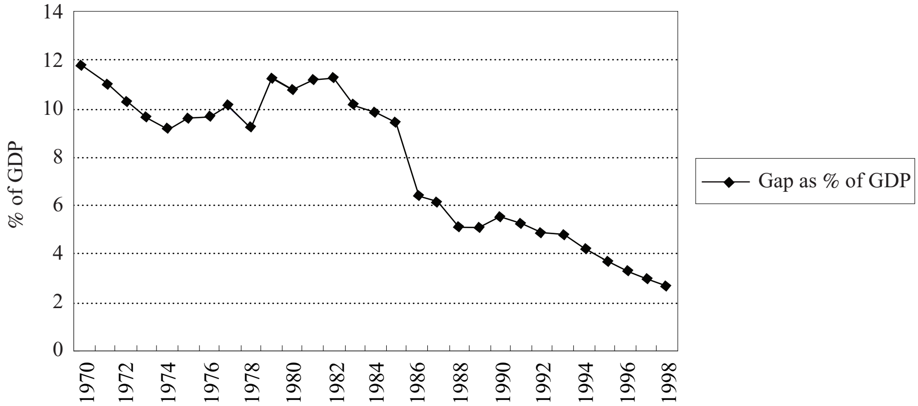
TABLE XI

UNITED KINGDOM: AVERAGE ANNUAL RATIOS OF EXTENDED NET SAVINGS TO GDP AND AVERAGE ANNUAL GS RATIOS TO GDP

(%)

	1970s	1980s	1990s
Average annual ratios of extended net savings to GDP	16.7	13.0	10.9
Average annual GS ratios to GDP	6.6	4.6	6.8

Fig. 5. United Kingdom: Gap between Extended Net Savings and GS, 1970–98



positive from 1970 till 1998. Table XI shows average annual ratios of extended net savings[16] to GDP and average annual ratios of GS to GDP during the periods of 1970s, 1980s, and 1990s. The table shows that extended net savings and GS are similar throughout the period concerned. According to the calculation definition as noted before, the difference between these two savings items are resource depletions and pollution costs. Figure 5 gives the picture of how the gap between extended net savings and GS changed from 1970 to 1998. The gap stands for the value sum of the United Kingdom's resource depletions and pollution costs.

In the case of the United Kingdom, we can see that before 1983, the total depletion and pollution costs as a percentage of GDP were between 9 per cent and 12 per cent; after 1983, the total costs as a percentage of GDP decreased nearly every year. From 1988 until now, the total depletion and pollution costs as a percentages of GDP kept within the range of between 2 per cent and 6 per cent. In these terms, we can conclude that the government's general environmental policy

[16] Please note that U.K. extended net savings has a different meaning position from Taiwan extended net domestic savings due to the difference in their definition.

has led to an improvement in the country's environmental degradation during the past fifteen years. Other causes of the decrease in depletion and pollution costs include such things as EU environmental directives and the change from coal to other energy sources for reasons unconnected with the environment. The detailed effects of these negative components of the GS will be discussed below.

C. *Component Effects in GS*

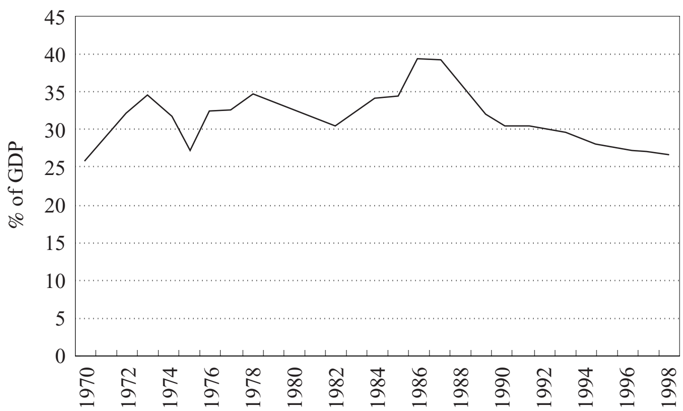
Given the differences of growth trends between GDP and GS as illustrated above, it is worth investigating which components have the most significant effects on the overall shape of the GS. The following is an analysis of the effects of both the positive and negative elements of the GS for the two countries.

1. *Positive items*

Let us firstly look at the positive contributions to the GS—the basis for the index (gross domestic savings) and human capital investment (government education expenditures).

From Figure 6, it is clear that between 1970 and 1973, Taiwan's gross domestic savings as a percentage of the GDP increased steadily. After 1973, however, the rates of gross domestic savings went down. From then on, the gross domestic savings rates underwent very little change until 1985. After 1985, the savings rates rose more than before, then after 1988 the rates declined again. Since gross domestic savings form the basis for the rest of the GSI, we would expect this effect to be passed through to the shape of the final index.

Fig. 6. Taiwan: Gross Domestic Savings as Percentage of GDP, 1970–98



As regards the United Kingdom, Figure 7 shows that the ratios of gross domestic savings to GDP fell steadily from 30 per cent to 20 per cent between 1970 and

Fig. 7. United Kingdom: Gross Domestic Savings as Percentage of GDP, 1970–98

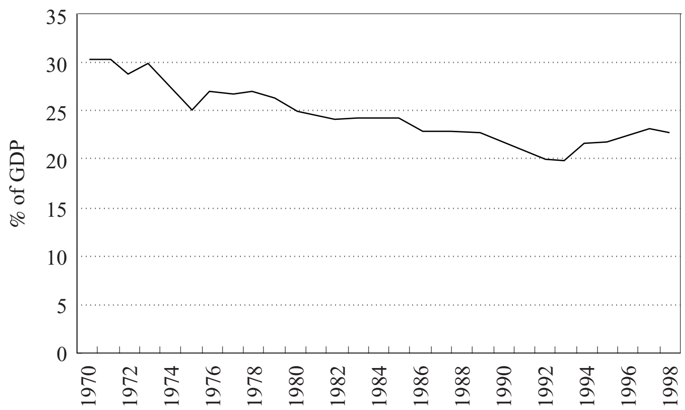
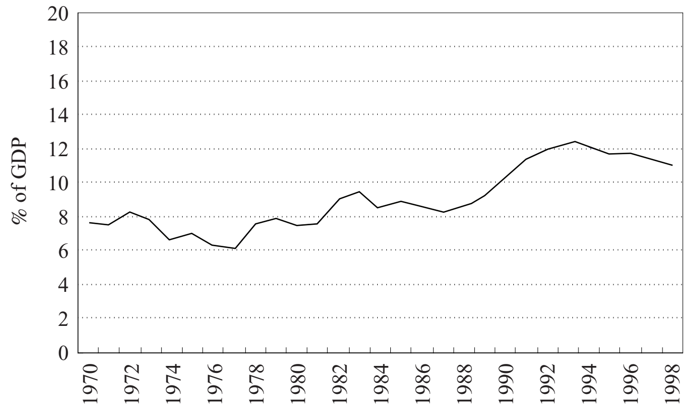


