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Some empirical evidence on materials consumption

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Abstract

Preventive environmental policy may be aimed at stimulating structural change in the consumption of materials. By reducing the resource input of production, less emissions and wastes will occur that have a negative impact on the natural environment. Several authors note that structural change in the consumption of materials has led to a de-linking of materials consumption and economic growth for developed industrial economies. This paper explores the concept of structural change by presenting an overview of the relevant contributions to this field and by investigating whether de-linking, enforced by structural change, has actually occurred in developed economies. Empirical estimations are discussed by considering cross-section, time series and decomposition analysis. These different approaches do not confirm de-linking unambiguously. Especially in the eighties, structural change turns out to be quite insignificant.

1. Introduction

It is generally acknowledged that a change in the structure of our economy may play a decisive role in achieving sustainability. This implies a specific orientation of environmental policy and strategies. End of pipe technology, for instance, may not be sufficient to reach sustainability, since several emissions (CO,) and wastes **can** hardly be reduced by add on technology. Economic growth will eventually boost such emissions up till the point that they will cause irreversible environmental changes. Environmental protection, especially in the long run, will therefore necessarily be conceived in terms of structural policy. This has been called the "ecological imperative" [Jänicke et al., 1993, p160]: In a growing economy the ecologically detrimental effect of growth must continuously be compensated. Initially, remedial environmental technologies can be successful. When such opportunities have been exhausted, more fundamental technological and structural changes may become essential [Opschoor 19901.

This paper explores the concept of structural change and the role it has recently played in de-coupling' environmental stress from economic growth in industrialized economies by focusing on materials consumption[2]. First an overview will be given of the existing literature dealing with structural change and environmental stress in Section 2. Most of it is concerned with exploring patterns in the input side of production (materials and energy). Section 3 contains a reiteration of one of these cross-section studies, reaching opposite conclusions. In Section 4 an explanation for observed trends in materials consumption will be offered using different models for estimating time-series in materials and energy demand. In Section 5 a decomposition-approach is proposed for analyzing patterns in materials consumption. This approach distinguishes between changes in the structure of final demand and changes in the technology of production. In Section 6, the decomposition will be applied in a case-study on energy consumption in the Netherlands between 1970 and 1990. Concluding comments are finally given in Section 7.

2. Structural change and the declining intensity of use

A preventive environmental policy strategy may be aimed at stimulating structural change. By reducing the resource input of production, less emissions and wastes will occur that have a negative impact on the natural environment [Jänicke et al.,

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'De-linking and de-coupling are being used here as synonyms

[2]Consumption refers here to the material use as input in production activities. Energy consumption is defined as the consumption of energy as input in production activities and the energy consumption by households.

19891. This has been called ‘ecological structural change’ [Simonis, 19891. According to Simonis [1989], this ‘ecological structural change’ is the result of process integrated investments that save energy and materials, and a shift in the structure of final demand towards less polluting products. Evidence for this kind of ‘ecological structural change’ was found in Janicke et al. [1989], who compared the time patterns in 31 OECD and COMECON countries between 1970 and 1985 for four indicators: the per capita consumption of tonnes steel and cement[3], Joules energy and the transported tonnes freight-transport[4]. These four indicators represent an approximation of the volume of ‘throughput’ of a country[5]. For 1970 and 1985, each indicator has been expressed as the procentual deviations from the sample mean in these years. Calculated in this way, the indicators lose their physical dimension, so they can be added up together in an aggregated environmental index, AEI[6] (see Appendix 1 on the calculation of the AEI). Jänicke et al. [1989] are interested in the relationship between the AEI and the level of income. The results of their cross-section analysis for 1970 and 1985 are given in Table 1 (t-statistics have not been provided by Janicke et al.).

Regression equation: $AEI = \alpha + ßGDP$

Years	1970	1985
Slope ß	0.17	0.046
Intercept α	-1.2362	-0.3951
Measure of strength R^2	0.57	0.09

Table 1. Structural change measured as the relationship of the AEI and per capita GDP (measured in 1000 1980 US$) between 1970 and 1985 for 31 countries (taken from Jänicke et al., 1989).

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[3]Cement production figures have been used as a proxy for cement consumption. Since these differ for some countries substantially (Greece for example, has a production level that is twice as high as their consumption level), one can cast doubt on the appropriateness of this indicator in reflecting the “ecological footprint” of a country, where import substitution is not counted as an environmental gain (see Opschoor & Reynders [1991] and Pearce [1993] on these concepts).

[4]Only rail and road transport is taken into account. This is justified by pointing out that these modes of transport represent the final stages of a transport network. The magnitude of transported tonnes by rail and road gives, according to Jänicke et al. [1989], a good approximation of the total transport chain which also includes international marine, inland waterways and air transport.

[5]In the United States in 1990 cement consumption accounts for 18% and steel consumption for 22% of all industrial minerals and metals consumed in the US economy (construction materials like crushed stone, sand & gravel excluded) [Berry 1993]. The weight of freight transport in tonnes (and not in ton-kilometres) is used as a general indicator of the volume aspect of production.

[6]One can question the environmental claim of this index, since each of the chosen indicators leads to different environmental pressures. However, interpreted in the framework of Daly [1991], it becomes clear that this indicator may give a true picture of the relative changes in the volume of ‘throughput’.

This table shows that per capita income in 1970 gave a much better explanation for the environmental index than in 1985: the slope is less steep in 1985 than in 1970 and the measure of strength has decreased substantially. The explanation for the decreasing slope is that the consumption of the selected materials and transport increased in the poorer countries, often more than the increase in GDP (e.g. Bulgaria, Greece, Portugal, Turkey) while this consumption decreased in absolute terms in several richer countries (e.g. Belgium, Denmark, France, Sweden, United Kingdom, West-Germany) between 1970 and 1985. In cross-section analysis, such developments will show up as a decreasing slope. The fact that the measure of strength has decreased can be explained by the divergent developments of middle-income socialist countries (Poland, DDR, Czechoslovakia, Hungary) which showed a very substantial growth in material consumption while the growth in material consumption of middle-income countries of the OECD (Italy, Spain, Ireland, New Zealand) stagnated. These developments are pictured in Figure 1 where the arrows give the linearized development between 1970 and 1985 for various countries.

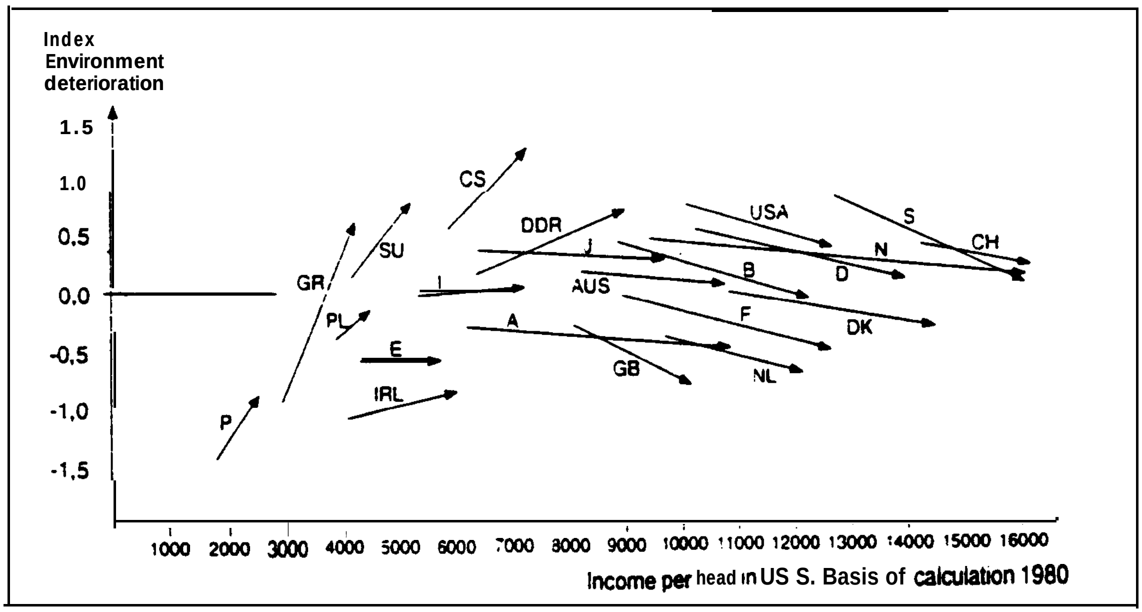

Figure I: De-linking economic growth from environmental pressure. for some countries (Mean E 1970 = 1985 = 0). Source: von Weiszäcker et al. (1994), after Jänicke et al.. (1989).

