South-North Materials Flow:
History and Environmental Repercussions

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Abstract

The current literature on the relationship between income and environmental quality is dominated by a notion of inverted "U" curve between both variables. However, a key variable is missing in this kind of studies: the extra-territorial environmental effects of national economies. International trade of raw materials may be a good proxy to estimate these "environmental load displacement" effects. The present work tries to elucidate some patterns in the relationship between economic growth in affluent countries and the quantity of non-renewable materials imported from less developed countries. The results indicate that a general de-linking between economic growth and Southern resources consumption is not occurring in the industrialized world. Thus, developed countries may be increasingly displacing the environmental costs associated with material throughput to poorer regions of the world.

Key Words: non-renewable materials; dematerialization; international trade; environmental Kuznets curve.

INTRODUCTION

Ecological Economics depicts the economic subsystem as being "embedded" in a bigger frame representing the environment. Under this approach, the economy depends on environmental functions, which provide basic support, raw materials, energy and sinks for wastes. Since it is impossible to have total independence of the economic performance from the environmental services provided by these functions, there are both biological and physical constraints to the economic process. An economy will be sustainable while it does not surpass these biophysical limits and thresholds. Thus, environmental sustainability can be defined as the maintenance of important (or critical) environmental functions (Ekins, 1998). This vision leads to emphasise biophysical (instead of monetary) variables as indicators of sustainability. From this viewpoint, the throughput, that is, the energetic and material requirement of a certain economy, can be viewed as a measurement of the size of the economic system in relation to the environmental one. (Daly, 1991; 1995; Hinterberger et al., 1997).

The economic system may be seen as analogous to a living system. All living systems are thermodynamically open systems that require high quality energy inputs to change the state of naturally occurring materials in their environment into states that are of higher value to them. This process produces wastes and heat. Therefore, from a thermodynamic perspective, the net effect of living systems is to maintain or increase order within their system boundaries and to decrease order in their environment. This feature is common to any dissipative system. The biosphere has a crucial property: the rates at which “wastes” are generated are the same as those of “assimilation”. On a global scale, the biosphere has effective mechanisms to close the material cycles. However, in the current economic process, the rates of waste production and assimilation are not at all similar. For example, the current quantity of recycled materials is much lower than those coming from the lithosphere. Moreover, the current anthropogenic flow of many elements exceeds the natural one. For example, the anthropogenic flow of lead exceeds 333 times the flow by natural processes. The same occurs with nickel (4 times), copper (14 times), zinc (23 times), cadmium (20 times), antimony (38 times) (Ayres, 1997).

Nevertheless, scarcity of materials does not appear to be a near-term threat to economic growth (Hodges, 1995; Ayres and Ayres, 1996). Instead, in the specific case of non-renewable resources, the danger seems to come from a disturbance of the “natural flows” of these materials produced by human (economic) activity. As a consequence, the new allocation of materials on the earth could produce a disruption of some key natural functions and threaten the economic system itself. The best known of these possible effects are global warming and ozone layer depletion.

Environmental Cost of Materials Extraction and Processing

Mining, processing and use of materials produce wastes, which threaten human, vegetal and animal life. There are two types of wastes associated with extraction *per se*. These are (i) soil displaced in the process of searching for and removing ore (overburden), which may involve deforestation and habitat fragmentation and (ii) unwanted contaminants (gangue) removed on-site or at the mill by physical methods, such as screening, washing, settling, flotation, centrifuging and so on. Further material processes, such as metal ore smelting and refining generate also separation wastes, such as slags, as well as air and water pollutants (Ayres and Ayres, 1998).

The discharge of wastes to the environment creates a variety of possibilities for adverse effects on humans and other living beings, both direct and indirect. Major examples include: a) contamination of soil, ground or surface water used by humans, wildlife, livestock, or for irrigation ; b) contamination of air by toxic or irritating combustion products (volatile compounds, SO_x, NO_x) with direct effects on health or disturbance of fresh water ecosystems by eutrophication or acid rain deposition; c) disturbance of ocean ecosystems due to oil spills, ocean dumping, ocean mining, etc.; d) climatic disturbance due to rising concentration of CO2 and/or other chemical pollutants in the atmosphere. (Ayres, 1996).

The metal content in ores normally is very low. Hence, the ancillary material (the material that must be removed from the natural environment, along with the desired material) exceeds many times the weight of the pure ore. Therefore, the quantities of solid mining and milling wastes produced by mining for metal ores are typically much greater than the quantities of processed metals. The excavated and/or disturbed material (e.g. soil displaced in the process of searching for and removing of ore) usually is also huge for metals. Table 1 shows Hidden Material Flows (ancillary material flow + excavated and/or disturbed flow) calculated by the Wuppertal Institute for some metals. It reveals that these flows are far from being negligible. They are an important variable to consider in estimating the environmental impact of the material requirement of an economy. Usually, the hidden flows are associated with habitat destruction, soil erosion and fresh water pollution.

Wastes are not only generated in the mining process. As it was said above, refining and smelting of metals also produce pollutants. The production of iron/steel is accompanied by the discharge of toxic gases (mainly CO) from coke ovens and furnaces, waterborne acidic wastes or sludges from “picking” sheet or strip. Copper, zinc, lead and nickel smelters are major sources of air pollution (mainly SO_2), despite recent efforts to improve environmental controls in some countries. These smelters also yield tailing slags, ashes, flue dust or sludges that are rich in quite toxic by-products. Thus for example, processing of zinc yields important quantities of cadmium, which may become accessible to biological organisms. Aluminium smelting can generate air pollution by fluorine (from the electrolytic cells). It also produces large quantities of caustic wastes, called “red mud”, which is hard to dispose of, or to utilise. It contains potentially toxic oxides like Fe_2O_3, TiO_2, SiO_2 and Al_2SiO_5 (Masini and Ayres, 1996). On the other hand, aluminium smelting needs a huge amount of energy. Because of that, smelters are normally associated with big coal or hydroelectric power plants, which produce air pollution or have produced flooding, damaging extensive areas of forest for example. Copper as well as nickel processing have arsenic as important by-product. This element has an extraordinary biotoxicity and moves relatively easily from one environmental compartment to another, e.g. from soil to air to water. Copper mining by acid leaching contributes significantly to water pollution. The major environmental problem of zinc is the by-product cadmium. It can be taken up and accumulated by plants and animals via the same biochemical mechanisms followed by zinc. In zinc metallurgy considerable emissions of sulphur, arsenic, copper and lead are also yielded (Ayres and Ayres, 1996). Mining of iron ore and processing of pig iron, steel, copper, nickel, lead, zinc and tin are classified as pollution-intensive activities in the U.S. because they have pollution abatement cost above 2 % of the total costs (Tobey, 1990). Based on actual emissions intensity (emissions per unit of output), they are among the most polluting industries according to the World Bank (Mani and Wheeler, 1997).

Processing of phosphate rock (into fertilizers) results in significant environmental impacts, of several kinds, including toxic fluoride emissions to the atmosphere and accumulation of (mildly) radioactive tailings (uranium oxide). By each ton of phosphoric acid 3.5 tons of wastes are generated (Bunker, 1996). The process also produces toxic mud and important erosion rates (Ayres, 1996). Petroleum and natural gas extraction can also generate extensive environmental damage. It can produce water pollution by oil spills and by direct dumping of “production water” (often saline), which is typically contaminated by drilling mud and materials removed from the holes and some hydrogen sulphide (H_2S). Drilling can also promote direct habitat fragmentation because it needs often the construction of new roads and human settlements in non-altered areas (forests for example). Gas associated with oil extraction if often burned in the field, producing greenhouse gases. Refineries emit carbon monoxide and dioxide as well as hydrocarbons, including volatile compounds such as benzene, toluene, xylene and other aromatics, most of them carcinogenic (Ayres and Ayres, 1996).

Materials Flow as Environmental Cost Shifting

Since a) the earth is a closed system b) there is a high interdependency between different ecosystems; c) many sorts of pollution do not recognize human political frontiers and d) we share the same oceanic water and atmosphere, the environmental effects of a national economic system can be properly evaluated only on a global geographical scale. As waste production and environmental degradation associated to the material throughput are mainly concentrated in the mining and processing steps of the material cycle, imports of ores or semi-processed non-renewable resources can be conceived as a rough indicator of the environmental load that a national economy produces abroad. They can be used as an approximation to the “ecological space” a country occupies. Natural resource flows can be seen as “ecological flows” in the sense that some countries may appropriate the carrying capacity of other countries (e.g. by importing natural resources), benefiting at the expense of their trading partners, whose own development prospects are constrained by the impossibility to appropriate carrying capacity from elsewhere (Naredo, 1998; Proops et al, 1999).