Fig. 8. Taiwan: Education Expenditure as Percentage of GDP, 1970–98



1994. After 1994, the ratios then lifted a little again.

As regards changes in Taiwan's education expenditure during the period, we can see from Figure 8 that from 1970 to 1989, the ratios of education expenditure to GDP fluctuated between 6 per cent and 10 per cent; from 1990 onwards, however, the ratios rose a little and then kept fairly stable at around 11 per cent to 12 per cent.

As regards changes in the United Kingdom's education expenditure, Figure 9 shows that education expenditure ratios to GDP fluctuated between 8 per cent and 4 per cent. In fact, after 1974, the ratios followed an almost consistently downwards trend until 1998.

Fig. 9. United Kingdom: Education Expenditure as Percentage of GDP, 1970–98

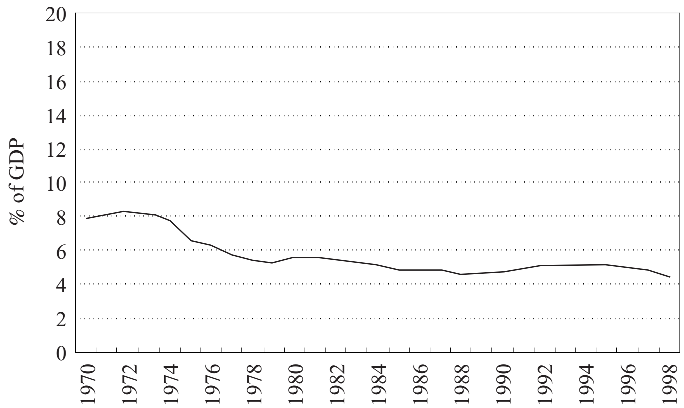
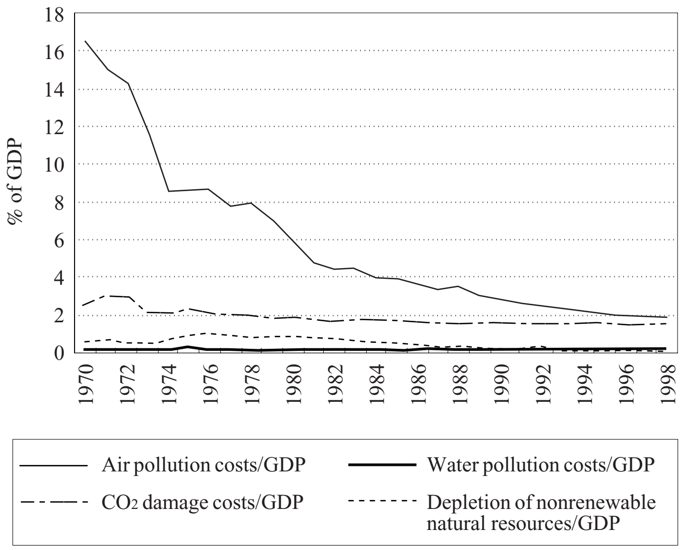


Fig. 10. Taiwan: GS Negative Item Effects as Percentage of GDP, 1970–98



2. *Negative items*

Four negative elements are included within the GS calculation—air pollution costs, CO_2 damage costs, water pollution costs, and natural resource depletion. Let us consider their separate effects on the overall GSI.

From Figure 10, it is evident that for Taiwan, the negative contributions of CO_2 damage costs, water pollution costs, and natural resource depletion have been

TABLE XII

TAIWAN: AVERAGE ANNUAL DECREASING RATES OF AIR POLLUTION COSTS

(%)

Year	Average Annual Decreasing Rates of Air Pollution Costs
1970–79	–9.3
1980–89	–7.1
1990–98	–5.6

TABLE XIII

UNITED KINGDOM: AVERAGE ANNUAL DECREASING RATES OF AIR POLLUTION COSTS

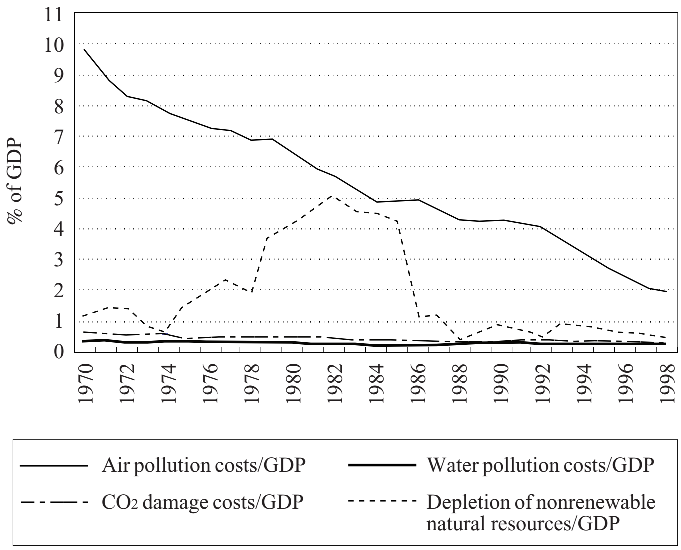
(%)

Year	Average Annual Decreasing Rates of Air Pollution Costs
1970–79	–4.4
1980–89	–3.9
1990–98	–9.6

quite small over the years. Taiwan has not experienced such huge changes in natural resource depletion, mainly because prices of other natural resources for Taiwan have not much changed, and its oil production has been relatively quite low. The air pollution costs, however, have shown an impressive decline over the years. The air pollution costs as a percentage of GDP can be viewed as a kind of side effect of economic production. Continuous decreases in this ratio throughout the period also indicate a situation in which there has been an improvement in air pollution relative to economic development (see Figure 10). Additionally, the data also show that the virtual air pollution emission amounts of Taiwan have fallen during the period, leading to a slide in air pollution costs. Table XII illustrates Taiwan's falling average annual rates of air pollution costs by decade. The improvement of air pollution in Taiwan has been largely due to the government's institution of environmental policies aimed at lowering emissions of main pollutants (i.e., exercising the air pollution tax policy so as to reduce air pollution emissions, see Appendix A).