The analysis by Jänicke et al. have been interpreted as a sign of de-linking materials consumption and economic growth through structural change in developed economies [Simonis, 1989; RIVM, 1991; Von Weizsäcker & Schmidt-Bleek, 19941. Several economies (e.g. Belgium, Denmark, France, Sweden, United Kingdom, West-Germany) showed 'absolute structural improvements [Jänicke et al. 1989, p178]; i.e. their aggregated material consumption declined in absolute levels, despite the growth in GDP. These results have been influential for the suggestion that it would be possible to grow out the environmental problems through structural change[7].

As stated above, analysis on the resource input implies analysis on the consumption of materials and energy. There has been a vast body of empirical investigations into the consumption of materials and energy from resource economists[8]. These investigations also indicate structural reductions in the demand for materials and energy since - in general - the first oil crisis. Most of these studies use the concept of intensity of use as the ratio between the physical inputs (materials) and monetary outputs (GDP). A hypothesis on the developments of the relationship of the intensity of use and income has been put forward by Malenbaum [1978]. According to Malenbaum the relationship between the intensity of use and per capita income could be described as an inverted U. This has been called the "intensity of use" hypothesis. According to this hypothesis, the intensity of use is expected to increase in the early stages of economic development, reach a saturation level and then tends to decline. This last stage is often called the stage of de-coupling or de-linking materials consumption from economic growth where the income elasticities are continuously decreasing and may even become negative. Reasons for this observed de-linking have been summarized as [Tilton 1986a]: (i) technological changes, such as material saving production techniques and the substitution of metals by lighter chemical products, and (ii) structural changes in the economy, such as the shift from a heavy-industry orientated economy towards an economy which is relying more on services. According to Malenbaum [1978, p31 I, technological change would have the effect of a shifting inward of the intensity of use curve as less materials will be used per unit income. Diffusion of technology implies that the intensity of use curve over time will differ among countries. Mexico in the nineties is unlikely to experience the same high levels of intensity of use that the United States has experienced in the early thirties, although they have a comparable level of GDP per capita.

It can be shown that the cross-section analysis by Jänicke et al. [1989] is in fact equivalent to the intensity of use hypothesis. Figure 2 gives the hypothetical intensity of use curve for four countries (Cl ..C4) with a shifting inward for poorer countries, resulting from the diffusion of technology as mentioned by Malenbaum [1978]. Because of the diffusion of technological knowledge, the poorer countries may not reach the same level of material consumption as has happened in the past in country Cl . The thick line in each curve represents the period of measurement (time 1,2,3) for each country. If these countries are taken together in cross-

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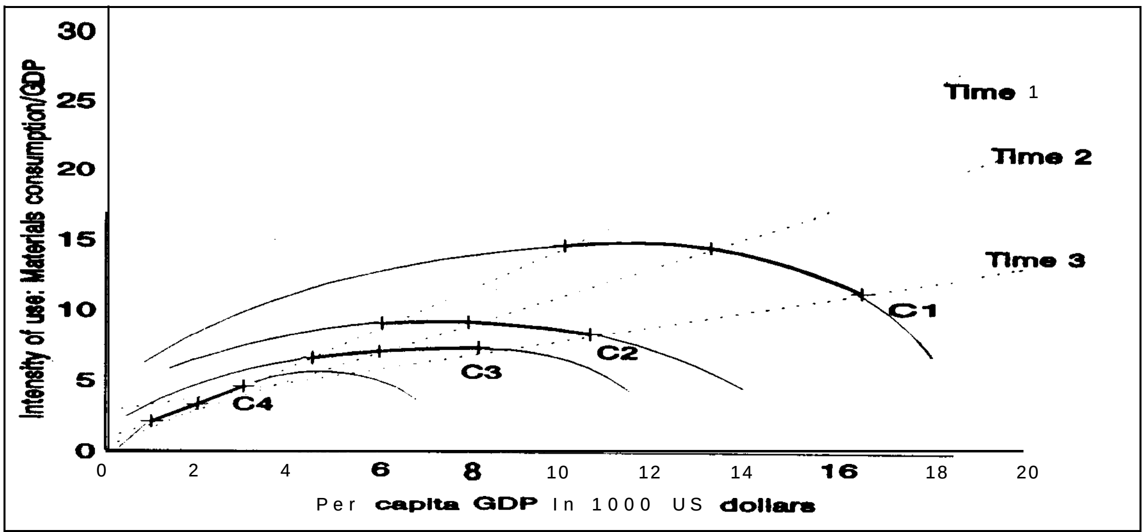
[7]The Dutch Environmental Planning Institute (RIVM, 1991) assumes, based on the work of Jänicke et al. [1989] that material consumption per unit income will decline by 20% in the year 2015 [RIVM 1991, pp 59]. See for criticism [Opschoor, 1990].

[8]See for example for energy: Humphrey, 1979; Bossanyi, 1979; Chesshire, 1986 and for materials: Malenbaum 1978; Tilton, 1990.

section regression analysis, period 1 will show a higher slope and a lower intercept than period 2 and 3[9].



igure 2: Graphical illustration that cross-section analysis that measure decreasing slopes and increasing intercepts assume declining intensities of use for developed economies.

The diminishing slope and increasing intercept indicates that countries converge in their aggregate materials consumption through time due to developments in the intensity of use-curve as being predicted by Malenbaum [1978]. So the cross-section analysis done by Jänicke et al. [1989] are in fact part of an existing body of knowledge: their results confirm a kind of parabolically shaped intensity of use-curve for individual countries. Interpret in this way, their results can indeed be seen as a suggestion for a process of de-linking materials consumption from economic growth for the more developed countries in the period considered.

3. De- or relinking? Results from additional cross-section analysis (1966-1990)[10].

The previous section gave an overview of studies that indicate a de-linking of materials consumption from economic growth through structural change. This section will discuss some weak points of the methodology that has been applied in the study by Jänicke et al. [1989]. A first observation on the study by Jänicke et al. [1989] is that it only contains comparisons between two years. Virtually no insight is gained in the development of the consumption of materials during years

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[9] The assumption is here: rising income levels over time.