Undoubtedly, the environmental impacts of material consumption are not only a matter of scale (the quantity of consumed or removed materials), but also of “quality”. That is, the potential environmental harm of the involved materials. In terms of potential environmental damage, one Kg of spilt radioactive wastes is not equivalent to one Kg of spilt petroleum. Although some authors consider that in the final analysis, it is the throughput (or scale) what determines the long-run sustainability of economies (Hinterberger et al, 1997), both parameters (quantity and quality) seem to be relevant. Therefore, it is recommendable to consider not only aggregated consumption or imports (in metric tons), but also to differentiate the throughput in its components. Policies intending to reach sustainability by reducing total throughput should begin trying to diminish the requirement of the most environmental harmful materials.

Income-Environment Relationship

Some authors have proposed that affluent countries have experienced a “dematerialization”, concomitant with a reduction in the emission of pollutants as a consequence of increasing income in the last decades (Anderberg, 1998). According to Larson et al. (1986), industrial countries appear to have reached a turning point: “they are now leaving the Era of Materials and are moving into a new era in which the level of material use will no longer be an important indicator of economic progress”. They suggest the following causes for this tendency. First, substitution of one material for another has slowed the growth of demand for particular materials. Second, design changes in products have produced an increase in efficiency of material use. Third, market saturation for products which are resource-intensive and the appearance of new markets tending to involve products that have a relatively low material content (communication, information, recreation). Reduction in energy/materials intensity is also associated with “desindustrialization”, a switch away from resource-intensive industry towards knowledge-intensive services (Glyn, 1995). Some models assume that the tendency to reduce the resource intensity of the global economy will continue in the future (Labson, 1997). According to these views, in the process of ongoing growth the economy would “delink” itself from its environmental base through “dematerialization” and “depollution”.

Besides, empirical studies have shown that there exists an inverted “U” shape curve between economic national income (GDP per capita) and some form of environmental degradation (this relationship is usually called “environmental Kuznets curve”). Most of these studies have been made using cross-sectional analysis and local environmental parameters like SO_2, NOx, lead, cadmium, arsenic, nitrates and CO emissions or concentrations, deforestation, lack of clean water, etc. (Selden and Song, 1994; Komen et al, 1997; Cole et al, 1997). The causes for this pattern have been associated mainly with the effects of structural economic change on the use of the environment for resource inputs and for waste assimilation (mainly by technological innovation) and the positive income-elasticity of demand for environmental quality (Barbier, 1991). Some researchers argue that most societies choose to adopt policies and to make investments that reduce environmental damage associated with growth (Shafik, 1994), and when nations experience greater prosperity, their citizens demand that more attention be paid to the non-economic aspects of their living conditions, including environmental quality (Grossman and Krueger, 1995). This has led some authors to support the general proposition that the solution against environmental damage is economic growth itself (Beckerman, 1992). That is, the poor are "too poor to be green". However, it has been argued that, while poor people cannot afford to buy environmental necessities and even less environmental amenities, nevertheless they quite often complain loudly (outside real or fictitious markets) against environmental degradation. For instance, the environmental justice movement in U.S. or the "environmentalism of the poor" (Guha and Martinez-Alier, 1997).

On the other hand, Ekins (1997) pointed out that it is possible that the consumption of environmentally intensive goods is increasingly being met by imports. If this is the case, the environmental costs are being displaced from one country to another, rather than reduced. Moreover, this way of reducing local environmental damage will not be available to the late developing countries, because there will be no countries coming up behind them to which environmentally intensive activities can be reallocated. The observed inverted-U curves may be the result of change in international specialization: poor countries may attract "dirty" and material intensive production while richer countries specialize in clean and material extensive production, without altering the consumption pattern (Stern et al, 1994). Imports of raw (and semi-processed) materials can be a viable way to allocate abroad the environmental costs of the local consumption. The quantity of imported resources can be a rough proxy of the degree an economy is responsible for pollution outside its political frontiers. If an increase in pollution-embodying imports has accompanied economic growth in developed countries, then the environmental Kuznets curve cannot be extrapolated at the global level.

The "dematerialization" thesis also has been criticised. Adriaanse et al (1997) analysed the total material requirement of Japan, Netherlands, U.S. and Germany during the last two decades. They found both a general convergence among the countries studied and, in most of them, a gradual rise in per capita natural resources use. They therefore conclude that a meaningful dematerialization, in the sense of an absolute reduction in natural resource use is not taking place. However, the efficiency in total resources use (Kg of resources required by unit of GDP) improved from 1975 until 1987 and stagnated from 1987 until 1993 (last year studied). Ayres and Ayres (1996) report that the annual world-wide production of most metals has constantly increased since the beginning of the century, showing that, at least for these materials, global dematerialization has not occurred. Total consumption seems a better indicator of environmental pressure than the efficiency relative to GDP. Inside one country, it could be argued that if the rise of resource consumption is less than growth of GDP (i.e. increased internal efficiency of resource use), then, the larger environmental impact due to increased resource extraction and waste generation can be compensated for by "defensive expenditures". However, internationally this may not apply due to structural conditions preventing the internalisation of environmental costs into the prices of environment-intensive products (e.g. minerals).

On the other hand, some empirical analyses on the relationship between income and environmental conditions have revealed that there can be a "re-linking" between economic growth and environmental degradation above a certain income threshold. This "N" relationship have been observed in isolated parameters like $S0_2$, fecal coliforms and total coliforms[1] (Ekins, 1997), but also in aggregated indicators of the throughput intensity of production. De Bruyn and Opschoor (1997) use an indicator which aggregates weighted cement consumption, steel consumption, freight transport and energy consumption. They show that the throughput relative to income decreases until certain threshold, after which there is a phase of "re-linking" (throughput increases more than income). According to the re-linking hypothesis, after a period of delinkage, may come a time or income level, at which growth of income overtakes weak delinking (reduction in throughput in relation to income) because the possibility of increasing energy and materials efficiency may have a technological or even an economic upper limit (Opchoor, 1995).

The present work has as general objective to analyse the evolution of South-North flows of non-renewable resources in the last 30 years. It tries to elucidate some patterns in the relationship between economic growth in affluent countries and the quantity of non-renewable materials imported from developing ones. Traded non-renewable materials are seen here as an indirect indicator of "environmental load" transference from importing to exporting countries. Hence, the results may also be used to postulate

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[1] Some studies have shown that municipal garbage and CO_2 may increase linearly with income (Barbier, 1997).

hypotheses about the relationship between economic growth in the North and the environmental-damage “displacement” to the South. As the industrialised countries witnessed almost relentless economic growth in the period considered, the time variable is assumed here to be correlated positively with income.

Data and Variables

The World Trade Annual, a hard-copy publication of the U.N. statistical office, was the source we used for trade data. This database contains data specifying imported quantity (in weight units), and country of origin. The period of analysis was from 1963 to 1996. Data were digitised manually. Imports by item and by country were classified according to origin. Three origins were defined: developed countries (high-income countries according to the World Bank classification), developing countries (middle and low income countries according to the World Bank) and central planning countries (East Europe until 1991, China, Vietnam, North Korea, Cuba). In the final analysis, the last two were summed up and renamed as “South”. For each item, “Northern imports” was defined as the aggregated imports (in Metric Tons) of U.S., Japan, France, Italy, Germany (Federal Republic until 1991 and unified Germany since 1991), Netherlands, Spain, Sweden, Denmark, U.K and Ireland.