In the case of the United Kingdom, among the four negative elements of the GS, air pollution costs are the most important in terms of the costs involved (see Figure 11). But between 1970 and 1998, the ratio of air pollution costs to GDP dropped from under 10 per cent to under 2 per cent. As was the case with Taiwan, better control of, and defense against pollution have achieved the effect of improving air pollution conditions. Table XIII shows the United Kingdom's average

Fig. 11. United Kingdom: GS Negative Item Effects as Percentage of GDP, 1970–98



annual decreasing rates of air pollution costs by decade.

As noted above, according to the newest study of the ExternE Project of the United Kingdom, PM_{10} causes the most social costs and is the most damaging form of air pollutant. However, the magnitude of the total cost values of air pollution emissions will obviously also depend on the quantity of each pollutant emitted. In this respect, in the case of the United Kingdom, sulphur dioxide (SO_2), either in terms of marginal social cost involved or the volume emitted, has exerted important influences throughout the period under examination. However, emissions of this pollutant fell quite steeply between 1980 and 1990, probably because of the United Kingdom's need to observe country commitments with respect to the UNECE[17] First Sulphur Protocol.

Figure 12 shows in more detail the degree to which the values of different types of air pollution damage have changed during the period. While damages caused by PM_{10} and NO_x are a steadily declining proportion of GDP, sulphur dioxide (SO_2) damages fell more dramatically. The total air pollution cost in relation to GDP between 1970 and 1998 has dropped by about 81.2 per cent.

The second component of negative effects is natural resources with regard to the depletion costs incurred. In Figure 11, we can see that between 1970 and 1978, the average ratios of depletion costs of nonrenewable natural resource to GDP were between 1 per cent and 2 per cent. From 1979 till 1985, the ratios in-

17 United Nations Economic Commission for Europe.

Fig. 12. United Kingdom: Air Pollution Elements, 1970–98

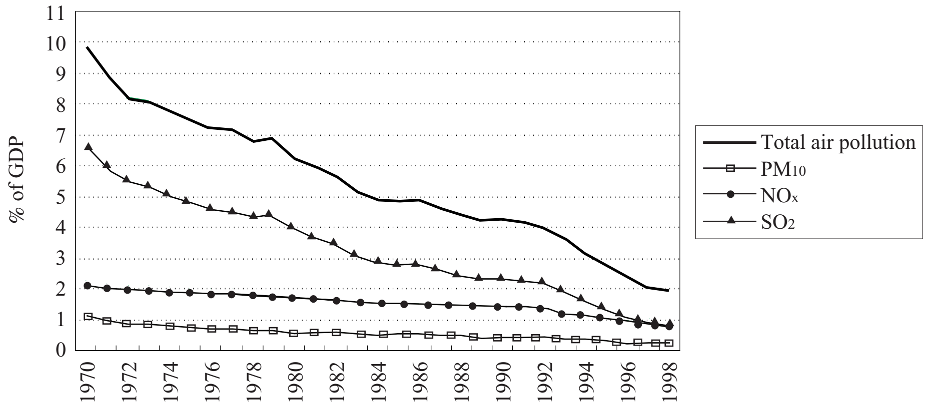
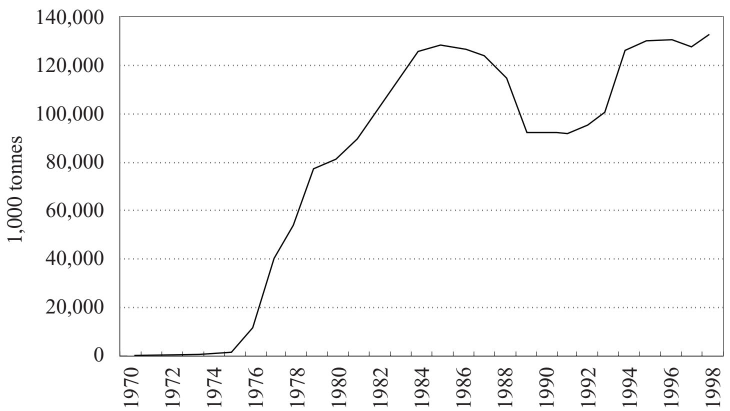


Fig. 13. United Kingdom: Oil Production, 1980–98



Source: United Kingdom, Department of Trade and Industry.

creased to between 4 per cent and 5 per cent, and that is because the market prices for these natural resources became higher during the period, so that the rents (costs) increased as well. Another reason is that the total production (mainly oil output, see Figure 13) also increased during the period. From 1985 to 1998, the depletion ratios then fell to between 0 per cent and 1 per cent.

III. ROBUSTNESS ANALYSIS AND SENSITIVITY ANALYSIS

A. *Robustness Analysis*

From the above discussion, it has emerged that certain individual factors contribute more significantly to the GSI than others. Figures 14 and 15 summarize