[10] This Section is based on: De Bruyn & Opschoor [1994].

in between. Hence the analysis is too general to draw strong conclusions about the stability of the de-linking hypothesis. It might be possible that the aggregate materials consumption declined from 1970 to 1980 as a result of the two oil crises, but increased again after 1980. This would indicate that de-linking is not a process which will autonomously lead towards less materials consumption in the future. Secondly, an observation can be made on the representation of the research results. In Figure 1, the AEI (Aggregated Environmental Index) for all countries has been calculated for both 1970 and 1985 as the deviation from the mean per capita consumption of the selected indicators in respectively 1970 and 1985. The arrows give the development between the deviations from the mean of 1970 and the deviations from the mean of 1985. Because the sum of deviations from the mean is zero by definition, Janicke et al. do not compare the absolute levels of 1970 and 1985. In other words, declining vectors in the figure do not automatically imply declining absolute levels of aggregate materials consumption. As the rise in the consumption of materials between 1970 and 1985 is not apparent, Figure 1 only shows that the consumption of materials in the countries with a lower per capita GDP rose faster relative to the countries with a higher per capita GDP. In this way, the overall parabolic shape in Figure 1 indicates convergence of aggregate materials consumption between countries and not de-linking. This fact seems to be completely overlooked by many others referring to the work of Jänicke et al. (eg, Simonis, 1989; Opschoor, 1990; RIVM, 1991; Von Weizsäcker & Schmidt-Bleek, 1994).
To overcome these shortcomings and provide a better insight in the process of structural change and de-linking, we have repeated the analysis of Jänicke et al. 119891 for a sample of twenty OECD and COMECON countries: Belgium, Denmark, Finland, France, Greece, Hungary, Italy, Japan, Luxembourg, the Netherlands, Norway, Poland, Spain, Sweden, Switzerland, Turkey, United Kingdom, the Unites States, Western Germany and (former) Yugoslavia. Data for Luxembourg have been added to that of Belgium because of the small size of the Luxembourg economy. Data have been taken from international sources as indicated in Appendix 2. Some improvements have been made according to the remarks made above. Firstly, the AEI for each country has been calculated as the deviation from a constant mean over time (see Appendix 1 on calculation of the AEI). Calculated in this way, the absolute increase in materials consumption will be included. Secondly, cement consumption has been used as an indicator instead of cement production which gives a more proper reflection of the 'ecological footprint' of a country (see footnote 3). Thirdly, the period under study has been extended and includes all years between 1966 and 1990. To obtain an overall -and yet comprehensive- view of the relationship between the AEI and GDP, we divided the period under study into four sub-periods of seven years: 1966-72, 1972-78, 1978-84, and 1984-90. These periods each represent a different stage of economic develop-

ment in most market-economies in terms of economic growth figures. In the first period, economic growth was high and not disturbed by external shocks. The second period was marked by the first oil crisis in 1973, which influenced several economic parameters. The third period was marked by the second oil crisis and the subsequent negative growth rates in the beginning of the eighties for most economies. The last period, finally, is characterized by a recovery in Western economies from the crisis in the beginning of the eighties while the economy in the formerly socialist countries collapsed.

The AEI for each country has been calculated as the deviations from the sample mean per capita consumption of the selected indicators: steel consumption, cement consumption'[1], energy consumption and freight transport by train and road[12]. The AEI's and GDP's have been calculated as the average value in each period of seven years. In this way incidental shocks in the economies or data are levelled out.

To investigate the patterns of the AEI in all periods and to compare these with each other, we are interested in the strength of the relationship between the level of income and the computed AEI. The conclusion by Jänicke et al. was that in 1985 the relationship between the AEI and GDP (measured by the coefficient of determination R^2) was weakened, and the slope was less steep (Table 1). The statistics of our cross-section regression analysis are laid down in Table 2.

Regression equation: AEI = a + ßGDP

Years	1966-1972	1972-1978	1978-1984	1984-1990
Slope ß	0.0765	0.0552	0.0409	0.0435
(T-value)	(5.830)	(3.926)	(3.381)	(4.711)
Intercept α	-0.5892	-0.4188	-0.3938	-0.4624
(T- value)	f-6.725)	f-3.800)	f-3.734)	f-5.061)
Measure of strength R^2	0.666	0.476	0.402	0.566
St. deviation of AEI	0.330	0.311	0.275	0.283

Table 2: Structural change measured as the relationship between per capita GDP (measured in 1000 1985 US$) for 20 countries: descriptive statistics for four periods.

They show that the relationship, measured by the R^2 was indeed weakened in the se-

"'For all countries except for Italy, Japan, Spain and Turkey for which production data have been used.

'*Rail transport has been used for all countries, road transport for all countries except United States, Spain, Italy and Greece. For these countries the quantity of freight transport was measured by train only. This is the same routine as Jänicke et al. took in their investigations in 1989.

cond and third period, compared to the first period. However, in the fourth period, the relationship was strengthened remarkably. The slope has decreased until 1984 but increased slightly in the last period. The intercept increased until the third period, but decreased in the last period. Interpreted in the framework by Jänicke et al. this would mean that the de-linking phase for developed economies has come to an end in the last period under study. Although apparently structural change has played a role in the second and third period, this has ceased to continue for developed economies in the eighties. It seems that these economies are entering a period of re-linking rather than continuing on the de-linking path. This is made more explicit by Figure 3 which gives the developments for several individual countries from period to period. Each dot indicates one period; the lines connect the dots for each country.

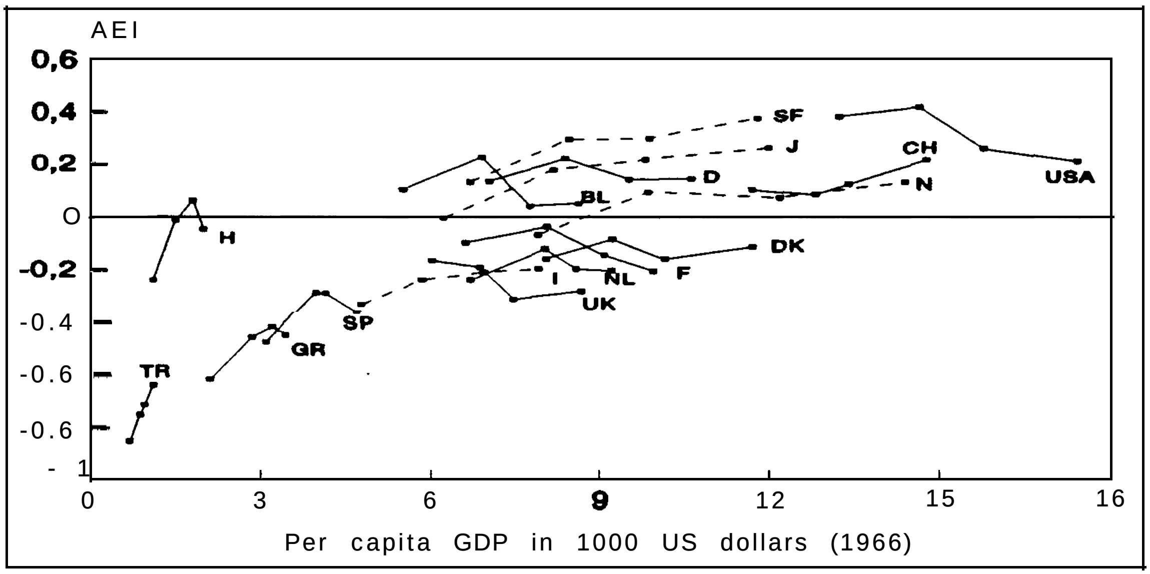

Figure 3: Developments of selected countries in levels of AEI and per capita GDP, 1966-1990.

