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An Analysis of Variables Influencing The Material Composition of Automobiles

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Abstract

The use of materials is studied broadly, because of the environmental problems related to extraction, production, consumption and waste treatment. The use and substitution of materials in products is therefore a relevant issue for environmental policy making. Studies have been done to describe the material flow or to measure the impact of materials or products on the environment. However, these studies do not often consider economic, substitution and dynamic aspects of material flows. Other studies on material flows analyse the relationship between the use of materials and economic growth, but they do not consider substitution between materials.

For environmental policy making economic, technological and environmental aspects of the use of materials need to be considered. Especially, substitution of materials is important. In various countries material and product policies are imposed on a variety of materials and products. For evaluation of these policies their environmental and economic effects need to be examined in detail.

This study aims to analyse the economic and technological factors influencing the use of materials and the substitution between different materials dynamically. The goal is to obtain an insight in the effect that material levies may have on the use and substitution of materials. The statistical analysis is performed on a specific product-group because decisions on the use of materials are taken on a product-level. The case study is performed on automobiles.

The results show that the material use is largely an autonomous development. The price of aluminium has a positive, significant effect on the use of that material. The price of plastics has a positive, but not signifcant effect on the use of plastics. Reasons may be that the costs of a raw material are small relative to the processing costs, and that the production process can only be changed slowly. Other factors, like competitiveness and consumers' tastes, may be more important for substitution. This implies that levies or subsidies on certain materials is not a promising policy to change the use of materials.

Besides time, there are two other factors that have a positive and significant relationship with the use of aluminium and plastics: the fuel efficiency, which is the distance driven divided by the energy used; and, the road tax, which depends on the weight of a car. However, these effects are caused by their positive relationship with time.

The main conclusion of the case study is that imposing a levy on materials may not have the desired or expected effect of reduction in material use.

Key words: Substitution of materials, material-related policies, time series analysis.

1. Introduction

The use and flows of materials are studied broadly, because of the environmental problems related to extraction, production, use and waste treatment of the various materials. Studies have been done to measure the physical flow of materials or the environmental impacts of some materials or products. The methods used are, for example, material flow analysis and life cycle assessment (for an overview of these methods, see Kandelaars *et al.*, 1998). These studies do often not consider economic, substitution and dynamic aspects of material flows. Other studies focus on the technological possibilities to reduce the material use (Herman *et al.*, 1989; Ayres and Simonis, 1994: Tromp, 1995). Others have analysed the relationship between material use and economic growth, but these analyses are mostly on an aggregated, macro level without considering substitution between materials (Labson and Crompton. 1993; Labson, 1995; de Bruyn *et* al.. 1997). Mannaerts (I 995) and van Dam *et al.* (1996) examine demand of primary (raw) and secondary (recycled) materials and the substitution between these on an aggregate level, but they do not focus on substitution between different materials.

The environmental impact of the use of certain materials may be reduced by substituting those materials for materials that cause less environmental problems. To analyse this substitution the factors that affect the choice for a certain material need to be studied. Materials are needed in the production process in order to meet the demand for products by consumers. Thus, the demand for materials is derived from the demand for products. Therefore, this study will look at a product level (micro-level) to the factors that influence the demand for materials. At the level of a product, substitution between materials can be taken into account. The central question is which factors affect the use of certain materials in a product. The decision which materials are used in the production process is taken at the firm-level. Therefore. the focus is not on consumers. but on the producers who decide which material inputs will be used in the production process. This analysis is done for a specific product, because for each product the decision will be different. As a case study automobiles are chosen, because the material flows are considerable, and because substitution has taken place and is expected to continue (Moll, 1993). It will be analysed whether economic and technological factors influence the use of materials in automobiles over time.

For policy makers who consider to impose policies to reduce or change the use of certain materials, this study is relevant, because it gives them an insight in the possible effects of various policies. For instance, when the results show that the price of a certain material highly affects its use. then policy makers who aim at reducing the use of that material may decide to impose a levy on that material. Or otherwise, when the price does not affect its use, they may decide to impose a regulatory instrument, such as a standard.

Section 2 examines the factors that may influence the substitution of materials in products, and the possible impact of material-related policies. Substitution of materials in automobiles is discussed in Section 3. Section 4 presents the model and the results of the estimations of the interactions between economic and technological factors, and material use in automobiles. Conclusions are drawn in the last section.