Fig. 14. Taiwan: Relative GS Component Values, 1970 and 1998

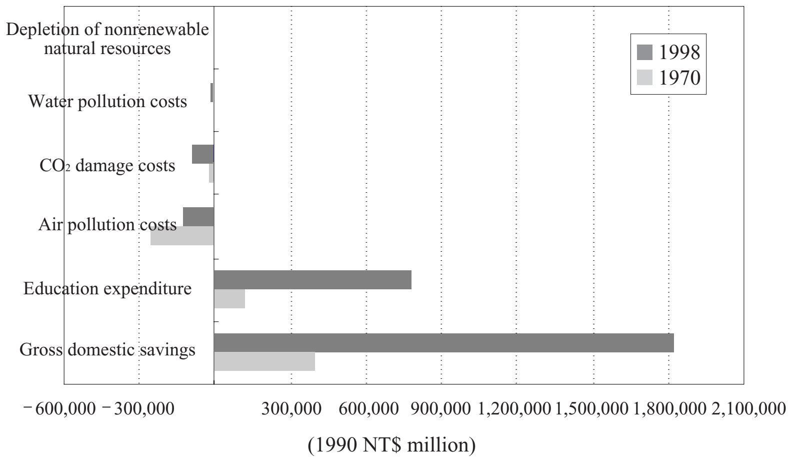
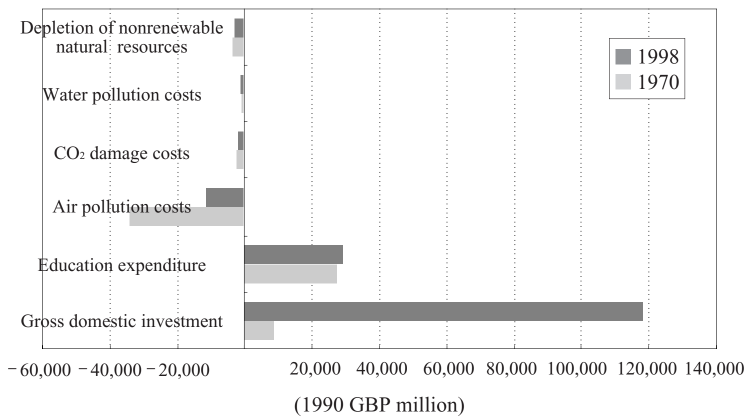


Fig. 15. United Kingdom: Relative GS Component Values, 1970 and 1998



the relative adjustments to gross domestic savings (investment) for Taiwan and the United Kingdom, for the two years 1970 and 1998: the beginning and end (respectively) of the study period. These graphs indicate not only the sizes of the contributions from individual items relative to each other, but also show how those contributions have changed over the course of the study period.

For Taiwan, as is to be expected from the previous discussion, both gross domestic savings and education expenditure are seen to have a substantial positive impact and their growth rates are fairly high during the study period. Air pollution costs have a rather strong negative impact, but as noted before, because of the relevant environmental policy practice, the costs also decreased considerably over the period. Another negative impact arises from CO_2 damage costs, which on the other hand increased slightly during the period. Less influential (negative) contributions are water pollution costs and depletion of nonrenewable natural resource.

In the United Kingdom's case, as we can see from Figure 15, both gross domestic investment and education expenditure have positive impacts, but the growth rate of education expenditure between 1970 and 1998 was not very high. The largest negative impact is from air pollution costs. However, air pollution costs also dropped somewhat during the period because of environmental policy efforts. Less influential (negative) contributions are CO_2 damage costs, water pollution costs, and depletion of nonrenewable natural resource.

B. *Sensitivity Analysis*

From the above robustness analysis, for the main body of the GS calculation, there are certain specific features in the index which contribute considerably to its overall shape. These are gross domestic savings (investment), education expenditure, and air pollution costs. Other items have comparatively little influence. Since these contributions rely implicitly on the quality (accuracy) of the data collected and specific underlying methodological assumptions, it is appropriate to investigate the sensitivity of the GSI to changes in the underlying factors. In the following we look particularly at the impact of data credibility for gross domestic savings (or investment) and education expenditure, and the impact of the methodological assumptions underlying the estimates of environmental degradation from air pollution.

1. *Sensitivity to data credibility with gross domestic savings (investment) and education expenditure*

Both gross domestic savings (investment) and education expenditure are directly derived from national statistical datasets. The national statistics outputs are usually appropriate for the purpose as there is always a standard process available to produce the data and to support the continuing improvement in the quality and value of the data outputs. Usually the government will operate data risk management and data quality control in such a way as to keep the published data up to fairly acceptable quality. For example, quality assurance is a key component of U.K. national statistics as set out in the government white paper, *Building Trust in Statistics*.[18] Especially for national economic accounts data, under the system of national accounts (SNA), all data outputs are produced through an internationally common calculation and compilation methodology. The data outputs can then be used as an accordant base for international comparison and analysis. In view of these circumstances, we can be relatively confident in using these published datasets as two series of inputs for calculating the GS in question. That said, national statistical outputs cannot, by their nature, be of perfect quality, although they must be of adequate accuracy to fit their main purposes.

Components of risk relating to reliability are identified by considering the various elements of the statistical process from user consultation and development to dissemination and archiving of the derived information. For each statistical process, the associated risks are identified in Table XIV. It sets out the various stages in the statistical process and the risks that are considered at each stage.

TABLE XIV

STATISTICAL PROCESSES AND ASSOCIATED RISKS TO DATA RELIABILITY

Activity	Major Risks for Reliability
Collection design	Inappropriate design, e.g., sample too small, or suboptimally allocated; collection mode not optimal for type of questions; respondent burden too great
Testing and development (including questionnaire development, systems, and procedures)	Inadequate testing to ensure data of high quality is available and provided by the methods and systems used
Estimation	Bias in estimation, e.g., outlier identification, use of benchmarks, and risks of model-based assumptions
Dissemination of standard aggregate outputs	Risk of the release being seen as being politicized; risks to timely dissemination of outputs; risks to accuracy of outputs resulting in flaws in the dissemination process
Dissemination of nonstandard aggregates	Risks to accuracy of outputs resulting in flaws in the dissemination process
Dissemination of nonidentifiable unit record data	Risks to accuracy of outputs resulting in flaws in the dissemination process

Source: United Kingdom, *National Statistics*.

[18] In October 1999, the U.K. Office for National Statistics published a white paper on the future of national statistics, *Building Trust in Statistics* (CM 4412, Stationery Office), detailing the accountability and governance arrangements for national statistics.