As can be seen from this figure three groups of countries can be distinguished. First, Turkey is an example of a poor country that has not yet experienced any structural change. The AEI has been rising faster than GDP in each period. Secondly, Hungary, Greece, Spain'[3] are countries that have experienced absolute improvements in the last period (1984-l 990) compared to the third period (1978-l 984). After rapid increases in their levels of AEI in the second and third period, these countries now find themselves in a period of de-linking. The group of richer countries show some more differences in the developments of their AEI. However, most countries showed absolute improvements in the third period, between 1978 and 1984. This development of de-linking continued in the last period only for France and the United States; it is remarkable that all the other countries showed a rise in their levels of the aggre-

[13]together with Poland and Yugoslavia which have not been given in this Figure for reasons of clearness.

gated material consumption in that period. For Finland, Japan and Italy this has been the case in each period, but the growth in their levels of AEI has been slackening. Switzerland is the only exception on this generalized pattern: decreases in the second period and remarkable increases in the third and fourth period as well[14].
Having noticed that the absolute structural improvements reported by Jänicke et al [1989] are rather an exception (induced by the years of measurement) than a general rule, the question arises whether the developed countries are still de-linking in relative terms: the aggregated consumption of materials may increase, but yet at a structurally slower rate than the increase in GDP. This would result in a continuously lower intensity of use of the materials involved. That this is not the case for several countries, can be seen from Table 3 (see Appendix 3). This Table gives the intensities of use during the eighties of several countries for steel, cement, energy and transport. It appears that the process of structural change was rather absent. The Netherlands, United Kingdom and Belgium-Luxembourg saw their intensities of steel and cement increasing, which indicates that the consumption of these materials increased faster than their increase in GDP. Only the United States experienced decreases over all periods. These observations will be used in the next section where we try to estimate several models for the demand for energy, steel and cement.

4. Economic growth and income as explanatory variables for patterns of materials consumption

The analysis in the previous section gave some suggestion for the fact that developed economies showed, for some materials, a re-linking with economic growth during the eighties. This would not only invalidate the conclusions by Jänicke et al. [1989], but also the intensity of use hypothesis which predicted continuously lower income elasticities of demand once economies have reached their saturation points. The question is whether a de-linking as predicted by the intensity of use hypothesis is virtually non-existent or whether high economic growth in the eighties simply has counteracted the possible material savings that follow a path like the intensity of use curve.
The demand for materials can simply be written as the product of the intensity of use and the level of GDP:

$$I_t = i_t \cdot Y_t \qquad (1)$$

where I_t is the demand for material and Y_t is the level of GDP in year t and i_t is the intensity of use, defined as the ratio between the physical inputs and monetary outputs (the division of the demand for materials by the level of GDP). The question is thus whether the variation in the demand for material I_t is mainly driven by variation in

[14] This matches the relatively sceptical conclusions by Swiss researcher Binswanger [1993] on the process of structural change in his country.

the level of GDP (the 'growth'-effect) or by the variation in the level of the intensity of use (the 'intensity of use'-effect). To answer that question, three models have been investigated. All the models have been expressed in terms of the first difference of the natural logarithm of the variables, which gives an expression for the growth in the variables. The models can be given as follows:

Model 1: Variation in materials consumption stems solely from the variation in GDP:

$$\Delta \ln I = \beta_1(\Delta \ln Y) + \epsilon \tag{2}$$

where the Δ stands for the first difference. Model (1) tries to estimate to what extent the growth in materials consumption can be explained by the growth in GDP. It is expected that β_1 would have a positive sign, indicating that economic growth will result in an increase in materials consumption. This equation assumes that materials savings as a result of the declining intensity of use curve can be ignored.

Model 2: Materials consumption follows a path like the intensity of use curve. The intensity of use curve can be given in translog form as[15]:

$$\frac{I_t}{Y_t} = \alpha_1 \cdot Y_t^{(\alpha_2 + \beta_2 \ln Y_t)} + \epsilon_t \tag{3}$$

From this the demand function for material I, can be given as:

$$I_t = \alpha_1 \cdot Y_t^{(\beta_1 + \beta_2 \ln Y_t)} + \epsilon_t \tag{4}$$

where β_1 is calculated as the sum of α_2 and 1. It is expected that β_1 exceeds one and that β_2 has a negative sign (see Suslick & Harris [1990]). To avoid serial autocorrelation, we have took the first differences of equation (4). In the logarithmic form, this becomes:

$$\Delta \ln I = \beta_1(\Delta \ln Y) + \beta_2 \{(\ln Y_t)^2 - (\ln Y_{t-1})^2\} + \epsilon \tag{5}$$

This equation assumes that the 'intensity of use'-effect gives the solely explanation for variation in materials consumption. Note, however, that the first term on the right hand side of equation (5) equals that of equation (2) in model 1. If economic growth also influences materials consumption, the pure 'intensity of use'-effect cannot be derived from this equation. Moreover, the assumption in this equation is that without a change in the level of income (zero economic growth) the change in materials consumption will also be absent. This would mean that structural and technological changes, responsible for the de-linking phase, are a function of economic growth and

[15]This translog equation has been introduced in Suslick & Harris [1990]. It can be shown to be equivalent to a lognormal distribution [Suslick & Harris, 1990]. This model implies an income elasticity of demand that varies with the income level, which is characteristic for the 'reversed U-shaped' intensity of use curve.

not of the level of income. Because this assumption seems to lack theoretical background, we estimated a third model:

Model 3: Variation in consumption is a function of the variation in income and the level of income.

This becomes in the logarithmic form:

$$\Delta \ln I = \beta_1(\Delta \ln Y) + \beta_2(\ln Y_t) + \epsilon \qquad (6)$$

It is expected that β_1 has a positive sign (representing the 'growth'-effect) and β_2 a negative sign (representing the 'intensity of use'-effect). Notice that this last effect will be greater for high income economies.

These models have been estimated for the per capita consumption of steel, cement and energy for each of the twenty countries mentioned in the previous section. Income has been calculated as the per capita GDP in 1000 constant (1985) USS [16]. Prices of steel, cement and energy for the US market have been added as an additional explanatory variable[17]. The results for Japan, the Netherlands and the United States have been given in Table 4 (see Appendix 3). Each model gives a much better explanation for energy than for steel and cement. Prices (parameter β_3) are in general insignificant at the five percent level, except the prices for energy in the Netherlands and the United States[18]. The first model gives a poor explanation in general. It is unlikely that the growth in the demand for materials can be explained by prices and growth in income only. The second model hardly provides a better explanation of the growth in materials consumption (one exception was energy consumption in Italy). The parameter β_2 is nowhere significant at the five percent level, indicating that the 'intensity of use'-effect is either absent or misspecified using this equation. Furthermore the signs of steel and cement consumption in the Netherlands and steel consumption in the United States are opposite as expected. The third model gives the best explanation of the growth in material consumption: all parameters have the expected signs and most of them are significant. The first parameter β_1 estimates the 'growth'-effect of the economy on materials consumption. For the countries selected in this table, this 'growth'-effect is for all materials significant at the five percent level. An economic growth of 1 % results, according to the estimators, in an increase in the

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[16] If we below refer to consumption and income, we implicitly assume per captia consumption and income.

[17] This may give a bias for the other countries involved in the estimations, because their prices may differ from the US-prices. Unfortunately we have not been able until now to collect all the prices for each country individually.

