# DIMITRI: a Dynamic Input-output Model to study the Impacts of Technology Related Innovations

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**Abstract**

One of the main challenges of the Dutch government on the road to sustainable development is delinking economic growth and environmental pressure. Policy makers with a concern for a sustainable relationship between the economy and environment have high expectations when it comes to technological progress. In policy plans, not only is an important role reserved for technological improvements at sector level, but also for innovations and technological breakthroughs beyond sector boundaries. A model is therefore very useful in facilitating the quantification of the impacts of new technologies on the economy and environment.

To this aim we developed DIMITRI, the Dynamic Input-output Model to study the Impacts of Technology Related Innovations on sectoral production, the use of natural resources and emissions to the environment. The choice for an input-output model is obvious, since input-output analysis has proved its worth in examining relationships of economic structure, energy use and the natural environment. Furthermore, input-output analysis satisfies desires of policy makers for a chain approach in the search for new technologies.

This paper presents the first empirical version of DIMITRI. The paper will discuss the structure and validation of the model. The paper will start however by presenting the results of a tentative analysis of the impact of technological change on energy demand by the Dutch economy during the period 1980-1997.

## Introduction

The realization of economic growth with far less undesirable consequences for the environment is one of the long-term challenges of the Dutch government (Ministry of Economic Affairs, 1997). Until now, the government has only succeeded partially in reducing environmental pressure in the Netherlands (National Institute of Public Health and the Environment, 1999a-b). The emissions of several pollutants, e.g. nitrogen, phosphate and sulfur dioxide, decreased substantially during the last twenty years, despite strong growth in production and consumption. Conversely, emissions related to fossil energy use and environmental pressure due to mobility are still increasing. More increases in carbon dioxide emissions are expected for the coming years as a result of the ongoing economic growth which goes faster than the growth in energy conservation. Since rising incomes and growth in consumption may counterbalance achieved reductions in energy use so far, a complete delinking of economic growth and environmental pressure is a very difficult task.

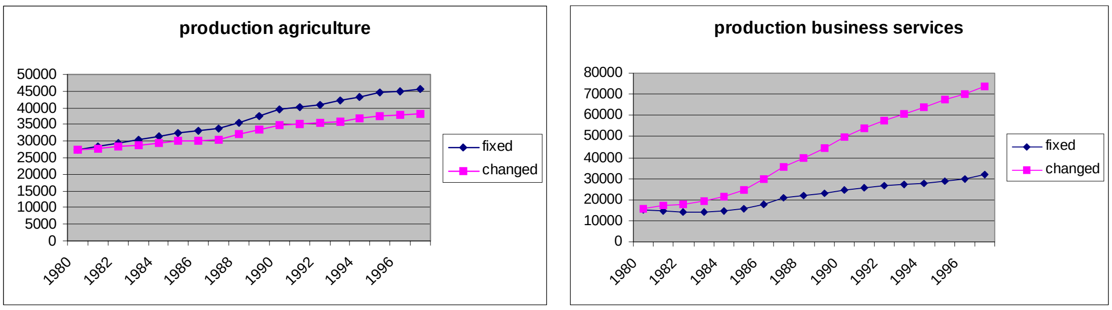
In the perspective of sustainable economic development, economic growth should go together with a reduction in the physical requirements for energy and materials, and waste amounts and emissions. So, the challenge of the government concerns a huge increase in environmental productivity implying the use of less energy and materials per unit GDP. One of the steps of the government on the road to a more sustainable economic development concerns policy aimed at research, development and implementation of new technologies. This search for new technologies, which concern both improvements in existing technologies and developments of new technologies, should not only be aimed at individual sectors, but also on chains of production processes.

In order to study the extent in which new technologies can contribute to a more sustainable growth, the overall effects of new technologies on economy and environment have to be investigated. For this purpose, we are developing a dynamic input-output model of the Dutch economy that enables the investigation of effects of technical changes in individual economic sectors on the whole economy and environment. Idenburg (1998) presented the first theoretical version of the model with the hope to get the model operational with empirical data. This paper shows the first empirical outcomes of the model, which was baptized DIMITRI in the meantime.