The non-renewable materials considered for this study were: **Fertilizers,** crude, including: animal and vegetal crude fertilizers, natural sodium nitrate, natural phosphates and natural potassic salts. **Iron Ores**, concentrates. **Copper Ores**, concentrates. **Nickel Ores**, concentrates. **Bauxite** . **Lead Ore**, concentrates. **Zinc Ores**, concentrates. **Crude Petroleum**. **Petroleum Products**, including: gasoline, kerosene, distillate fuels, residual fuel oils, lubricating oils, greases, wax and petroleum coke**. Gas natural and Manufactured**. **Pig Iron**, including: spiegeleisen, cast iron, iron and steel powders, sponge iron and steel, ferro-manganese alloys and other ferro-alloys. **Iron and Steel Shapes**, including: iron and steel wire rod and bars and big and small steel sections. **Copper**, alloys unwrought and worked. **Nickel**, alloys unwrought and worked. **Aluminium**, including: alloys unwrought and worked, bars, wire, plates, sheets, strips, foil, powders, flakes, tubes and tubes fitting. **Lead**, including: alloys unwrought and worked, bars, wire, plates, sheets, strips, foil, powders, flakes, tubes and tubes fitting.

Zinc, including alloys unwrought and worked, bars, wire, plates, sheets, strips, foil, powders, flakes, tubes and tubes fitting. **Tin**, alloys unwrought. and worked.

RESULTS

Figures 1-19 show some aggregated non-renewable material imports of the “North”, that is U.S., Japan, France, Italy, Germany, Netherlands, Spain, Sweden, Denmark, U.K and Ireland from developing or central planning countries. We are assuming these imports are a representative sample of real South-North (low-middle income - high-income countries) material flows across time. Imports in all the figures are expressed in weight units (millions metric tons: MMT).

Despite the fact that there is no a unique tendency across all the figures, based on the results one can say that, except for fertilizers (Fig. 1), lead ores (Fig. 11) and tin ores (Fig. 15), there is no evidence of a “de-linking” of northern material requirement from the South. For pig iron (Fig. 3), iron and steel shapes (Fig. 4), copper ores (Fig. 5), copper alloys (Fig. 6), nickel alloys (Fig. 8), aluminium (Fig. 10) and zinc (Fig. 14) it is clear that current South-North flows are larger than 30 years ago. For these materials, Northern imports from the South have witnessed an increase between 32 and 660 % in the considered period (see Table 2) with a trend still to grow.

In the case of bauxite (Fig. 9), lead (Fig. 12), zinc ores (Fig. 13), tin alloys (Fig. 16), petroleum products (Fig. 18), gas natural and manufactured (Fig. 19), crude petroleum (Fig 17), nickel ores (Fig. 7) and iron ores (Fig. 2), the results do not reveal any clear tendency across time. Nevertheless, only the three latest show 1990’s imports below those of the 70’s (see Table 2) and none of them is below –12 % of change. Imports of tin ores (Fig. 15) and fertilizers (Fig. 1) have declined almost continually the last 20 years, and lead ores’ imports have an inverted “U” tendency. These are the only items that show an increasing Northern “delinking” from “Southern” resources.

DISCUSSION

The clear diminution of Northern consumption of fertilizers from the South (Fig. 1) possibly responds to substitution of synthetic fertilizers (made from petroleum or gas) for mineral fertilizers. The other item which presents a clear tendency of diminishing imports along time is tin ores. This is likely to be the result of technological substitution. However, semi-manufactured tin imports did not follow the same trend as the ores. Actually, they experienced an increment of 12 % between 1971-76 and 1991-96 (see Table 2). This evidence seems to reveal that there is occurring a substitution of imports between ores and semi-manufactured tin. Probably, this is also the case with lead, whose ores imports are 10 % less in the 1990´s than in the 70`s and the semi-manufactured ones 9 % larger. In the case of crude petroleum (Fig. 17), a first diminution of imports occurred in the early 1970's, surely associated to the OPEC success in rising international prices. A second important sustained diminution of imports occurred in the 80's, probably as a consequence of the second international oil crisis (due to the political instability in the Persian Gulf). This crisis was accompanied by a rise in the consumption of nuclear energy and a bigger exploitation of the North Sea reserves. The 1990's witnessed very low prices of oil and an increasing dependency of the North on Southern sources of petroleum[2].

Northern Imports from the South of all semi-manufactured metals in the period 1991-96 were larger than the average 1971-96 (see Table 2) and in many items they showed a continuos trend to increase across time (zinc, iron, nickel, copper, aluminium). Although it is very difficult to link material flows with actual specific environmental degradation and the above-presented results can be interpreted in different ways, increasing Northern imports of semi-manufactured metals (from the South) is probably concomitant with enlarging Southern environmental load associated to extraction and processing of materials. Imports of semi-manufactured materials may imply larger environmental-cost-shifting compared to imports of non-processed materials because

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[2] The environmental consequences of oil consumption are not restricted to drilling or processing activities. Wastes coming from petroleum and gas final products, like CO_2, hqves broad environmental effects at a global level. Hence, a county importing petroleum and emitting CO_2 to the "international" atmosphere is producing a "double" environmental-cost-shifting.

they embody the environmental impacts of both extraction and processing. Establishing relationships between material flows and environmental pressures, like pollutant emissions or habitat change, is still a relatively unexplored area of research. One of the few attempts to develop this idea is the work of Wyckoff and Roop (1994), who estimated the amount of carbon dioxide emissions embodied in the imports of manufactured goods in six of the largest OECD countries. They found that a significant amount, about 13 % of total carbon emissions of these countries, is embodied in manufactured imports. They point out that this result suggests that standard measures of carbon emissions relying solely on domestic sources such as annual carbon produced per unit of GDP or per capita will be misleading if a real reduction of emissions is intended. This kind of analysis can be included in enlarged national accounting systems and would aid to assess the “environmental” terms of trade between regions (Arden-Clarke, 1992).

The inclusion of indicators of environmental load displacement by imports into the national accounts can be a very useful tool for establishing final causes of environmental degradation at a global level. Trade allows that the environmental pressures associated to local economic performance occur in geographically remote areas. Hence, local people are unaware of the ultimate environmental repercussions of their behavioural and consumption patterns (Redclift and Sage, 1999). Unless a link can be shown between local consumption and foreign environmental change, to convince local population to adopt more sustainable consumption patterns will be a hard task. Indeed, many economists do not see a negative relationship between consumption and environmental quality. On the contrary, they point out that countries with higher per capita private consumption levels do have lower emissions of air and water pollutants, as well as lower deforestation rates. That is, they have a better environmental performance (Vincent and Panayotou, 1997). This notion is supported by the fact that in the industrialised world, where the largest levels of consumption occur, services and low material-intensity activities increasingly account for most of the GDP. However, our results show that, at least for semi-manufactured metals, the North seems to have an increasing dependency on foreign resources (in physical terms). Although imports cannot be considered as a direct indicator of consumption, increasing Northern imports probably mean swelling material requirements. If increasing imports do not mean larger consumption, then they mean substitution of local production by trade (and abroad-displacement of polluting activities). In fact, Mani and Wheeler (1997) show that in the U.S., Japan and Western Europe the (monetary) share of pollution-intensive industries has significantly declined in the last decades. This drop in local polluting industrial activities, they point out, is attributable to low income-elasticity of demand for pollution-intensive products and stricter environmental regulation. In two of the regions (Japan and the U.S.), this decline has been accompanied by a net displacement of polluting production to trading partners, while Western Europe has preserved a stable trade balance (measured in monetary units). Mani and Wheeler (1997) argue that this trade "specialization" through comparative advantages (lower environmental standard) is not permanent, but transitory, because when poorer trade partners become richer (thanks among others to trade) they will also diminish the local share of polluting activities.

Nevertheless, when poor trade partners become wealthy enough they may decrease the local production of polluting products not by reducing real total consumption (in physical terms), but by importing them and thus shifting the environmental load to some other countries down the line. If this is the case, there may occur a cascade in polluting activities according to the "level of development" (wealth). This way of reducing local environmental damage by environmental-cost-shifting may not be available to the latest developing countries, because there will be no countries "coming up behind" to which to displace environmental damage (Ekins, 1997). Table 3 shows the percentage of change between 1974 and 1994 of the domestic production of metals and the hidden flows produced abroad to cover internal material requirements of Japan, Netherlands, United States and Germany. This table was computed from data reported by Adriaanse et al (1997). These numbers seem to reveal that, in these countries (with the exception of Germany), simultaneously to a reduction in local production of pollution-intensive products, it has occurred a rise in the environmental load shifted abroad. According to Mani and Wheeler (1997), developed countries have witnessed in the last 20 years ever stricter environmental standards and an increasing demand for environmental quality. However, it seems difficult to say that, for example, the Japanese economic success has contributed to improve the environmental condition of the earth as a whole. For instance, Japanese forested area has expanded in the last twenty years but Indonesia has a high rate of deforestation, in part to cover Japanese requirements of tropical wood.