[18] This is in line with a number of other studies that found out that prices are in general not an important variable for determining material demand [Auty, 1985; Holmes, 1990a, 1990b; Tilton, 1990; Mannaerts 1993]. The demand for materials is typically a derived demand: derived from the demand for final consumption goods. Material costs are only a small proportion of the total costs for producing these goods [Malenbaum 1978, p65].

steel consumption of 2.4% in Japan, 3.4% in the Netherlands and even 4.8% in the United States. This 'growth'-effect is, however, counteracted by the 'intensity of use'-effect (parameter β_2 which has a negative sign in all cases). This parameter is not significant at the 5% level for steel consumption in Japan and energy consumption in the Netherlands and the United States. In all other cases, the effect of the declining 'intensity of use' that varies with the income level is significant. This effect is in all countries greater in the case of steel than in the case of cement or energy. The interpretation of the parameters is rather difficult, since the impact of β_2, the parameter for the 'intensity of use'-effect, will differ with the income level. So if the income-level (measured in 1000 USS per capita) in the Netherlands is 10, this would result in a decline in steel consumption per capita of almost 7% [19]. With an economic growth of 1 %, this would finally make up a decrease in the steel consumption of 3.5% .
One interesting feature of model 3, which also would make the interpretations a little bit more easier, is that it allows us to introduce the concept of 'technological growth'. Technological growth refers to an economic growth that does not result in a growth of materials consumption but solely stems from improvements in the efficiency of transforming materials into valuable products and income[20]. This rate of technological growth can be calculated by solving the right hand side of equation (6) for the case that the growth in materials is zero. This gives the following condition:

$$\beta_1(\Delta \ln Y) + \beta_2(\ln Y_t) \leq 0 \tag{7}$$

This equation can be expressed as:

$$\ln\left(\frac{Y_t}{Y_{t-1}}\right) \leq \frac{-\beta_2}{\beta_1} \cdot \ln Y_t \tag{8}$$

By solving the right-hand side of this equation for the parameters estimated from model 3 and the level of income, the maximum rate of the economic growth is obtained. It indicates which rate of growth will not result in a higher consumption of the selected materials. Table 5 gives the results from condition (8) for the United States, Japan and the Netherlands for energy, steel and cement, where the prices have been assumed to stay constant over the whole period. The average level of GDP and the average growth over 1966 till 1990 have been chosen as explaining variables.

[19] Calculated by taking the natural logarithm of 10 and multiplying this by β_2.

[20] This zero growth in materials consumption could also be interpreted as a first step towards envisaging a steady state [Daly, 1989]. Daly [1989, p65] discusses the installation of depletion quotas: "to be set near the existing extraction rates. The first task would be to stabilize, to get off the growth path. Later we could try to reduce quotas to a more sustainable level, if present flows proved too high."

Table 5: Model 3 and the concept of 'technological growth'

Calculated using average income level and average annual rate of growth over 1966 till 1990. Per capita figures of steel, cement, energy and income have been taken.

		GDP		Materials consmpt.	
		Technolog. growth'	Actual growth	Pred. growth*	Actual growth
Japan	Steel	2.68%	4.56%	4.19%	3.67%
	Energy	2.05%	4.56%	3.32%	3.39%
	Cement	2.92%	4.56%	2.43%	2.48%
Netherlands	Steel	1.83%	2.21%	1.19%	2.21%
	Energy	1.05%	2.21%	2.30%	0.94%
	Cement	2.08%	2.21%	0.16%	0.18%
United States	Steel	1.98%	1.56%	-2.11%	-1.71%
	Energy	0.80%	1.56%	0.72%	0.66%
	Cement	1.58%	1.56%	-0.10%	0.47%

. estimated using the parameters from OLS regression of model All parameters were significant at the 10% level.

The fifth and the last column in this Table compare the annual growth rate predicted by the model with the actual annual growth rate. This shows that the fit of the model is rather good, except for energy consumption in the Netherlands and cement consumption in the United States. In column 3 the rate of technological growth, as has been calculated from equation (8) is presented. It appears that the rate of technological growth in Japan is for all materials about 1 percent point higher than in the Netherlands and the United States. Furthermore, the rate of technological growth seems for energy in all countries lower than for cement and steel, which indicates that economic growth will sooner result in a rise in energy consumption than in a rise in steel or cement consumption.

What is the reason that the rate of technological growth is higher in Japan than in the Netherlands and the U.S.? From equation (8) we can see that the rate of technological growth will be determined by the ratio of the parameter of the 'intensity of use'-effect and the parameter for the 'growth'-effect, together with the level of income. This ratio reveals something about a process of structural change that may have played a more pronounced role in the Japanese economy than in the Dutch and U.S. economy. The forces behind this proces of structural change can be clarified using a decomposition methodology in analyzing changes in the intensity of use in a country. This will be discussed in the next section.

5. Analyzing patterns in the intensity of use: decomposition into structural and technological changes.

The previous section has shown that structural changes in material consumption are a function of a 'growth'-effect and an 'intensity of use'-effect. With an equation that is based on this insight better explanations for the growth in material consumption may be being offered than with the usual translog intensity of use function used by resource economists (model 2). Indeed, the fact that the intensity of use curve seems to be invalid has also been noted by other economists [Auty 1985, Tilton 1986, Valdes 19901. Quite recently, they became dissatisfied with simply linking materials consumption to income. The intensity of use-hypothesis virtually provides no insight into the factors underlying materials consumption. Moreover, the predictive power from translog models capturing the inverted U-shape proved to be rather poor, especially during the eighties [Valdes, 19901. Radetzki & Tilton [1990] have argued that a movement along the intensity of use curve can only be explained by changes in the structure of final demand, while technological changes in a country would shift the intensity of use curve downwards. As a logical result, regression analysis using the translog model will usually capture both effects and lead to wrong predictions[21].
All this confirms our results from the previous section where it was shown that economic growth would positively influence materials consumption, despite the material savings predicted by the intensity of use-hypothesis. However, resource economists have not searched for solutions to this problem in building other equations, but developed a new approach towards studying changes in the intensity of use using an aggregated decomposition methodology [Tilton 1986a; see also Bossanyi, 19791.
It is usual to decompose the intensity of use into two separate effects: the material composition of products and the product composition of income. As a general formalization the following identity can be used[22]:

$$\underbrace{\frac{I_t}{Y_t}}_{IU} = \underbrace{\frac{I_t}{Q_t}}_{MCP} \cdot \underbrace{\frac{Q_t}{Y_t}}_{PC1} \qquad (9)$$

In this formula I, are the inputs (for example steel), Y_t is the gross monetary output level (GDP) and Q_t the physical output, such as the produced numbers of a certain final consumption good (for example batteries). The left hand defines the intensity of use as the ratio between physical inputs and monetary output. The first ratio of the right hand side (I_t/Q_t) gives the material composition of products (MCP) [Tilton 1986a]. The MCP can be regarded as the average amount of a material (steel) that is embodied in one product, such as an automobile. It depends on the state of technol-

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[21] For a clear graphical presentation of this last point see Radetzki & Tilton [1990, p29].

[22] This equation is derived from a simple demand based model which can be found in Radetzki & Tilton [1990].

ogy that is being applied. The second ratio (Q_t/Y_t) gives the product composition of income (PCI) that is used as a proxy for the amount of income that is spent on physical products. According to Tilton [1986a] this product composition of income is a function of structural changes in the economy such as the shift from an economy orientated at heavy industry towards an economy orientated at services. So, with equation (9), a distinction between technological and structural changes can be made. Although such a division may lead to useful insights in the demand for materials, the application of it in empirical analysis is unnecessarily complicated and limited, as will be shown below. For one material (e.g., steel) and one product (e.g., automobiles), it may be useful to determine whether a change in the steel intensity of use in automobile manufacturing stems from changes in the MCP or PCI. It may be useful to determine whether the MCP has changed because steel has been substituted for other materials or whether the PCI has changed as a result of the fact that automobiles have higher prices and value added, so that less automobiles can be bought with the same amount of money. Complications will occur if more products are analyzed together. Suppose that an economy produces only bicycles and automobiles. The decomposition of the steel intensity of use in automobile and bicycle manufacturing provides useful insights. For the whole economy, this may not be the case. The reason is that substitution between products can hardly be incorporated in this analysis. Substitution may not result in a change in the intensity of use of individual products (assuming constant economies of scale), but will yet influence the intensity of use of the whole economy. Simply adding the inputs, products and monetary outputs of automobiles and bicycles together will render meaningless interpretations of the PCI and MCP. Suppose that for two points in time the inputs and monetary outputs for the whole economy stay the same, but that the production of bicycles over time has decreased by 50%, while the automobile production in the same period increased by 5%. This will show up as an increase in the MCP and a decrease in the PCI, while the intensity of use will stay the same. Information on this aggregated level is difficult to interpret unambiguously; in the MCP and PCI-terms complex information regarding substitution is incorporated. One possible escape from this is to represent Q_t not as the numbers of production, but as the total input of material I_t that is being embodied in the product, as has implicitly been done by Roberts [1990]. Then it may be possible to add different products on their material content. However, it is clear that such data will seldomly be available. Subsequently the division by Tilton I19861 pretends to allow a distinction between technological changes and changes in the structure of final demand, but fails to do so because the various products cannot be added. Therefore, another approach will be attempted: we propose a seggregated decomposition of the intensity of use into intrasectoral and intersectoral changes. *Intrasectoral* changes in the intensity of use are changes within an industrial sector. The intensity of use may decrease within an industrial sector as a result of increased efficiency in the processing stage [McSwineey & Hirako, 19901, higher prices of the products as a result of more sophistication of the product[23], dematerialisation of the products [Herman et al., 19891 or substitution of input materials (transmaterialization according to [Wadell & Labys, 19881). These factors can all be labelled technological changes. *Intersectoral* changes in the intensity of use represent then changes in the structure of final demand, such as the shift from an economy orientated around heavy industry towards an industry orientated around services.