2. Substitution of materials and material-related policies

Substitution of materials can take place in two ways: (i) direct substitution between materials: and. (ii) indirect substitution between materials and other production factors, such as labour and capital. Here. the focus is on the reasons for the direct substitution between two materials. The substitution of materials in products is driven by technological. economic or environmental factors. Amongst the technological factors are: the discovery of new and lighter materials; new design; and, new production techniques. Economic factors can be divided in demand factors of the consumers and supply factors of the producers. Demand factors are, amongst other things. the price, the attractiveness (fashion), the costs of using the product. For automobiles an increase in the price of fuels which make lighter (and smaller) cars more attractive. For producers the economic factors are. for instance, the prices of the inputs, the costs of the production process and the price of the product. competition of other producers. Environmental factors which are closely related to the economic and technological factors are the concern about the emissions, the possibility of repair, re-use or recycling of the product. The option to recycle various materials in products is a mixed factor between technology (is recycling technically possible?), economy (is recycling not too costly?. is there a market for recycled materials?) and environment (recycling makes that less primary materials need to be extracted).

Many studies on material substitution have focused on the technological aspects of substitution, mostly related to short term (e.g., more efficient use of materials) and long term adaptation (e.g., new design or new materials) of the production process. An example of a product in which the use of materials has changed over time are beer cans (Roberts. 1992). Both the use of materials has become more efficient, i.e. less materials needed per can, and other materials are used, i.e. steel cans are substituted by aluminium cans.

Governments may influence the use of certain materials and products by imposing policies. In the Netherlands, the materials-related policies have mainly focused on command-and-control policies, such as standards, or on voluntary agreements. such as the packaging covenants. Economic or financial policies are rarely used (for some exceptions see OECD. 1994). For applying economic policies to materials and products it is important to know which effect policies related to materials may have. To make a policy successful. i.e. reducing the use of a material or a product, a qualitative good substitute has to be available.

This study looks at the substitution of materials and the factors that may influence the use of materials in a product. This may give an insight in the possible effects of economic policies like a materials levy. For example, a levy on a material may reduce the use of this material, but increase the use of a (imperfect) substitute material. The use of materials may be analysed for an economy. However, this level is too aggregated for the purpose of' this analysis. because substitution between materials in a product are not visible. and because decisions on the use of materials are taken on a product level (or firm level). Therefore. the analysis is performed on the level of a product (group) to observe the actual substitutions that have taken place in the past.

3. Substitution of materials in automobiles

For the analysis of substitution of materials and the underlying factors a case study is performed on automobiles. Automobiles are chosen because: (1) the material content and the weight of cars has changed substantially over time and is expected to continue to change: and. (2) the number of cars and the weight per car make that a considerable amount of the steel and iron consumption is due to cars (Eggert, 1990). Figure 1 shows the use of materials over time for an 'average automobile in the Netherlands. Three types of materials are distinguished: iron and steel; plastics; and. aluminium. Other materials such as glass and rubber are not taken into account in the analysis. Figure 1 shows that the total weight of cars has increased over time and that the percentages of aluminium and plastics in the total car weight have increased.[2] In 1960 a car consisted of 2% aluminium and 1% plastics, while in 1986 these percentages have increased to 4% aluminium and 7% plastics.[3] Note that here the material composition per car is studied and not the total use of materials in the automobile sector.