Currently, Japan imports some 80 millions tons of forest and agricultural resources such as timber, fodder and food (Giampietro and Mayumi, 1998).

If developed countries are improving their local environmental conditions by displacing environmental load abroad, through trade of environment-intensive goods, then the environmental Kuznets curve (EKC) is not applicable at a global level. The EKC is neither applicable when the environmental degradation is irreversible, like biodiversity loss, or when an ecological threshold are surpassed before reaching a sufficient income level to start to reduce environmental pressure (as it may happen with greenhouse-gases emissions). If this is the case, when countries would have enough income to start to worry about environmental conditions, it could be "too late to be green". Therefore, the EKC, and the policies deriving from it, have to be taken cautiously.

In the environmental and ecological economics literature the concepts of "weak" and "strong" sustainability have been associated to different approaches towards the degree of substitutability between natural and human-made capital. The weak sustainability concept assumes no restriction on the degree of substitutability between both kinds of capital. Under this viewpoint, natural and human-made capitals have to be translated into monetary units in order to measure the degree of sustainability of a certain economy. An economy is considered sustainable in a weak sense if its savings rate is greater than the combined depreciation rate on both kinds of capital (Cabeza, 1996). On the other hand, the strong sustainability indicators assume the existence of a non-substitutable "critical natural capital" and tend to address sustainability in biophysical terms. A recent study (Proops et al, 1999) evaluate the degree of sustainability (in a "weak" sense) of different national economies considering the local performance, but also the natural capital depletion in money terms caused abroad to cover national imports of non-renewable resources. In this analysis, all developed countries appear as sustainable and Japan leads the list of the most sustainable countries (in the "weak" sense). Nonetheless, if the degree of sustainability were measured in physical terms (at least in material requirements), Japan and many developed countries probably would lead a hypothetical "black" list of "unsustainable" countries. Conclusions about the degree of sustainability of a certain economy can vary importantly depending if we address the problem with a biophysical or a monetary perspective. A conflict between both approaches can easily arise. Some very influential institutions, like the World

Bank, adopt the weak sustainability criterion in order to evaluate projects and policies. Therefore, results based upon monetary scales, like those of Proops et al (1999), can have far-reaching consequences: they can promote local and international environmental and economic policies which are misleading from a bio-physical viewpoint.

The assessment of natural capital in monetary terms has significant shortcomings.: a) Not all environmental values are commensurable in a unique unit of value, namely money (O'Neill, 1997); b) Monetarization of environmental externalities is a hard task when there is a high degree of uncertainty (Functowicz and Ravetz, 1994); c) Prices are unable to reflect the long-term effects of critical natural capital depletion (Rees and Wackernagel, 1999), and d) the evaluation of environmental externalities depend on the distribution of power and income (Røpke, 1999). That is, when the environmental damage occurs in poor and powerless areas, the costs tend to be lower (Martinez-Alier and O'Connor, 1999). Because of these caveats, "environmental space" or "ecological footprint" may be better metaphors than "Weak Sustainability" to tackle the assessment of the spatial component of sustainable development. However, much more research is needed to translate these metaphors into meaningful and methodological consistence indicators.

(Millions Metric Tons)

Fig. 1 Fertilizers

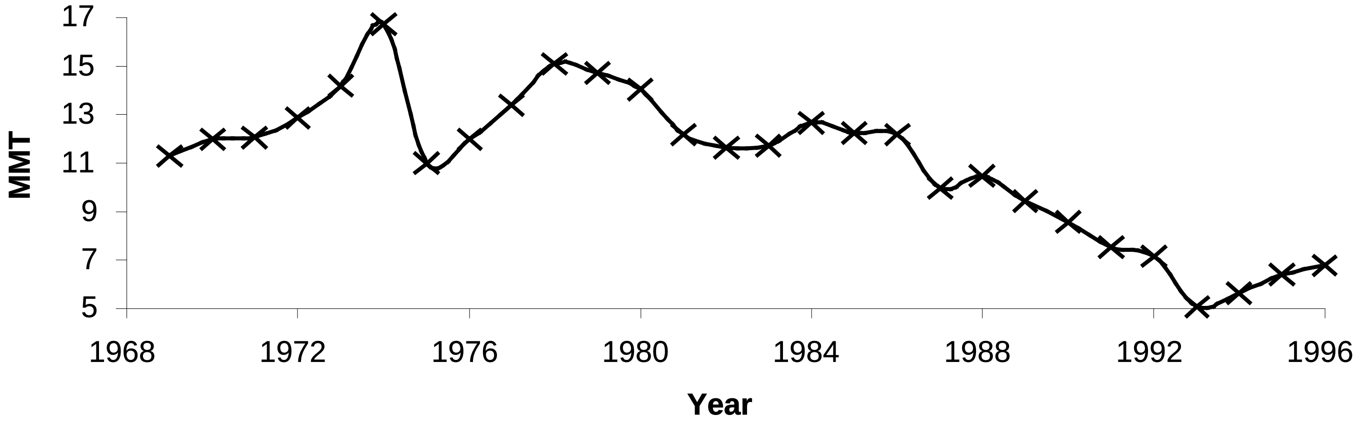


Fig. 2 Iron Ores

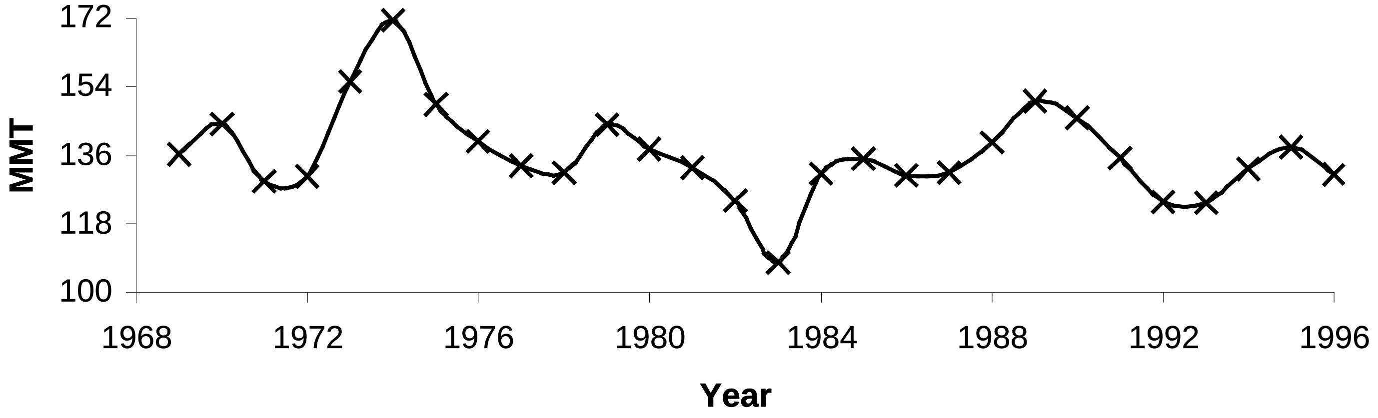
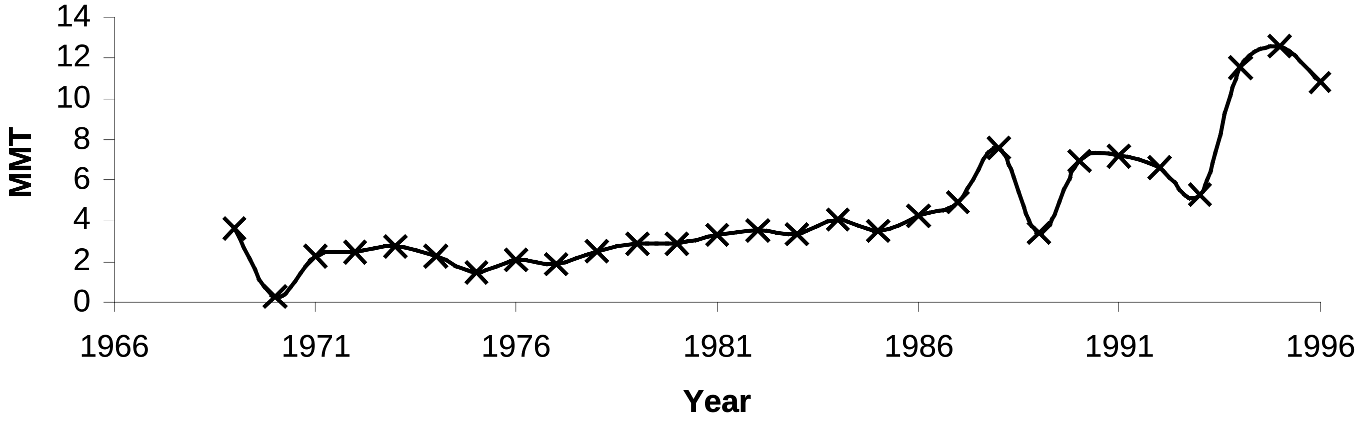