The distinction between intrasectoral and intersectoral changes in the intensity of use can mathematically be specified and empirically applied. It requires that data are available on the input of material i, $I_{i,j,t}$ and value added $Y_{j,t}$ for a range of {j = 1 ..n} sectors. Sectors include the production of final consumption goods, investment goods and intermediates. The intensity of use of the total economy in year t is the sum of the inputs of each sector divided by the sum of the monetary output of every sector.

$$\text{Overall intensity of use} = \frac{\sum_{j=1}^{n} I_{i,j,t}}{\sum_{j=1}^{n} Y_{j,t}} \qquad (10)$$

The sum of the value added of every sector gives the GDP of an economy:

$$GDP = \sum_{j=1}^{n} Y_j \qquad (11)$$

Throughout this section, the variables that are not indexed by j will refer to the sum over all the j sectors (and thus represent the figure for the whole economy). For materials inputs, this means:

$$I_{i,t} = \sum_{j=1}^{n} I_{i,j,t} \qquad (12)$$

and for income:

$$Y_t = \sum_{j=1}^{n} Y_{j,t} \qquad (13)$$

Equation (10) can be rewritten as the sum of the intensity of use of the individual

[23]Several products nowadays incorporate more knowledge than twenty years ago. For example televisions, photo camera's, bicycles and automobiles are becoming increasingly more sophisticated, inhabit more functions and usually have higher (relative) prices or value added. The prices of new automobiles manufactured in the United States rose for example between 1975 and 1985 by 27% (deflated by the GNP implicit price index) [Eggert 1990]. This is because new cars inhabit now more functions regarding safety, power of engine and emissions control equipments than in 1975.

sectors by weighting them by their market shares in outputs:

$$\frac{I_{i,t}}{Y_t} = \sum_{j=1}^{n}\left(\frac{Y_{j,t}}{Y_t} \cdot \frac{I_{i,j,t}}{Y_{j,t}}\right) \tag{14}$$

where the first ratio on the right hand side gives the market share of sector j, defined as the value added of a sector divided by the total value added of the economy. The second ratio gives the intensity of use of sector j. Taking the differences from equation (14) will result in the following expression for the change in the intensity of use of the whole economy, specified in changes in the intensity of use of the individual sectors.

$$\frac{I_{i,t+1}}{Y_{t+1}} - \frac{I_{i,t}}{Y_t} = \underbrace{\sum_{j=1}^{n}\left(\frac{Y_{j,t}}{Y_t} \cdot \left(\frac{I_{i,j,t+1}}{Y_{j,t+1}} - \frac{I_{i,j,t}}{Y_{j,t}}\right)\right)}_{\text{Intrasectoral}} + \underbrace{\sum_{j=1}^{n}\left(\left(\frac{Y_{j,t+1}}{Y_{t+1}} - \frac{Y_{j,t}}{Y_t}\right) \cdot \frac{I_{i,j,t+1}}{Y_{j,t+1}}\right)}_{\text{Intersectoral}} \tag{15}$$

The interpretation of equation (15) is quite straightforward: intrasectoral changes are the sum of the changes in the intensities of use of the sectors individually, multiplied by their market shares. Intersectoral changes are the sum of each sector's change in market shares multiplied by the intensity of use.[24] Simple algebra will confirm that the sum of intrasectoral and intersectoral effects equal the total change in the intensity of use. It will be clear that the precise distinction of intersectoral and intrasectoral changes will depend on the number of sectors that will be used in the analysis. In general, the greater (smaller) the number 'of sectors, the more (less) changes in the intensity of use will be intersectoral of nature. If data can be found that are sufficiently detailed, one could treat the lowest level of aggregation as the fabrication process itself. Intrasectoral changes would then truly represent actual physical efficiency.

6. A case-study on intersectoral and intrasectoral changes in the energy-intensities in the Netherlands (1970- 1990).

The decomposition methodology that is described in the previous section, will now be used in an empirical study of intersectoral and intrasectoral changes in the intensity of energy-use in the Dutch economy. Three years of reference have been chosen: 1970, 1980 and 1990. Data for these years have been collected on energy consumption and value added of ten industrial and six non-industrial sectors. The sources of the data

[24]This decomposition is not unique; there are other decompositions possible which will not be given here, but see Ang & Lee [1994] on decomposition of the demand for energy. The decomposition which is given here gives a relatively large value for intersectoral changes, since some interaction terms are incorporated in it.

are reported in Appendix 2.

The industrial grouping consists of the following manufacturing sectors: foodstuffs, textile, paper, chemical, fertilizer, refineries, building materials, base-metal, metal products and other industry. The non-industrial grouping consists of: agriculture, mining, power generation and distribution, other public utilities, construction and the service-sector which include commercial and governmental services. Energy-consumption is measured as the energy-input that is being meant for fuel-combustion. This results in the fact that energy that is being embodied in the final products (for example naphtha) has not been taken into account. A second consequence is that the consumption of electricity is not counted as energy-input. In general, the share of electricity in the total energy requirement is rather low in industry[25]. The value added consists of the value of sales of each sector minus the consumption of intermediates (energy, materials, contracts conducted by third parties). Value added equals thus the sum of salaries paid, depreciation of capital and levies paid for social security[26]. Table 6 shows that the energy intensities, measured as energy consumption divided by value added, differ greatly between sectors. Especially the fertilizer industry and electricity generation have a high energy intensity. Both have a typical labour-extensive and energy intensive production, so that they add relatively few value added compared to their energy input. It is indeed quite evident that construction has the lowest energy intensity because of the labour intensive character of this kind of activity. In Table 6 also the developments for 1980 and 1990 have been given in the energy intensities, expressed as Laspeyres indices with base year 1970. These indices show that the intensity of use of the whole Dutch economy have declined over these twenty years. At first sight it is remarkable how much the public utilities and the mining sector have succeeded in decreasing their energy-intensities. This is, however, quite logical, because during the seventies, the Dutch have extracted on a large scale natural gas and closed their coal-mines. Since the extraction of natural gas requires less energy than the extraction of coal, this has lead to a much lower energy intensity for the mining sector. For the public utilities, the distribution of natural gas instead of the gasification of coal has resulted in much less energy use. In comparison, energy intensities in the agriculture sector and the chemical industry more than doubled in 1980 compared to 1970. For the agriculture sector this is due to the boom in horticulture which uses natural gas for heating purposes. The industry as a whole had in 1980 a slightly higher energy-intensity than in 1970. However, in 1990 the energy intensity has also declined in the industry. The share of industry in total GDP (the last three columns of Table 6) declined in 1980, but increased afterwards to 20% in 1990. The market share for the mining sector almost quadrupled, due to the large

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[25]In future research electricity consumption will also be included. A correction for double-counting must be made then since electricity is produced with the consumption of energy-sources by the power sector, and then distributed and consumed by the other sectors.