**Preliminary results 1980-1997**

Before we present a mathematical description of the dynamic input-output model DIMITRI, we illustrate some of the possibilities of the model on the basis of an analysis of the Dutch economy for the period 1980-97. We show the impacts of changing technologies on economy and environment by calculating the effects of the technological change on sectoral production and energy use for two scenarios. Starting-point for the calculations is the production structure of the Dutch economy in 1980 depicting the mix of technologies implemented in the years before 1980. In the first scenario (changed technology), the observed changes in technologies are simulated for the period considered by implementing all new investments on the basis of the technological matrix of 1997 (which depicts a mixture of technologies implemented in the periods before 1997). The model calculates dynamically the production structures for the period 1980-97 in this scenario. The second scenario (fixed technology) concerns the imaginary situation that no technological change occurs: the 1980 technology is fixed for the whole period.

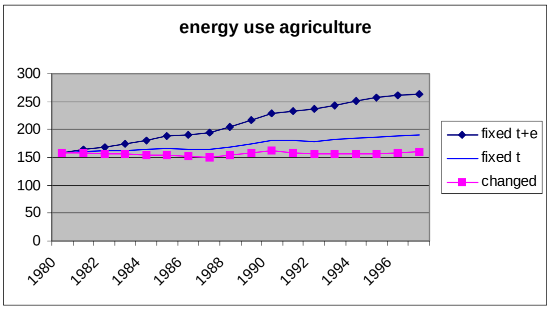
**Figure 1** *Production (in million Dutch guilders) for the sectors agriculture and business services calculated with DIMITRI for two scenarios for the period 1980-97.*

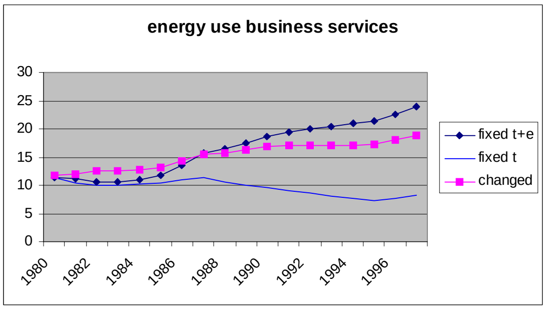



The model calculates production for each sector on the basis of the production structure and the sectoral final demand consisting of exports, household and government consumption, and investments. Part of final demand, viz. exports and consumption, is exogenous to the model and is derived from statistics. The investments, which are necessary for the maintenance and extension of the production capacity, are endogenous. Figure 1 shows values for production in agriculture and business services for both scenarios mentioned. The fixed-technology scenario depicts the development in the production of agriculture and business services due to changes in final demand by all sectors only. The differences between these values and the values based on the changed-technology scenario indicate effects of changing production structures. The figure shows that the importance of the business services in the production structure of the Dutch economy increased strongly in the period 1980-97. On the other hand, there is a slight decline in the importance of agriculture in the production structure in the period considered. We present these sectors, since they show the largest differences between the two scenarios. For other sectors, the differences between production based on both scenarios are smaller.

We use the demand for energy as an example for illustrating the effects of technological change on the environment. Energy use in a sector is the result of the physical production in that sector and the energy efficiency of production. Figure 2 shows the developments in energy use calculated with DIMITRI in the same sectors as above for three scenarios: changed technology and two variants of fixed technology. In the first variant of the fixed technology scenario (fixed t+e), production structure and energy efficiency are fixed on the 1980 values for the whole period 1980-97. The developments in energy use per sector are the same as the developments in production in figure 1 (fixed scenario). In the second variant (fixed t), only the production structure is fixed. So, this scenario compared with the previous one shows the improvements in energy efficiency that occurred in the period considered. The growth in production, as a result of changing final demand, is cancelled out by improvements in energy efficiency in both sectors. The changed-technology scenario shows that the energy use in the agricultural sector remains at the same level during the period 1980-97 due to changing production structures and energy efficiencies. In the sector business services, energy efficiency improvements moderate the growth in energy use (as a consequence of an increasing importance of this sector in total production).