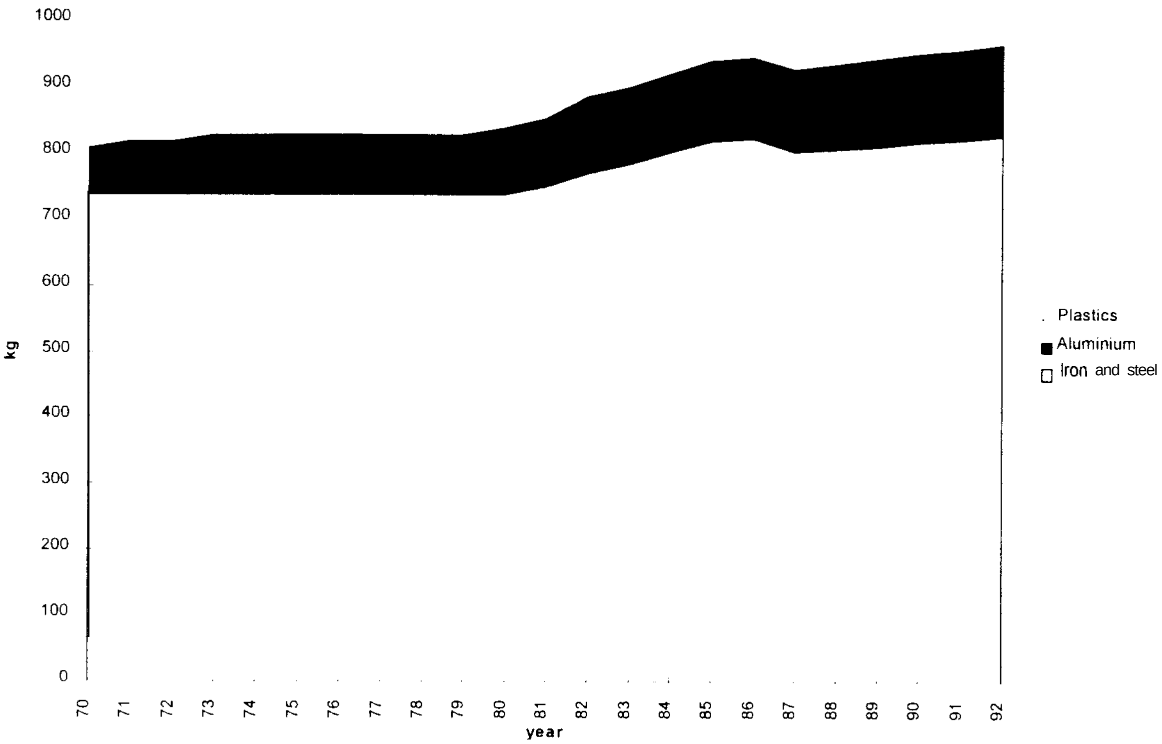

Figure I. The use of materials in automobiles.

Studies on the material use and substitution in automobiles are mostly dealing with the physical or environmental aspects. Moll (1993) studies the dynamic life cycle of automobiles. Cornelissen (1993) investigates the possibilities of using aluminium in cars to reduce the use of fuel. Ginley (1994) analyses various material flows from raw materials to recycling and re-use for other uses and waste treatment to show the cyclical and dissipative flows. The identification of those flows provides information on their possible environmental effects. Besides those studies there is a literature on recycling of the materials of cars and the related social, technological and economic (management) difficulties (Hoyle, 1995; den Hond, 1996; Lee, 1997). Eggert (1986) and Gjostein (1986) describe the material composition of American automobiles over time. It results that for the average vehicle in the United States the weight has declined due to downsizing and substitution of lightweight materials. In the Netherlands the average vehicle weight has increased over time (CBS, 1974-1994). Gjostein (1986) discusses the prices of materials shortly without providing or analysing data. It is stated that prices do affect material substitution, but that these effects are only indirect and small. They are indirect

[2] The average weight of an American car has decreased from 3761 lbs in 1976 to 3137 lbs in 1992 and is expected to decrease further (Das et al., 1995).

[3] The trend towards more use of aluminium and plastics and less iron/steel is the same for the United States and Europe.

because materials substitutions cannot be done immediately. and small because the material price is often small compared to the manufacturing costs. The fuel efficiency of cars (distance driven divided by energy use) has increased over time, which is partly attributable to the use of aluminium and plastics, materials that are lighter than iron and steel (Das *et al.*, 1995).

Studies dealing with prices and substitution of materials can be divided in two types. First, studies which use statistical or econometric techniques. such as regression analysis. to determine the relationship between prices and substitution. Second. studies based on a survey of the manufacturers of products in which the manufacturers are asked whether material prices. technical, governmental or legislative factors influence the use of materials.

In this study, the prices and substitution of materials in the automobile industry are studied statistically. The reason is that with regression analysis the relationship between technological and economic factors, and the use of materials may be determined. Furthermore. based on the results of the regression analysis, the effect of a specific policy. for example, a levy on the use of certain materials, on the use of materials may be studied.

4. Results of the statistical analysis

Economic and technological factors may be relevant for the use of materials in cars. In the analysis materials iron and steel, aluminium, and plastics are taken into account. Other materials such as copper, glass and rubber are not considered because of their relative small part in the total weight of a car. The material composition of cars can be seen as a dynamic decision process: the choice of materials for cars is influenced by changes over time. for instance. changes in technology or prices. For evaluating the influence over time of physical and economic factors on the material composition of cars, regression analysis is used. Regression analysis allows one to obtain a quantitative insight in the importance of economic and physical factors on the material composition. For the statistical analysis times series data on prices, material composition and weight are required. These data are gathered for the Netherlands.

Time series data are collected from the following sources: the price of steel and aluminium (Metal Bulletin's Prices and Data, 1982- 1995; OECD. 1970- 1982; CPB, 1996): the price of plastics[4] (Kunststof en Rubber, 1976-I 993): price deflation and exchange rates (CPB. 1996); the weight of an average car (CBS, 1974-1994); the annual road tax that is based on the weight of a car (Centraal bureau voor de motorrijtuigenbelasting. 1996); the distance driven per year (Annema *et al.*, 1996): the price of gasoline (Annema et *al.*, 1996): the fuel efficiency. that is defined as the distance driven per year divided by the annual used energy in Joules (Annema *et al.*, 1996); and. the material composition of a car (Tilton, 1990).