Fig 3 Pig Iron



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(Millions Metric Tons)

Fig. 4 Iron and Steel Shapes

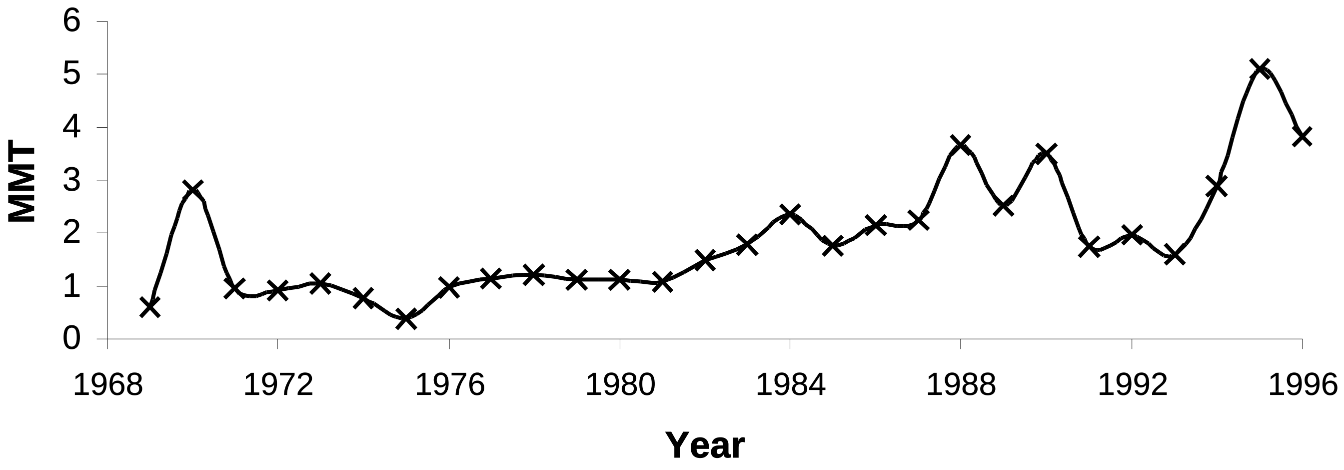


Fig 5 Copper Ores

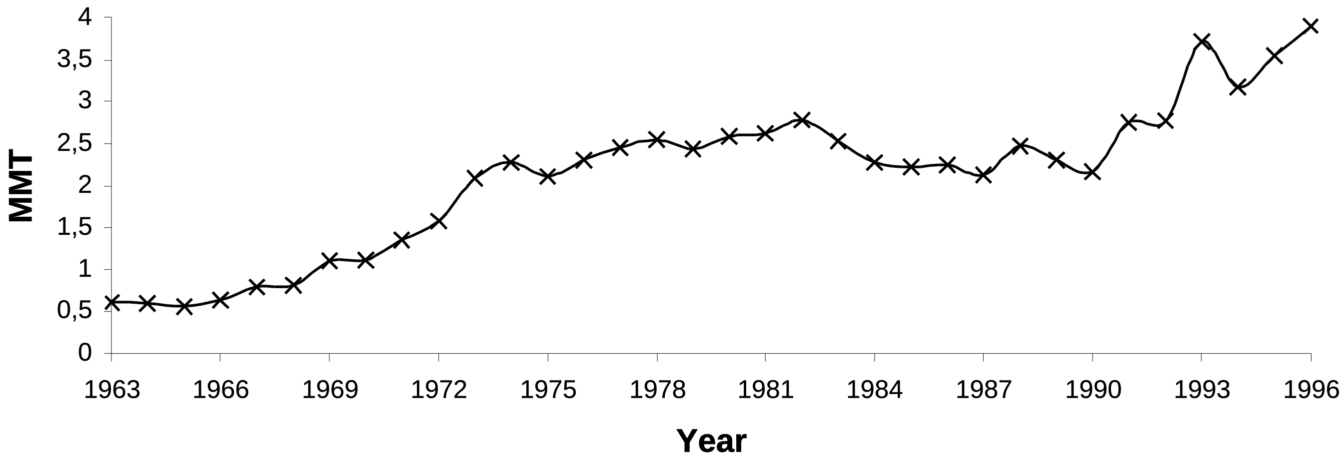
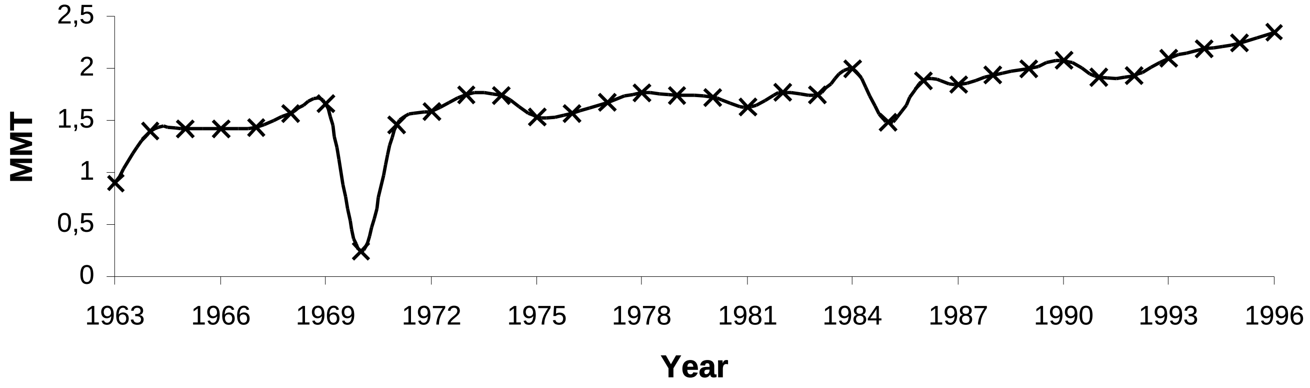


Fig 6 Copper (Alloys)



(Millions Metric Tons)

Fig 7 Nickel Ores

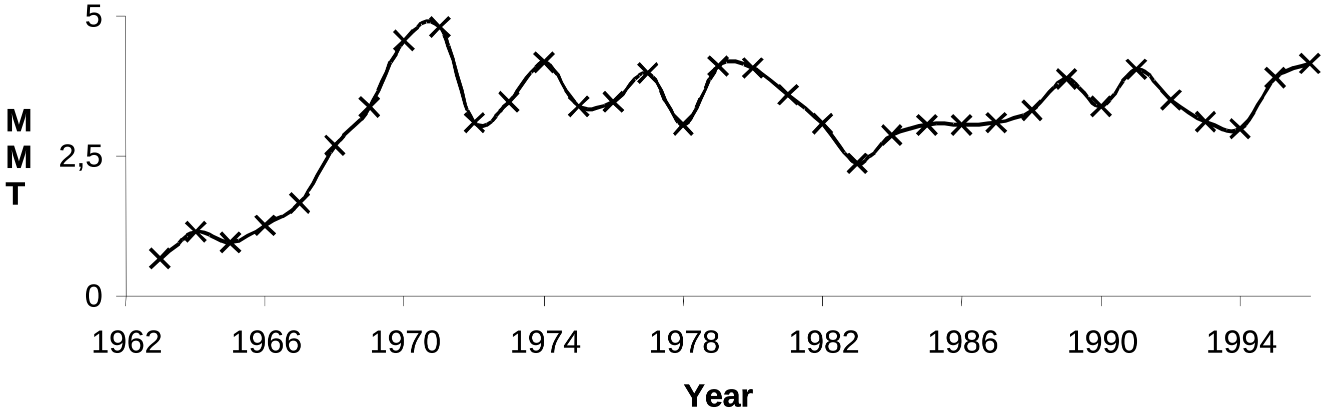


Fig 8 Nickel (Alloys)