[26]For the non-commzrcial governmental sector, value added has been calculated in this way.

scale extraction of natural gas. The contributions of base-metal and building materials industry to the GDP have been declining over all the years.

Table 6: Developments of market shares and intensities of use of the Dutch economy

Sectors	Intensity of use 1970 value	1970	1980	1990	Market share 1970	1980	1990
		indexnumbers with 1970-=100			Measured in percentage of total value added		
Agriculture and fishery1	5.01	100	217	128	5.7%	3.6%	4.3%
Mining	3.63	100	6	20	1.6%	5.3%	3.2%
Total industry	3.52	100	102	76	26.8%	18.5%	20.1%
Foodstuffs	5.41	100	118	a3	4.7%	3.3%	3.7%
Textile	4.35	100	119	53	1.1%	0.5%	0.4%
Paper	15.78	100	a4	65	0.8%	0.6%	0.6%
Fertilizer	107.44	100	45	a3	0.3%	0.2%	0.1%
Other chemical	13.63	100	226	116	3.3%	1.7%	2.8%
Building materials	15.64	100	101	67	1.1%	0.8%	0.7%
Base-metal	14.32	100	119	33	1.3%	0.8%	0.7%
Metal products	1.19	100	147	68	8.6%	5.7%	6.3%
Oil industry2	43.23	100	81	53	1.8%	1.2%	1.5%
Other industry	2.03	100	64	33	3.7%	3.7%	3.2%
Electricity3	33.63	100	98	80	1.6%	1.5%	1.5%
Other public utilities	11.34	100	2	19	0.6%	0.7%	0.3%
Construction	0.84	100	6 7	23	8.0%	7.3%	5.5%
Service-sector	1.56	100	51	44	55.6%	62.6%	65.2%
Total economy4	5.60	100	76	61	100.0%	100.0%	100.0%

Remarks by Table 6

1. Energy data only for agriculture
2. Oil industry consists of refineries and cokesfabrication
3. Electricity includes production and distribution of electricity
4. Total economy excludes the consumption of fueltypes by households

Energy counted as TJ input, Value added in mln Dutch constant (1980) guilders

Energy intensities thus reflect the million joules input per guilder value added

With these data, it is possible to calculate what factors have contributed to the decreases in the energy intensity in the Netherlands. The question is whether these decreases are induced by intrasectoral decreases due to improvements in the technology of production, or induced by a change in the structure of the Dutch economy. Using equation (15) this has been calculated; the results are depicted in Table 7. Two periods have been distinguished: the second column compares the developments between 1970 and 1980 while the third column compares the developments between 1980 and 1990. It is remarkable that these two periods exhibit completely different developments. In the first period, the intensity of use for the whole economy declined by more than 24%[27] It appears that this is solely due to intersectoral changes. The structure of the Dutch economy has become less energy-intensive. Technological changes, measured as the sum of the intrasectoral changes, have only played a marginal role during this decade. It appears that energy-saving considerations within sectors were not important in the way of producing (this is largely due to the increase in energy consumption in the chemical sector). In the second period (1980-1990), this picture is reversed: the individual sectors have succeeded in an energy saving per unit output of more than 22%, due to technological changes. The structure of the economy has, however, been worsening. Changes in the structure of the Dutch economy have resulted in an increase in the energy-intensity of more than 2.5%.

Table 7: Intrasectoral changes and intersectoral changes in the intensity of use

Expressed in percentage change over 10 years

	1970-1980	1980- 1990
Total economy	-24.14%	-19.80%
o.w. intrasectoral	-0.53%	-22.46%
o.w. intersectoral	-23.61%	2.67%
Total industry	1.97%	-25.57%
o.w. intrasectoral	12.83%	-28.56%
o.w. intersectoral	-10.87%	2.99%

If only the Dutch industry is taken into account, these developments are a little bit more pronounced. As already has been remarked, the energy-intensity in Dutch industry increased in 1980 compared to 1970. It is remarkable that the intrasectoral changes are responsible for this. The energy-input per unit monetary output has increased by almost 13% in that period. It appears that especially the Dutch industry was unsuccessful in applying energy-saving technology up till 1980. Because of a shift in the structure of industry, more than 10% energy per unit value added has been saved up till 1980. In 1990, this picture is reverse. Industry has succeeded in cutting down their energy-intensities by more than 28%. Because of the unfavourable sector-shift, which has contributed to a 3% increase in energy-intensities, the total outcome is a saving in energy-inputs per unit value added of 25%.

This case-study shows that the method of decomposition proposed in this paper can provide an answer to questions related to the declining intensities of use. As a main conclusion of the application of this method to the Dutch economy, one can notice that the effect of the first oil shock (1973) has resulted in a change in the structure of our economy, while the second oil shock (1979-81) has resulted in technological changes in production towards energy-saving.

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[27] This result can (of course) also he found in Table 6 where the index of 1980 declined from 100 towards 76.

6. Conclusions

Structural change is considered to be an important element in the de-linking of materials consumption from economic growth. This consideration has been put into a wider environmental economic context by pointing at the necessity of reducing 'throughput' as a preventive environmental strategy in achieving sustainable development. The cross-section empirical work done by Jänicke et al., [1989] proved to be premature in their conclusions. Our cross-section analysis on the consumption of steel, cement, energy and freight-transport for twenty countries between 1966 and 1990 suggest that the consumption of materials has been increasing in several developed economies since the mid-eighties. Also the parabolic intensity of use curve [Malenbaum, 19781 turned out to provide weak explanatory power in time-series analysis. Explaining materials consumption by distinguishing between a 'growth'-effect and an 'intensity of use'-effect seems more fruitful for further applications. It appears that the demand for materials is positively influenced by the growth in income and negatively by the level of income. This 'intensity of use'-effect is not always significant. The growth rates of the Dutch, Japanese and U.S. economies between 1966 and 1990 have been well above the rate of 'technological growth', i.e. the rate of growth where the increase in income does not lead to a higher consumption of materials. Statistical decomposition methods can provide us with answers to the factors underlying the changes in the intensity of use. The here developed method makes clear why energy saving in the Netherlands has been so much higher in the seventies than in the eighties, despite the launching of energy saving programs in the eighties. The process of structural change, defined here as a change in the structure of the economy, turned out to be rather absent in the eighties. Contrary to the seventies, the structure of the Dutch economy has become more energy-intensive: sectors with a high energy intensity grew more than the sectors with a low energy-intensity. This all places serious doubt on the stability of a process of structural change which has been forecasted by environmental economists as the driving force behind de-linking materials consumption from economic growth.

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Appendix 1. A methodology for the calculation of the AEI.

The calculation of the Aggregated Environmental Index (AEI) in Section 3 involves a two step procedure. First, sample means have been calculated for all countries and all years. For each indicator this was done using the following formula:

$$\overline{x_i} = \frac{\sum_{t=1966}^{1990} \sum_{c=1}^{20} C_{i,c,t}}{\sum_{t=1966}^{1990} \sum_{c=1}^{20} POP_{c,t}} \qquad (16)$$

where i = indicator (1..4), c = country (1..20), t = year (1966..1990), Xi = per capita consumption of indicator i, POP = population, Ci = measured yearly consumption of indicator i.