For the OLS regression analysis the following additive structure was adapted: $Y_t = \alpha + \beta X_{t,1} + \gamma X_{t,2} + \varepsilon_t$. The percentage of a material (in kilograms) used per car (total weight. in kilograms) (Y_t) is related to a constant (*a*), variables $X_{t,1}$ and $X_{t,2}$ (with coefficients β en γ) and an error term ε_t.

Tables 1 to 3 show the results for aluminium. plastics. and iron and steel. Estimation 1 shows that time is an important variable with a high explanatory value. in describing the use of aluminium over time. This result may be interpreted as the use of aluminium in relation to the weight is an autonomous development over time.

[4] The various types of plastics that are used in the production of cars are aggregated. For the price of plastics is taken the unweighted average of the prices of plastics that are mostly used.

The use of aluminium is positively correlated with the price of aluminium (estimation 2). The correlation between the use and the price of aluminium is significant, but the explanatory value is low. This result is not straightforward because this means that an increase in the price of aluminium does not result in a reduction in the use of aluminium. For policy makers this is interesting because a material policy on aluminium does not necessarily have the expected result.

The fuel efficiency is positively correlated with the use of aluminium (see estimation 3). The explanatory value of this estimation is high, possibly because the use of more aluminium reduces the weight of the car and therefore increases the fuel efficiency.

Estimation 4 of Table 1 presents the positive and significant correlation between yearly fuel costs and the use of aluminium. This may result from an increase in the use of aluminium as a result of increasing fuel costs. Aluminium may be used as a substitute for the heavier steel in order to lower the fuel costs.

Table 1. Results of the analysis for the use of aluminium (period of analysis is 1970-I 992).

Estimation	*α (t-value)*	$X_{t,1}$ *β (t-value)*	$X_{t,2}$ *γ (t-value)*	R^2
1		time		0.82
	3.01 (23.3)	0.0925 (9.8)		
2		aluminium price		0.17
	3.12 (6.1)	0.139 (2.1)		
3		fuel efficiency		0.84
	-4.66 (-5.6)	0.0266 (10.6)		
4		yearly fuel cost		0.27
	-0.925 (-0.5)	0.1279 (2.8)		
5		time	yearly fuel cost	0.89
	0.302 (0.43)	0.0841 (11.0)	0.0709 (3.9)	
6		price of gasoline		0.71
	-1.27 (-1.8)	6.4 (7.2)		
7		time	price of gasoline	0.85
	14.5 (1.7)	0.0676 (1.7)	2.23 (1 .8)	
8		road tax		0.56
	0.233 (0.3)	1.27 (5.2)		

The explanatory value of time and yearly fuel costs in relation to the use of aluminium is high (estimation 5). Both time and yearly fuel costs are significantly and positively related to aluminium use. The difference with estimation 1 where time is the only explanatory variable is relatively small, implying that the addition of yearly fuel costs has not a big impact.

Time and the price of gasoline as explanatory variables give a good estimation in terms of explanatory value (estimations 6 and 7). The positive relationship between the price of gasoline and the use of aluminium implies that an increase in the price of gasoline may result in an increase in the use of aluminium, because that reduces the weight of a car.

Estimation 8 shows that the relationship between the road tax and the use of aluminium is positive. An explanation is that the road tax consumers pay depends on the weight of a car. If producers substitute steel by aluminium. the weight of the car decreases, which may have a positive impact on the consumers' decision to purchase the car.

Table 2 shows the results of estimations 9 to 16 for the percentage of plastics in a car.

The result of estimation 9 shows that time is an important variable for the use of plastics (compare with estimation 1 in Table 1). As for aluminium. this shows that the use of plastics is an autonomous development over time. Estimation 10 shows that the price of plastics is positively correlated with the use of plastics. This seemingly positive price elasticity is explained by the low explanatory value of this regression. For policy makers this is an important result because a material policy on plastics may not have the effect they expect. The fuel efficiency has a positive and significant correlation with the use of plastics (estimation 1 1). The use of plastics reduces the weight of cars and therefore, increases the fuel efficiency. Estimation 12 shows the yearly fuel costs have a positive significant impact on the use of plastics. but the explanatory value is very low. When time and the yearly fuel costs are taken as explanatory values, the fit does not improve compared to an analysis with only time as the explanatory value (compare estimations 13 with 9). Furthermore. the yearly fuel costs do not have a significant impact on the material composition. Estimations 14 and 15 show the results of the estimations with the price of gasoline, and the price of gasoline and time respectively. The explanatory value does not increase compared with estimation 9. The relationship between the road tax and the use of plastics is positive and significant (estimation 14). The explanatory value is high. The explanation given for the relationship between the road tax and aluminium is also valid for the use of plastics (see analysis of estimation 8 above).