From the above, we know that the government-published data by their nature still include some level of error risks. But we can say that minor data errors caused by any of the above processes are uncertain and must have been reduced to a very low degree. We do not think these effects will contribute greatly to the alteration of the final GSI. Five per cent of the bias range could be assumed under a reasonable statistical discipline.[19] With these qualifications in mind, Figures 16 and 17 show the sensitivity of the Taiwan-GS and the U.K.-GS as regards the re-

Fig. 16. Taiwan-GS: Sensitivity to the Published Data Reliability, 1970–98

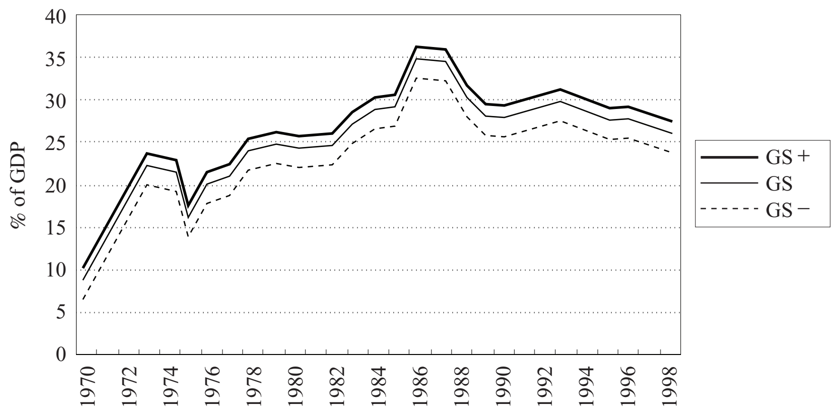
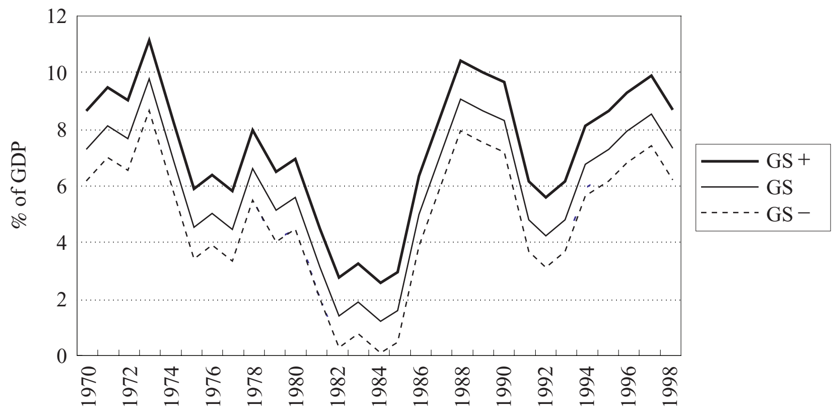
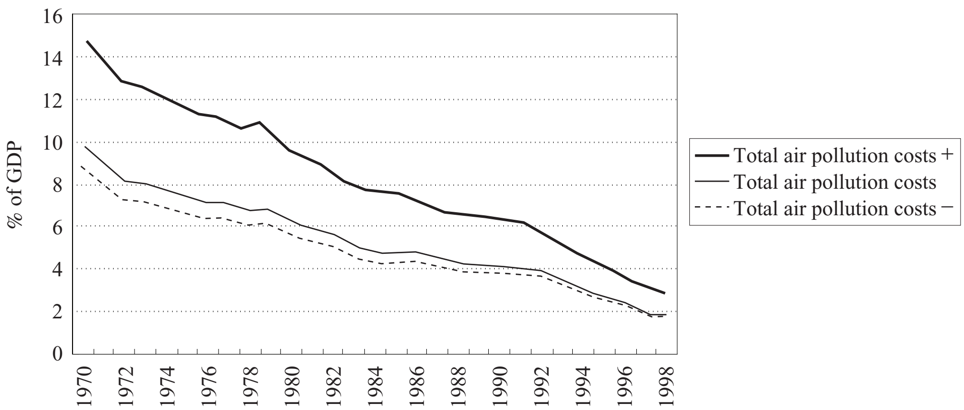


Fig. 17. U.K.-GS: Sensitivity to the Published Data Reliability, 1970–98



[19] This is suggested by the Taiwan's National Statistical Division (DGBAS) (personal communication). The sensitivity range of the GS to the published data reliability varies from year to year. If we assume that 5 per cent bias range is with the published data, then the bias range of the GS for different year will be: {± 5% × [that year's (gross domestic savings + education expenditure)/that year's GS]}.

Fig. 18. United Kingdom: Range of Air Pollution Costs, 1970–98



liability of the published data. Because of some uncertainty concerning the credibility of the published data, the sensitivity ranges of the Taiwan-GS and U.K.-GS during the period range between GS+ and GS −.

2. *Sensitivity to costs of environmental degradation (mainly air pollution)*

We mainly discuss here the sensitivity of the GSI to the costs of air pollution. The main reservation about calculating annual air pollution values is the assumption of marginal social cost.

The social/damage costs we adopted here are the estimates from Berry et al. (1998), as noted above. For SO_2, the damage cost is 6,818.2 ECU (1998 price) per tonne; for NO_x, the damage cost is 5,736 ECU (1998 price) per tonne; and for PM_{10}, the damage cost is 14,062.5 ECU (1998 price) per tonne. However, according to the report of "ExternE National Implementation," the damage cost of main air pollutants for different EU countries as listed above falls within a range of estimation. In the case of the United Kingdom, for SO_2, the estimation range of damage cost is 6,027–10,025 ECU (1998 price) per tonne; for NO_x, the estimation range of damage cost is 5,736–9,612 ECU (1998 price) per tonne; and for PM_{10}, the estimation range of damage cost is 8,000–22,917 ECU (1998 price) per tonne. Figure 18 illustrates graphically the possible range of U.K. air pollution cost results based on the above.

The explanation for the range of estimates is that different air pollution cost inputs lead to different GS values. Figure 19 shows in graph form the U.K.-GS's sensitivity to air pollution costs between 1970 and 1998 according to a range of damage cost assumptions. The GS ratios to GDP are shown to vary between GS+ and GS −. We can see from this graph that in 1982, 1983, 1984, and 1985, the

Fig. 19. U.K.-GS: Sensitivity to Air Pollution Cost, 1970−98

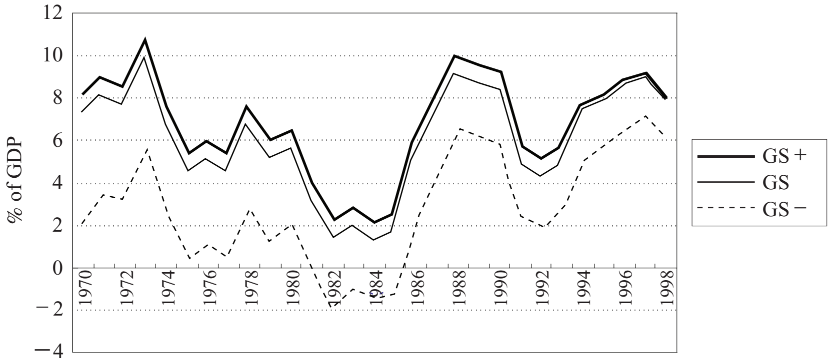


TABLE XV

TAIWAN: RANGE OF AIR POLLUTION SOCIAL COSTS

(In 1991 prices)

Energy	Air Pollution Social Costs
Fuel oil	6.01–11.15 (NT$/liter)
Motor gasoline	0.43–0.79 (NT$/liter)
Diesel oil	2.02–3.74 (NT$/liter)
LPG	0.12–0.22 (NT$/liter)
Natural gas	0.07–0.13 (NT$/m3)
Coal	5.45–10.13 (NT$/kg)

GS − values are themselves negative because of the assumption of greater air pollution damage.