**Figure 2** *Energy use(in petajoules) in the sectors agriculture and business services calculated with DIMITRI for three scenarios concerning the period 1980-97.*



This tentative analysis of the period 1980-97 illustrates how DIMITRI can be used for investigating the effects of changing technologies on economy and environment. At the end of the paper, more possibilities of DIMITRI will be discussed.

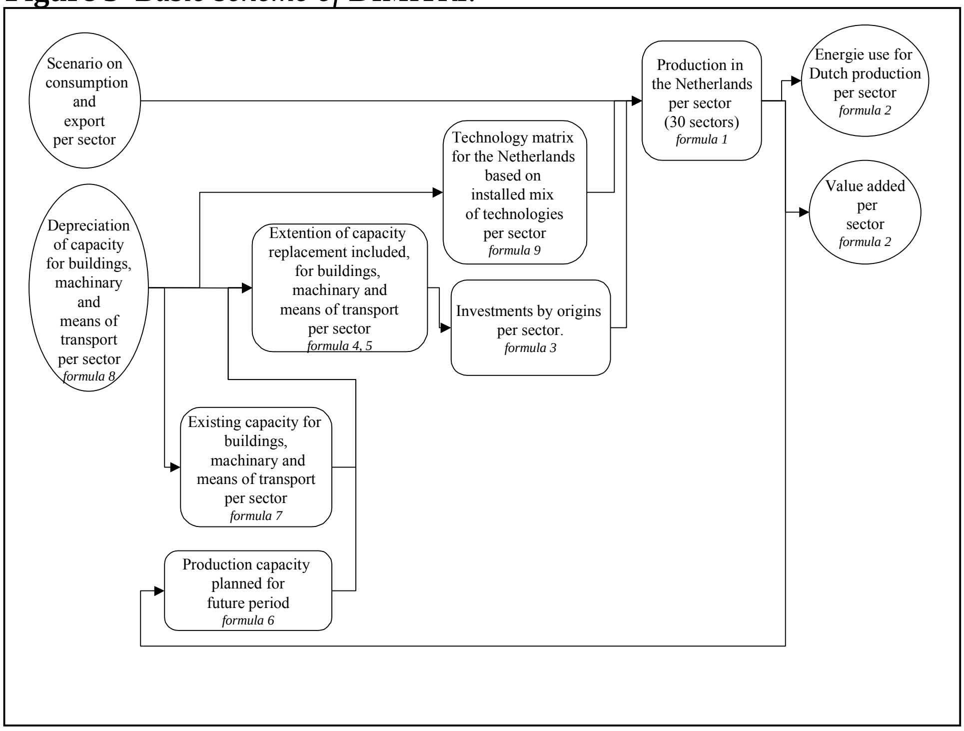
**Description of the model**

The model is based on input-output analysis, which is a useful tool in studying the relations between economy, technology, and environment. Starting point in input-output analysis, which is originally developed by Leontief, is an input-output table, which describes the flows of goods and services through an economy in financial terms. The columns in the so-called technological matrix, which can be easily derived from an input-output table, can be seen as a description of the technology in the individual sectors. With technology is meant the way in which intermediate inputs, capital and value added are combined for production. So, the columns are the links between descriptions of technologies at the micro-level and the macro-economic system. Changes in column coefficients in time give insights in technological change. See e.g. Rose (1984) for an overview of the early literature on technological change in combination with input-output analysis. Instead of investigating technological change in series of input-output tables, input-output analysis also enables the study of the impacts of new technologies on economy and environment by adjusting input-coefficients. Duchin and Lange (1994), e.g., investigated the potential of technological measures to fulfill economic objectives (in terms of GDP per capita) and environmental objectives (in terms of $CO_2$, $NO_x$ and $SO_2$ emission reductions). Since Wright (1974), and Bullard and Herendeen (1975) published their articles on the calculation of sectoral energy intensities, input-output analysis has also proved its worth for investigating the flows of natural resources from the environment through the economy.