Table 2. Results of the analysis for the percentage of plastics (period of analysis: 1970-1 992)

Estimation	a (t-due)	$X_{t,1}$ β (t-value)	$X_{t,2}$ γ (t-value)	R^2
9	5.42 (27.8)	time 0.157 (11.0)		0.85
10	7.03 (12.0)	price of plastics 0.276 (0.5)		0.01
11	-6.88 (-4.3)	fuel efficiency 0.0430 (8.9)		0.79
12	2.08 (0.6)	yearly fuel costs 0.132 (1.5)		0.10
13	4.37 (3.1)	time 0.154 (10.3)	yearly fuel cost 0.0272 (0.8)	0.85
14	-1.05 (0.1)	price of gasoline 10.0 (5.8)		0.61
15	-4.97 (-3.6)	time -0.150 (5.7)	price of gasoline -0.629 (0.3 1)	0.85
16	3.79 (11.1)	road tax 0.00689 (10.7)		0.80

The results of the estimations of the percentage of steel are presented in Table 3. Estimation 17 shows that time is negatively correlated with the use of steel. but this correlation is not significant. This may be due to the high constant (84.1) which for its part may be explained by the small fluctuation or change in the percentage of steel used (see Figure 1 in Section 2 and compare with the percentages of aluminium and plastics). The variables in estimations 18 to 24 are not significant. and most estimations have a low explanatory value. Also these results mav be explained by the marginal changes in the use of steel in the period 1970- 1992.

Table 3. Results of the analysis for the percentage of steel (period of analysis: 1970-1992).

Estimation	a (t-value)	$X_{t,1}$ β (t-value)	$X_{t,2}$ γ (t-value)	R^2
17		time		0.83
	84.1 (89.2)	-0.0484 (-0.7)		
18		price of steel		0.32
	85.7 (39.8)	-1.29 (-1.1)		
19		fuel efficiency		0.01
	-86.6 (13.3)	-0.00923 (-0.5)		
20		yearly fuel cost		0.10
	73.8 (11.7)	0.245 (1.6)		
21		time	yearly fuel cost	0.16
	72.5 (11.5)	-0.0838 (-1.2)	0.302 (1.9)	
33		price of gasoline		0.84
	86.3 (19.9)	-3.37 (-0.7)		
23		time		0.02
	84.9 (12.5)	-0.0353 (-0.3)	-1.17 (-0.1)	
24		road tax		0.06
	87.4 (25.2)	-1.27 (-1.1)		

5. Conclusions

The goal of this study was to analyse statistically the economic and technological factors that may influence the use of materials in automobiles over time. Unlike many other analyses, this dynamic analysis includes substitution between materials, which may be an important strategy for reducing the use of certain materials. For policy makers it is also relevant to know which factors affect the use of materials, for instance, for material-related policies.

The results show that the use of the three materials studied (iron and steel, aluminium and plastics) is largely an autonomous development over time. The explanatory value of the price of materials on the use of these materials is small. For policy makers this result implies that a levy (subsidy) on plastics or aluminium will not necessarily have the expected effect of a reduction (increase) in the use of these materials. Reasons may be that the costs of materials are small relative to the processing costs, or that the production process can only be changed slowly so that small or sudden changes of the prices of materials cannot be followed.

Besides time, there are two other factors that have a positive and significant relationship with the use of aluminium and plastics: the fuel efficiency, which is the distance driven divided by the energy used; and, the road tax, which depends on the weight of a car. The change in fuel efficiency results from technological development. However, these effects are caused by their positive relationship with time.

This case study illustrates that analysing the economic and technological aspects of the material use on a product-level may give insights in the effects of material-related policies. It also shows that levying the use of materials may not always have the desired effect. This is a relevant result for policy makers.

Further research may be directed at describing quantitatively and dynamically the economic and physical factors of waste treatment and recycling of the materials of which the automobile is made. With these time series data trends and possible government or sectoral interventions may be analysed. On a more general level, this research has illustrated that the use of materials and policies related to its use need to be analysed on a product-level. mainly because decisions on materials use and substitution are made on that level, and not on an aggregated level. Moreover, when policy makers want to reduce the use of a material, then they have to take into account that producers will substitute that material for another material, which may have a higher or another environmental impact.

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