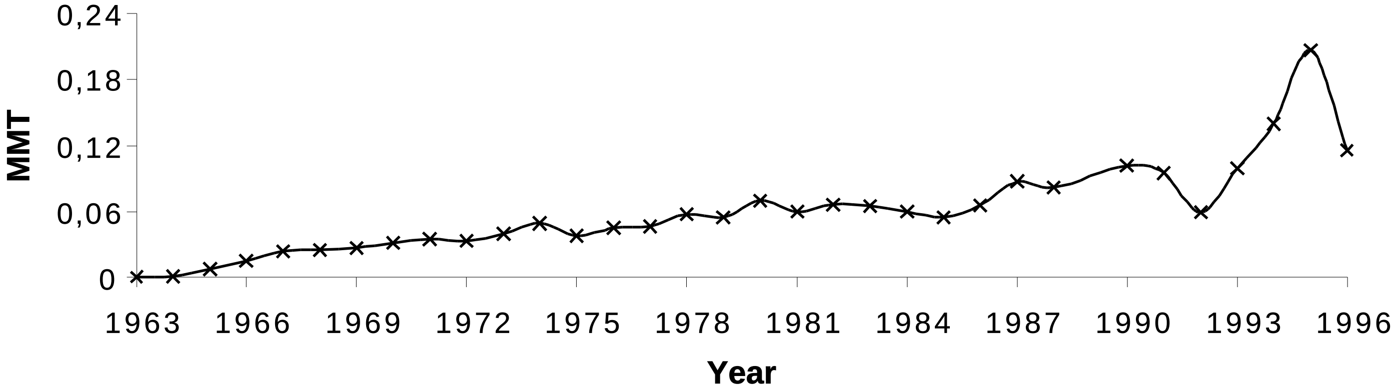
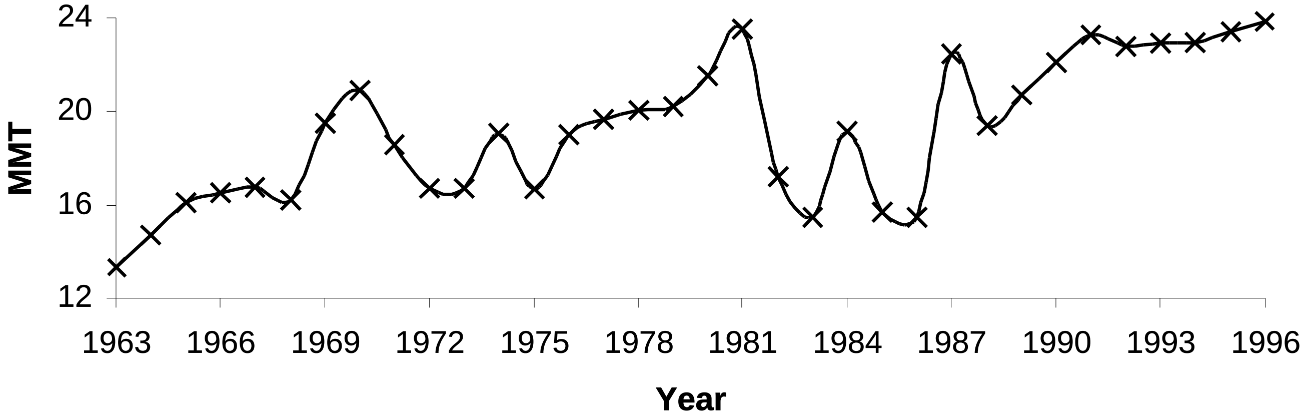


Fig. 9 Bauxite



(Millions Metric Tons)

Fig 10   Aluminium

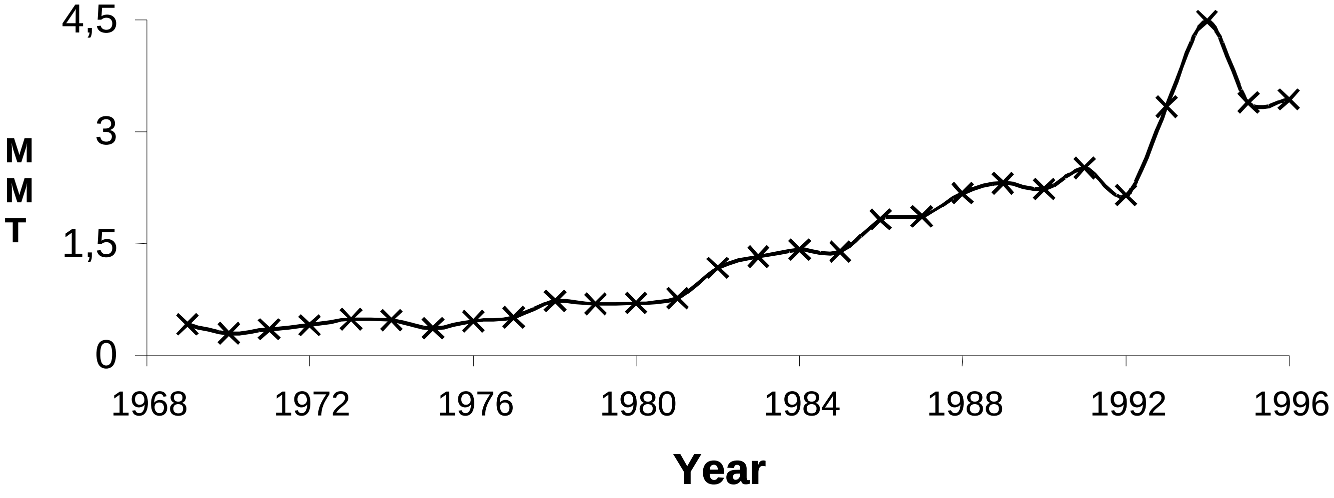


Fig. 11   Lead Ores

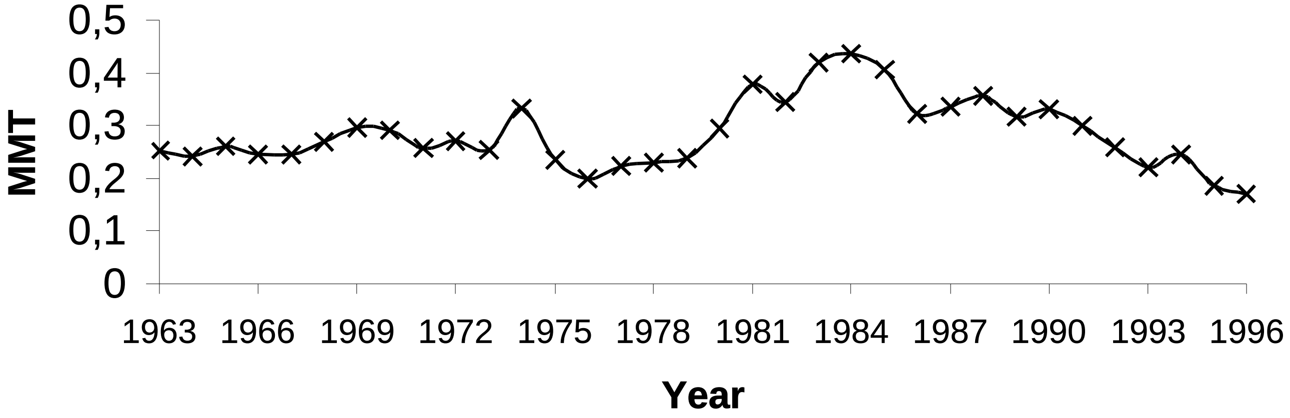
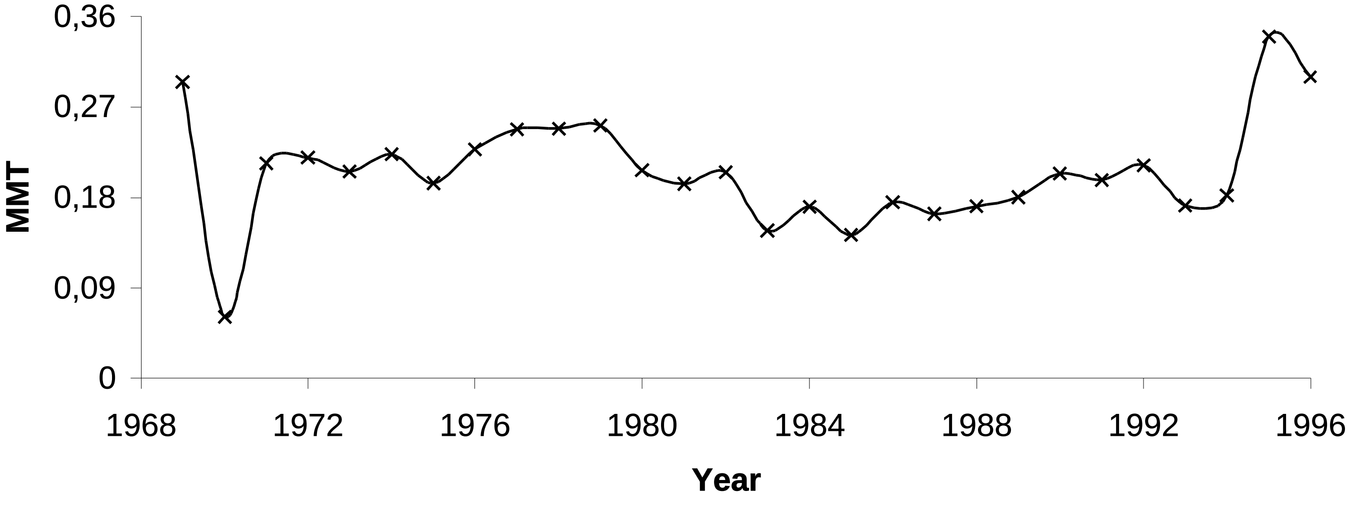