For Taiwan's air pollution cost estimation, according to Lu (1993), the figure of NT$482 (see Appendix B for the estimation process for the unit social cost of Taiwan's air pollution) has an estimation range of 30 per cent. Therefore, α (=18.2757) (also see Appendix B) has a range of 30 per cent, too. Table XV shows the range of air pollution social costs in Taiwan caused by per unit of energy consumed. Figure 20 illustrates graphically the possible range of Taiwan air pollution cost resulting from the above. Figure 21 shows the Taiwan-GS's sensitivity to air pollution costs between 1970 and 1998 according to the uncertainty of the estimation of air pollution costs.

Finally, other GS elements have little influence on the shape of the index itself. This means that the sensitivity of the GSI to those items is relatively low. It must nevertheless be pointed out that for U.K. CO_2 damages, the PAGE95's estimate

Fig. 20. Taiwan: Range of Air Pollution Costs, 1970−98

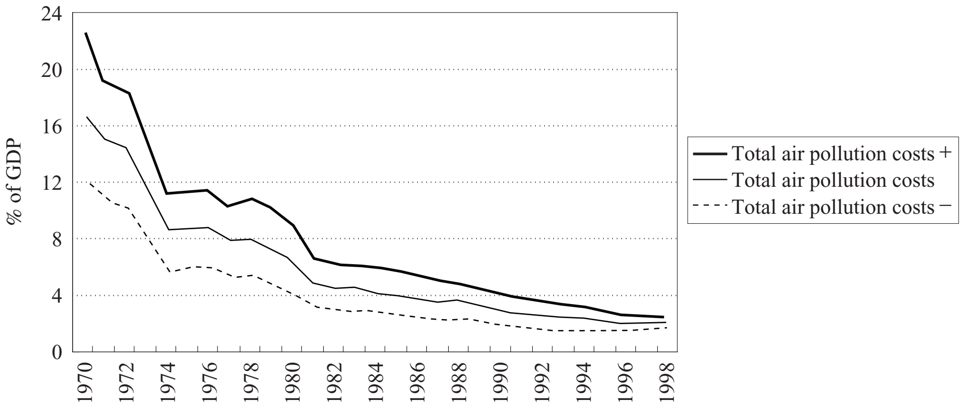
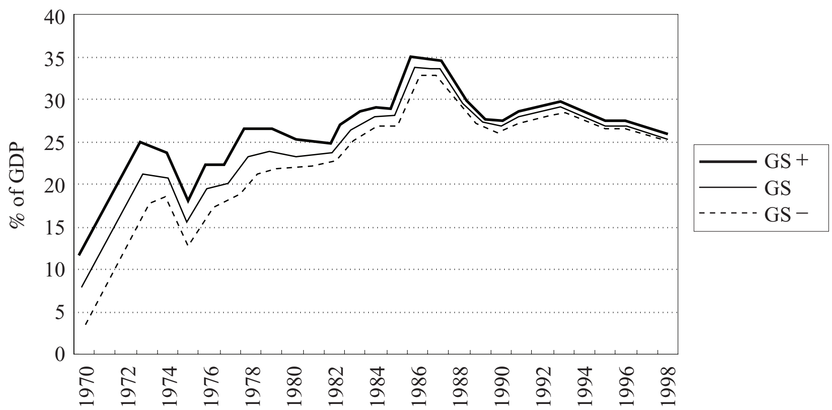


Fig. 21. Taiwan-GS: Sensitivity to Air Pollution Costs, 1970−98



of marginal impacts U.S.$21 per tC has a 90 per cent uncertainty range of U.S.$10–48 per tC. Figure 22 shows the uncertainty range of the CO_2 cost estimation for the United Kingdom from 1970 to 1998. Figure 23 shows the sensitivity of the U.K.-GS to CO_2 cost estimation from 1970 to 1998. For Taiwan CO_2 damage cost estimation the social marginal impacts U.S.$21 per tC have the same uncertainty range.

As regards the natural resource depletion estimate, as already discussed, the outcome depends upon scarcity rents, which should be measured as price minus marginal cost of extraction (including a normal return to capital). In practice, however, marginal production cost data are almost never available, and practitioners[20] fall back on using average extraction costs. This will tend to overstate calculated resource rents and hence will understate the genuine savings.

Fig. 22. United Kingdom: Uncertainty Range of the CO_2 Cost Estimation, 1970–98

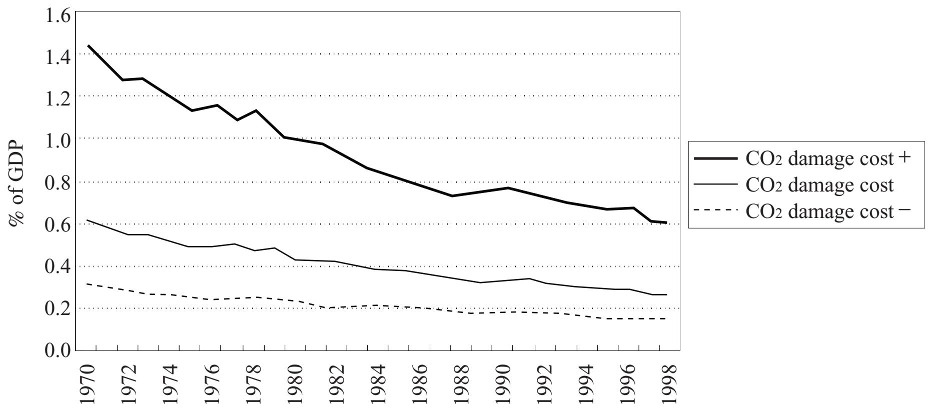
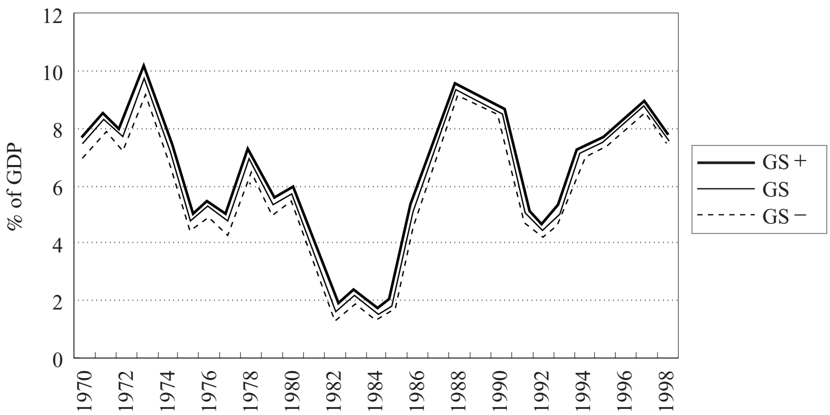