The environmental index (AEI) for each country c and for each year t is then calculated by adding the relative deviations from the mean per capita consumption of each indicator ($X_{i,c,t}$), dividing it by 4 which results in an equal weighting of each indicator. In formula this becomes:

$$AEI_{c,t} = \sum_{i=1}^{4} \frac{1}{4} \cdot \left(\frac{x_{i,c,t} - \overline{x_i}}{\overline{x_i}}\right) \qquad (17)$$

The formula used by Jänicke et al. [1989] differ from this, since the sample mean was year-specific: i.e. the summation signs over the years 1966 till 1990 in equation (16) were not taken into account. Both for 1970 and 1985 they calculated the AEI as the deviations from the mean for respectively 1970 and 1985.

Appendix 2. Data sources and data quality.

Our data were taken from a number of international sources as listed below.

Cement consumption:	Economic Commission for Europe of the United Nations: "Annual Report on Housing and Building.". United States: CRB: "Commodity Yearbook". For Italy, Japan, Spain and Turkey: cement production from Statistical Office of the United Nations: "Statistical Yearbook".
Energy consumption:	Measured as Total Primary Energy Supply (TPES). International Energy Agency (IEA): "Energy Balances of OECD Countries", "Energy Balances of Non-OECD countries", "World Energy Statistics and Balances"; For Hungary, Poland and Yugoslavia before 1971 growth rates extracted from: United Nations: "World Energy Supplies" (Total Final Consumption).
Steel consumption:	Until 1987: United Nations: "Statistical Yearbook". After 1987: Eurostat: "Eisen und Stahl" for EC members, Economic Commissions for Europe of the United Nations: "Annual Steel Statistics for Europe" for non-EC members. Series

	have been standardized on each other using three years averages.
Freight transport:	Economic Commission for Europe of the United Nations: "Annual Bulletin of Transport Statistics for Europe". International Road Federation: "World Road Statistics". European Conference of Ministers of Transport (ECMT): "Transport Statistics". Especially for road transport series show differences. Series have been standardized.
Population:	Worldbank: "Worldtables".
Gross Domestic Product:	Worldbank: "Worldtables", 1992. For Yugoslavia, Poland and Hungary before 1971 growth rates have been extracted from : Summers, R, A. Heston: "A new set of international comparisons of real product and price levels estimates for 130 countries, 1950-1985" in: Income and Wealth, 1988.
Structure of Dutch Economy:	Value Added data have been extracted from: CBS (1985): "Nationala rekeningen 1969-1981 met herziene reeksen voor de jaren 1969-1976. From 1977 and on: CBS (1978-1991): "Samenvattend overzicht industriestatistieken". For the fertilizer industry data taken from: Statistical Yearbook of the Netherlands (1972-1993). For power generation by public utilities, data taken from: Statistiek van de elektriciteitsvoorziening in Nederland (1970-1991). Value added has been calculated as gross value added using marketprices.
Energy input in Dutch economy:	Delivered from CBS databases.

Table 3: Indexnumbers of the intensity of use in the eighties

		Steel	Cement	Energy	Transport	El
Belgium	1961	51.20	56.30	03.29	65.69	65.66
	1906	56.25	44.54	01.37	91.16	60.94
	1909	55.97	51.95	77.06	107.44	62.29
Japan	1901	72.06	90.20	06.14	71.44	79.64
	1906	71.13	64.00	77.43	65.29	66.37
	1909	77.27	62.19	75.70	66.94	67.41
Netherlands	1961	74.27	69.44	100.06	99.20	00.71
	1906	71.01	56.20	105.76	90.09	74.00
	1909	75.15	61.90	100.10	102.90	75.42
United Kingdom	1981	47.03	56.22	79.13	94.06	61.95
	1906	39.02	54.04	71.90	06.13	55.09
	1909	43.03	62.60	66.40	94.01	50.45
United States	1901	50.37	79.43	92.60	95.11	74.17
	1906	49.93	06.07	02.94	05.93	66.34
	1989	40.01	79.94	01.02	07.06	64.21

Indexnumbers with 1966= 100 based on one year moving avarages
Consumption and income expressed in per capita figures

Table 4: Estimation of alternative models of materiels consumption

			Model 1 dlnl = b1(dlnY) + b3(dlnP)			Model 2 dlnl = b1(dlnY)+b2{(lnYt)^2 -(lnYt-1)^2}+b3(dlnP)				Equation 3 d ln I = bl(d ln Y) + b2 ln Y +b3 (d ln P)		
			bl	b3		bl	b2	b3		bl	b2	b3
Expected signs			+			+				+		
Japan	Steel	Slope	1.457	-0.055	Steel	3.370	-0.503	-0.103	Steel	2.354	-0.029	-0.016
		T-statistics	3.209	-0.117		1.247	-0.718	-0.216		3.350	-1.616	-0.035
		R2 and DW	24.7%	2.224		26.4%		2.337		32.7%		2.310
	Energy	Slope	0.939	-0.330	Energy	2.249	-0.343	-0.300	Energy	1.379	-0.013	-0.056
		T-statistics	7.403	-1.472		3.170	-1.878	-1.407		6.411	-2.421	-0.241
		R2 and DW	62.4%	1.979		67.6%		2.323		70.3%		2.442
	Cement	Slope	0.916	-0.142	Cement	2.722	-0.402	-0.274	Cement	1.570	-0.021	-0.101
		T-statistics	3.940	-0.420		2.050	-1.381	-0.793		4.745	-2.557	-0.334
		R2 and DW	36.6%	1.167		41.6%		1.262		51.1%		1.425
Netherlands	Steel	Slope	1.807	-0.479	Steel	-4.792	1.643	-0.460	Steel	3.396	-0.030	-0.517
		T-statistics	2.409	- 1.200		-0.489	0.675	-1.164		3.430	-2.100	- 1.406
		R2 and DW	24.5%	2.303		26.0%		2.294		37.9%		2.547
	Energy	Slope	1.464	-0.692	Energy	5.422	-0.964	-0.666	Energy	2.032	-0.010	-0.553
		T-statistics	5.490	-2.041		1.544	-1.130	-2.749		5.259	- 1.930	-2.297
		R2 and DW	60.7%	1.691		62.9%		1.913		66.4%		1.942
	Cement	Slope	0.779	-0.164	Cement	- 1.067	0.460	-0.152	Cement	1.624	-0.016	-0.254
		T-statistics	1.955	-0.540		-0.190	0.344	-0.496		3.021	-2.165	-0.905
		R2 and DW	16.3%	2.204		16.7%		2.202		31 .0%		2.006
United States	Steel	Slope	2.610	0.026	Steel	-12.159	2.740	0.017	Steel	4.706	-0.035	0.129
		T-statistics	3.356	0.064		-0.595	0.723	0.041		7.156	-5.293	0.472
		R2 and DW	32.2%	1.945		33.7%		1.097		70.2%		2.734
	Energy	Slope	0.773	-0.353	Energy	5.400	-0.079	-0.360	Energy	0.970	-0.003	-0204
		T-statistics	5.195	-2.746		1.475	- 1.260	-2.090		5.003	- 1.526	-2.143
		R2 and DW	64.6%	1.111		67.0%		1.360		60.0%		1230
	Cement	Slope	1.901	-0.201	Cement	0.522	0.257	-0.196	Cement	2.920	-0.017	-0.255
		T-statistics	3.604	-0.547		0.039	0.103	-0.519		5.402	-3.192	-0.020
		R2 and DW	41.2%	1.261		41.2%		1.265		59.0%		1.541

Note: Income levels (Y) have been expressed as 1000 US constant (1985) dollars per capita
Steel and cement consumption in per capita ktons. energy consumption in per capita PJoules.