Fig 12   Lead



(Millions Metric Tons)

Fig. 13 Zinc Ores

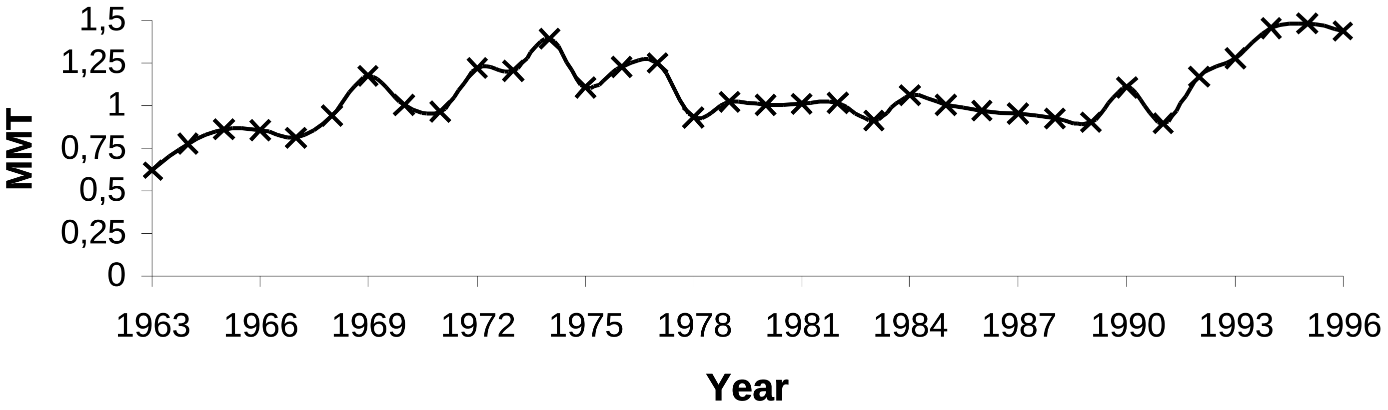


Fig. 14 Zinc

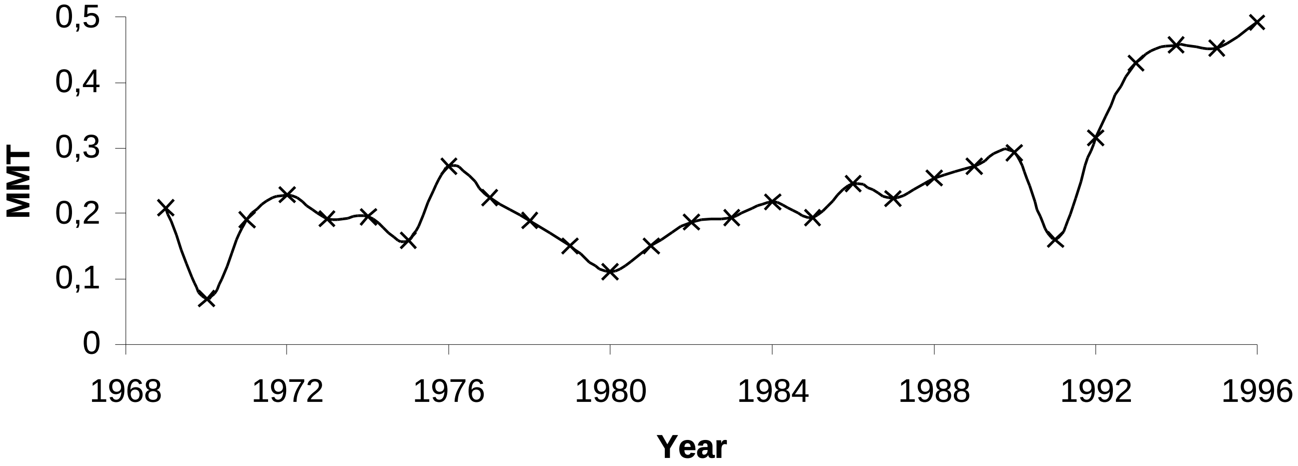
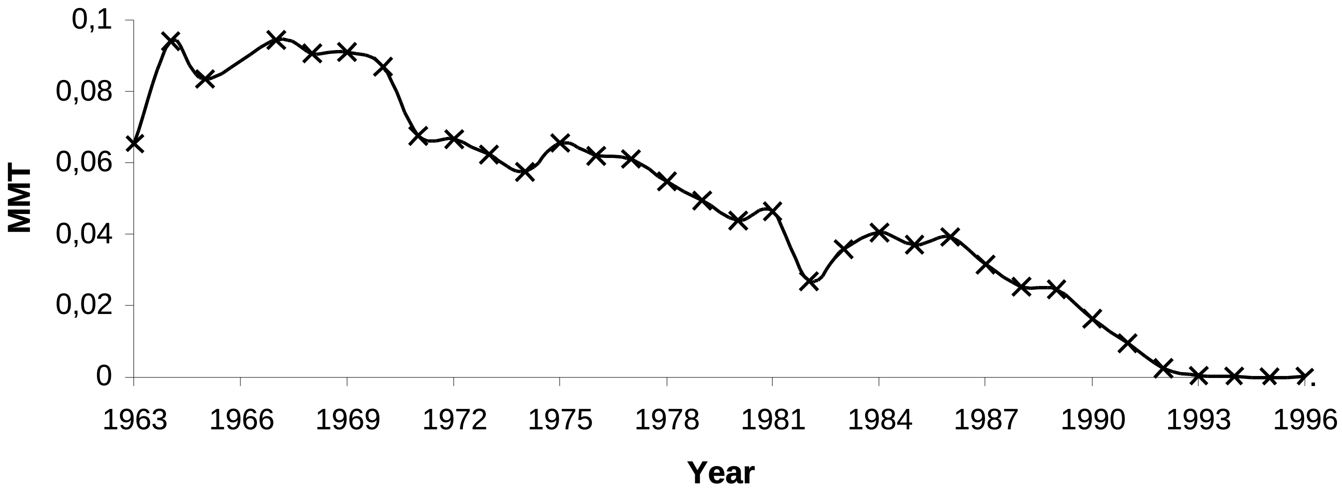


Fig 15 Tin Ores



(Millions Metric Tons)

Fig 16 Tin (Alloys)