Fig. 23. U.K.-GS: Sensitivity to CO_2 Damage Costs, 1970–98



[20] As the data in this regard are from the World Bank (1997), the practitioners should be the World Bank's researchers.

IV. CONCLUSION AND SUGGESTIONS

The analysis in this case study of compiling the GSI has both policy implications and methodological implications. On the policy side, the study provides evidence that recent economic outputs—GDP levels—for both the United Kingdom and Taiwan seem to be sustainable. However, as a resource-rich country, the United Kingdom's higher resource depletion rates and lower education expenditure rates to GDP over years also depressed its GS rates during the study period. This result has been accordant with the prior research claims: many resource-rich countries have achieved slow or no long-term improvements in their standard of living. One possible explanation is that they have failed to offset the depletion of their natural resource stocks with sufficient investment in physical (equipment, structures, infrastructure) and human capital (knowledge and skills). Taiwan, by contrast, appears to be in good shape. But in both cases, action could be taken to increase investment in reproducible capital so as to offset the depletion of natural resources as well as the depreciation of physical capital.

In this regard, whereas the earlier World Bank estimate did not include an air pollution item, in this paper, by contrast, we have made more detailed calculations leading to several significant results and analyses. We find that both countries had decreasing rates in the growth of air pollution costs between 1970 and 1998 (however, the United Kingdom's decreasing rates strengthened from the 1970s through the 1990s, whereas Taiwan's decreasing rates lessened over the years), and this is because of the implementation of related environmental policy, as already noted.

On the methodological side, the analysis demonstrates that calculation of the genuine savings is feasible at the national level. The GS-related rates have also proved to be a group of user-friendly indicators of sustainability. The above sensitivity analysis also increases our confidence in our results: even though the issue of uncertainty is considered, most of the uncertainty falls into acceptable ranges.

Constructing projections for individual resources on the basis of detailed physical accounts and detailed analyses of future supply and demand conditions was beyond the scope of this study. It is probably well within the capability of resource management agencies in the countries concerned, however. More sophisticated projection methods than the ones employed in this paper are certainly possible.

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APPENDIX A

In order to reduce air pollution for the sake of environmental and human health, the government of Taiwan has taken some important measures in the past thirty years. These include:

- fuel use control,
- air pollution tax levy,
- setting of emission standards,
- emission amount control,
- mobile source control strategies, and
- low pollution technology practices.

Obvious progress has been made in this respect and the following section will offer some relevant examples.

Significant Decrease in National Unhealthy Air Quality Station-Days

In the preliminary stage after the establishment of the Environmental Protection Administration (EPA) (during the period of 1987 to 1991), the percentage of the unhealthy air quality station-days was about 16 per cent. After the Air Pollution Control Act was promulgated in 1992, the EPA actively promoted the adoption of pollution control technology for industries and vehicles. In 1997, the percentage of the unhealthy air quality station-days fell to 5.46 per cent, which meant that the 6 per cent target had been achieved. (In 1986 and 1987, the rates of progress were 15 per cent and 68 per cent, respectively.) In 1998, the percentage of the unhealthy air quality station-days was further reduced to 5.09 per cent. These significant achievements show that air quality management tasks are moving toward a milestone in Taiwan. According to the stipulated targets of the National Environment Protection Plan, the percentage of the unhealthy air quality station-days will be reduced to 3 per cent in 2001, 2 per cent in 2006, and 1.5 per cent in 2011.

National Air Pollutant Concentration Trend

According to the air quality monitoring information, PM_{10} and O_3 are the main pollutants so far as ambient air quality standards are concerned. Following the promotion of air pollution control tasks over the years, air pollutant concentrations have fallen, and the risks to humans from air pollution have decreased. Statistical analysis indicates that the average annual concentrations of different air pollutants all showed an improvement between 1991 and 1999. Although the CO and NO_2 concentrations increased slightly in 1996 and 1997, the pollutant concentration trends have nevertheless improved in the last five years. The rates of progress for average concentration of different air pollutants (from 1991 to 1999) are listed as follows:

SO_2	40% (significantly improved)
PM_{10}	20%
Pb	25%
CO	21%
NO_2	10%
O_3	13%

Source: Air Pollution Division, EPA.

APPENDIX B

The following concerns the estimation process leading to the appraisal of Taiwan's unit social cost of air pollution from energy consumption.

1. *The estimation of sickness risks from different air pollutants*

Based on studies made by the Chiang Ching-Kuo Foundation for International Scholarly Exchange and Academia Sinica,[a] the change in health risk is estimated

[a] The survey time: November and December 1991 and January 1992 (totally ninety-two days). Survey locations: Taipei city's Shi-Sung train station, Taipei county's Yung-Ho train station, Kaohsiung city's Fu-Hsing train station and Sang-Ming train station, and Hua-Lieng city's city train station. The number of samples: 92 (days) × 953 (people) = 87,676.

as follows: NO_2: 9.038751 × 10^{-6}; SO_2: 0.000142133; and PM_{10}: 1.4260855 × 10^{-6}. That means, when the emissions of NO_2, SO_2, and PM_{10} increase 1 ppb (or 1 μg/m^3) individually, the risks of getting breath-related sickness due to these air pollution will be lifted by (9.038751 × 10^{-6}), (0.000142133), and (1.4260855 × 10^{-6}), separately.