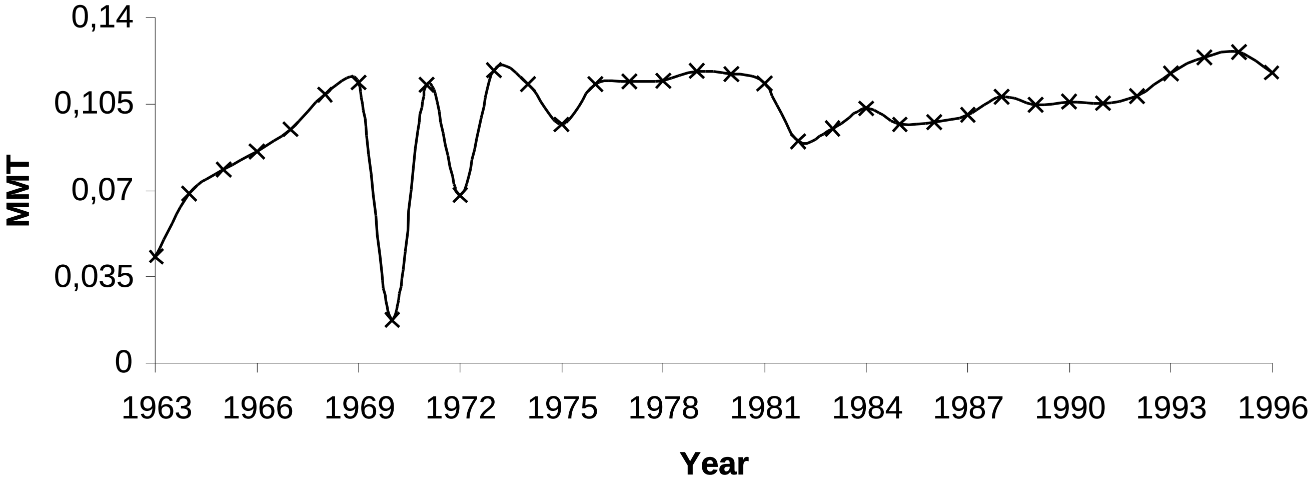


Fig. 17 Crude Petroleum

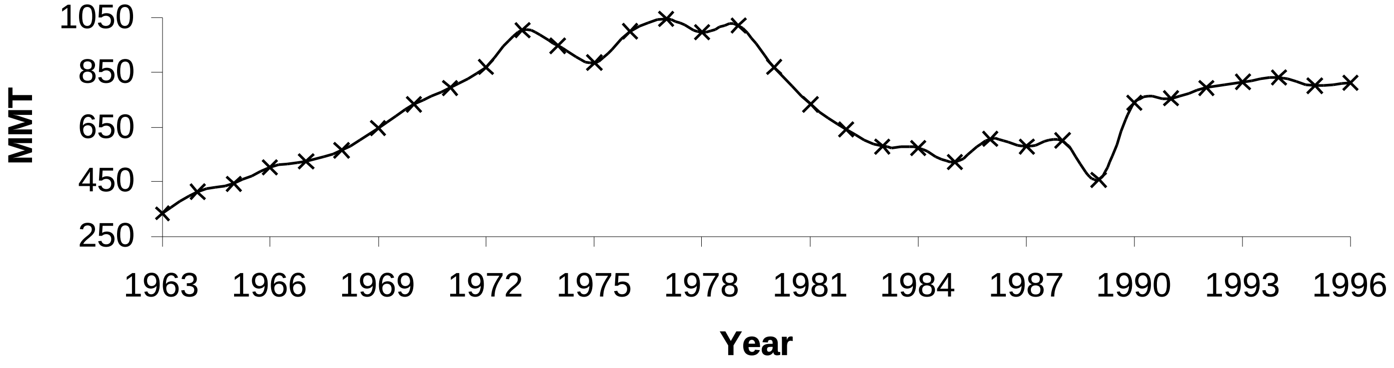
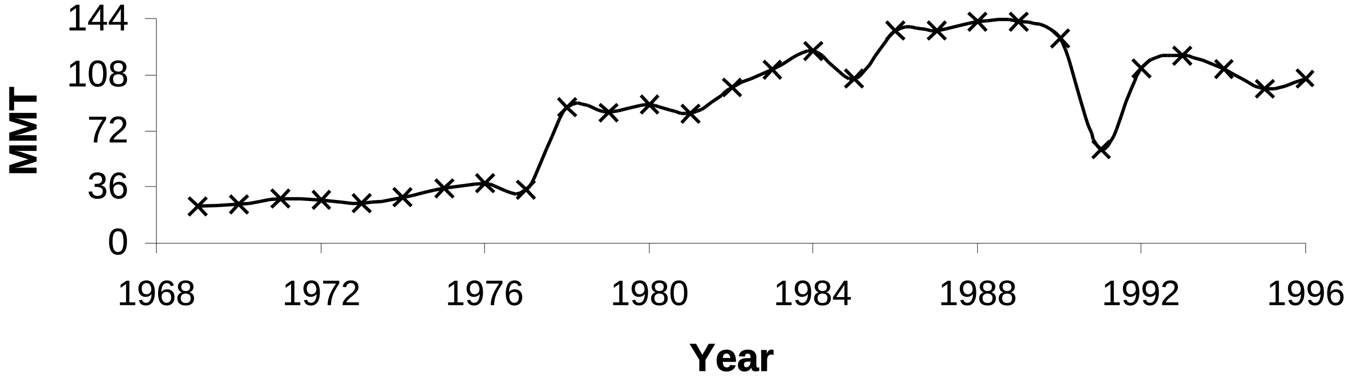


Fig. 18 Petroleum Products



(Millions Metric Tons)

Fig. 19 Gas Natural and Manufactured

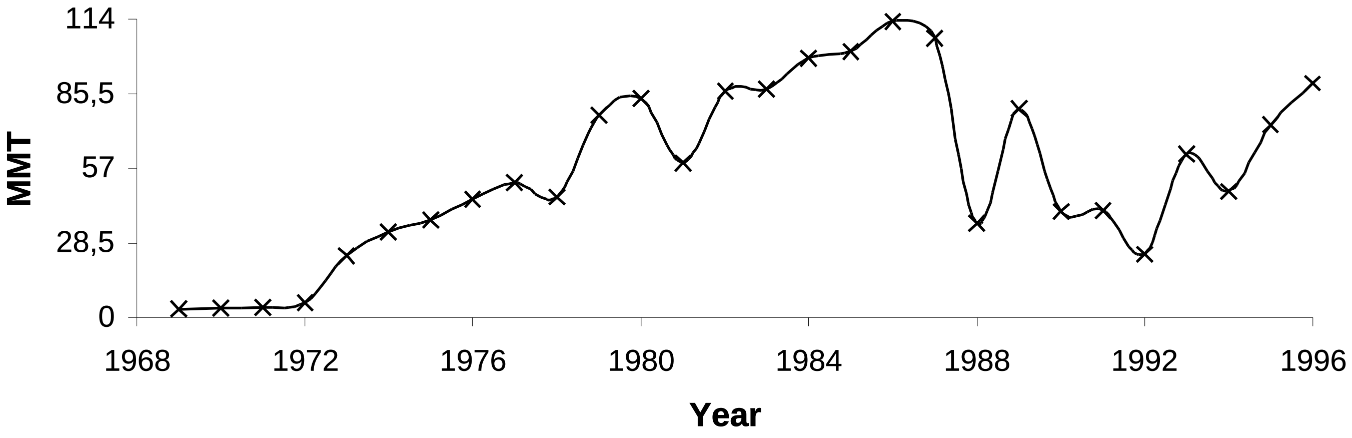


Table 1. Metals Hidden Material Flows

Metal	**Hidden Flow** (tons per purified ore ton)
Lead	9.9
Zinc	11.5
Nickel	17.5
Tin	1448.9

Source: Adriaanse et al (1997).

Table 2. Change in South-North materials flow between 1971-76 and 1991-96

Item	**% of Change**
Aluminium	660
Pig iron	306
Iron and Steel Shapes	238
Petroleum Products	230
Nickel (Alloys)	196
Gas Natural and Manufactured	128
Zinc	87
Copper Ores	70
Copper (Alloys)	32
Bauxite	30
Tin (Alloys)	12
Lead	9
Zinc Ores	8
Nickel Ores	-3
Iron Ores	-10
Lead Ores	-10
Crude Petroleum	-12
Fertilisers	-51
Tin Ores	-97

Table 3. Change in Domestic Production of Metals and Hidden flows of Imported Materials

	% of Change 1975-1994	
	Domestic Metals Production	**Hidden flows of Imports**
Japan	-92	60
Netherlands	no production	72
U.S.	-13	100
Germany	-89	-6

Source: Adriaanse et al (1997)

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