2. *The estimation of pollution intensity of* j *air pollutant per unit of* i *energy consumed*

Pollution Intensity of *j* Air Pollutant per Unit of *i* Energy Consumed = (Pollution Intensity of *j* Air Pollutant)/(Total Consumption of *i* Energy to Produce Uncontrolled *j* Air Pollutant Emissions). Appendix Table I presents Taiwan's energy consumption and air pollution emissions due to the consumption of energy. Appendix Table II shows *j* air pollutant's pollution intensity in relation to *i* energy consumption.

APPENDIX TABLE I

TAIWAN: ENERGY CONSUMPTION AND AIR POLLUTION EMISSIONS DUE TO CONSUMPTION OF ENERGY, 1991

Energy	Total Energy Consumption	Uncontrolled Air Pollutant Emissions (tonne)		
		SO_2	NO_2	PM_{10}
Fuel oil (1,000 kl)	12,230.1	353,144.1	121,044.6	27,578.9
Motor gasoline (1,000 kl)	5,896.9	10,172.2	16,511.3	1,474.2
Diesel oil (1,000 kl)	4,725.5	40,757.4	13,231.4	62,376.6
LPG (1,000 kl)	2,348.9	805.7	3,617.3	70.5
Natural gas (10^6 m^3)	2,863.0	28.6	6,413.1	137.4
Coal (1,000 tonne)	14,675.6	377,750.0	133,548.0	107,131.9
Total		784,659.2	297,314.9	198,832.7

Source: Ministry of Economic Affairs, Energy Commission, "The Energy Balance Table," 1991.

APPENDIX TABLE II

TAIWAN: ENERGY CONSUMPTION AND AIR POLLUTANT INTENSITY, 1991

Energy	Air Pollutant Intensity		
	SO_2 (ppm)	NO_2 (ppm)	PM_{10} (μg/m^3)
Fuel oil	0.0112515000	0.0097710220	9.1197349
Motor gasoline	0.0003240961	0.0013328333	0.4340315
Diesel oil	0.0012985700	0.0010680720	18.3648170
LPG	0.0000256704	0.0002919975	0.0207000
Natural gas	0.0000009112	0.0005176814	0.0404530
Coal	0.0120354000	0.0107803000	31.5416000

Source: Liang (1993).

3. *The estimation of willingness to pay (WTP)*

What is estimated here is the willingness of individuals to pay (WTP) to obtain a reduction in the mortality caused by sickness. There are two sources of empirical estimates of individuals' WTP for mortality risk reductions: revealed preference studies, based on compensating wage data or consumer behavior; and stated preference studies, including those employing contingent valuation methods (Hammitt and Graham 1999). The compensating wage approach is basically a transfer of estimates from compensating wage to immediate reductions in risk of death (Krupnick et al. 2000). Contingent valuation asks people to express their WTP using a range of survey techniques. The WTP figures can be used to compute the corresponding value of a statistical life (VSL). We can compute the VSL by dividing annual WTP by the size of the annual risk reduction (i.e., 5 in 10,000 or 1 in 10,000). According to Hsiow et al. (1993), the each-time WTP per person in Taiwan equals NT$1,800 in 1991 prices, and the average days of sickness are four days, so the unit WTP for Taiwan residents is estimated to be NT$450 in 1991 price. This result comes from an application of the contingent valuation method.

4. *The estimation of air pollution health cost per unit of energy consumed*

Air Pollution Health Cost per Unit of Energy Consumed = Σ_j (*j* Air Pollutant Intensity Related to Per Unit of *i* Energy Consumed × Change in Health Risk Caused by *j* Air Pollutant) × National Population × 365 × Unit WTP.

For example, the "air pollution health cost per unit of motor gasoline consumed" would be: $\{[(0.0003240961)/(5{,}896.9) \times (0.000142133)] + [(0.0013328333)/(5{,}896.9) \times (9.038751\times10^{-6})] + [(0.4340315)/(5{,}896.9) \times (1.4260855 \times 10^{-6})]\} \times 20{,}557{,}000 \times 365 \times 450$.

Appendix Table III is then the estimation result of the air pollution health cost caused by per unit of energy consumed.

APPENDIX TABLE III

TAIWAN: AIR POLLUTION HEALTH COST CAUSED BY PER UNIT OF ENERGY CONSUMED

(In 1991 prices)

Energy	Air Pollution Health Cost
Motor gasoline	0.03363 (NT$/liter)
Diesel oil	0.15749 (NT$/liter)
Fuel oil	0.46909 (NT$/liter)
LPG	0.00908 (NT$/liter)
Natural gas	0.00574 (NT$/m^3)
Coal	0.42634 (NT$/kg)

Source: Liang (1993).

5. *The estimation of air pollution social cost of energy consumed*

According to the survey of Lu (1993), the cost for individuals living in Taiwan to pay to reduce half of the total air pollution intensity would be NT$482 (in 1993 prices) for each person per month, so the total social costs caused by energy consumption leading to one half of the air pollution intensity would be: 482 × 12 × 20,557 (1,000 people), which equals 118,901,688 (NT$1,000).

If we assume that the air pollution social cost of i energy consumed = α × air pollution health cost of i energy consumed,[b] then 118,901,688 = 1/2 Σ_i air pollution social cost of i energy consumed = 1/2 × α × Σ_i air pollution health cost of i energy consumed = 1/2 α × Σ_i (i energy total consumption × air pollution health cost per unit of energy consumed), and therefore we get that α = 18.2757. So,

per unit air pollution social cost of motor gasoline = (18.2757) × 0.03363 = 0.6146 (NT$/liter);
per unit air pollution social cost of diesel oil = (18.2757) × 0.15749 = 2.8782 (NT$/liter);
per unit air pollution social cost of fuel oil = (18.2757) × 0.46909 = 8.5729 (NT$/liter);
per unit air pollution social cost of LPG = (18.2757) × 0.00908 = 0.1660 (NT$/liter);
per unit air pollution social cost of natural gas = (18.2757) × 0.00574 = 0.1049 (NT$/$m^3$);
per unit air pollution social cost of coal = (18.2757) × 0.42634 = 7.7917 (NT$/kg).

[b] The air pollution social cost generally includes health cost, agricultural production cost, acid-rain cost, and landscape damage cost that are caused by air pollution.