Generally, a static input-output model is sufficient to determine the impacts of new technologies on economy and environment. In order to investigate the penetration of new technologies too, a dynamic approach is required. Contrary to static input-output models, in which investments are part of final deliveries, dynamic input-output models include the stocks and flows of capital goods explicitly. Duchin and Szyld (1985) described such a dynamic input-output model with assured positive output for the US. Leontief and Duchin (1986) extended this basic model in order to investigate the effects of new technologies on employment. For the same purpose, Kalmbach and Kurz (1992) developed a dynamic input-output model for Germany. We are developing DIMITRI, a dynamic input-output model for the Dutch economy, on the basis of the model worked out in Duchin and Szyld (1985), and Duchin and Lange (1992).

The remaining part of this section presents the mathematical representation of DIMITRI. The core of the model concerns the determination of the physical production and the implementation of new technologies. Figure 3 depicts the main structure of the model.

**Figure 3** *Basic scheme of DIMITRI.*




*Production*

The model describes the relations between production, final demand and investments in time. The production is determined as usual in dynamic input-output models:

$$x(t) = [I - A(t)]^{-1} [y(t) + z(t)] \qquad (1)$$

where:

$x(t)$ vector of total outputs in period t;
$I$ identity matrix;
$A(t)$ matrix with technological coefficients for period t (see formula 9);
$y(t)$ vector of final deliveries (excluding investments) for period t (the final deliveries are exogenous);
$z(t)$ investments (by origin) in period t.

The main purpose of the model is the calculation of the impacts of new technologies on environmental characteristics like the use of energy and materials, and emissions to the environment. Besides, the consequences for economic characteristics as GDP and employment are of interest. Both environmental and economic characteristics are closely related to sectoral production and they can be accounted for by distinguishing the items as separate value-added categories. Value added is calculated as follows:

$$v(t) = V(t)\, x(t) \tag{2}$$

with:
$v(t)$ vector of total value-added per category in period t;
$V(t)$ matrix with value-added coefficients per category per sector for period t.

Energy use, material use and emissions are modeled in a similar way. In these cases matrix V(t) has to be extended with coefficients concerning energy use (in petajoules), material use (in kilograms) or emissions (in relevant units) per unit of sectoral production for period t.

*Investments*
Sectors plan their investments on the basis of existing capacity, depreciation of capital goods and the expected or planned capacities for the subsequent periods. We assume that investments for capital replacement and extension are carried out with the same technology available at the moment of investment. This assumption is different from the approach of Duchin and Szyld who distinguished investments for extension and replacement. They assumed that replacement of capacity is carried out with old, original technologies. The investments by origin are determined with:

$$z(t) = \sum_k B^{N,k}(t)\ c^{\Delta,k}(t) \tag{3}$$

where:

$B^{N,k}(t)$ matrix with capital requirements for capital good k per unit of production installed in period t;

$c^{\Delta,k}(t)$ extension of the capacity (inclusive the replacement of depreciated capacity) of capital good k installed in period t.

The present version of DIMITRI distinguishes three types of capital goods, viz. buildings, machines and means of transport. The matrix of capital coefficients, B, describes the required capital goods per unit of capacity per sector. Since DIMITRI is developed for the Dutch economy, this matrix is based on domestic production of investment goods. So, machines or means of transport that are imported are exogenous to the model.

*Extension and replacement of capacity*

The capacity to be installed newly in every period consists of replacement of existing capacity that will be depreciated in the subsequent periods and extension of capacity. The latter is based on expectations of future capacities per sector (see formula 6). The planning of new capacity is an amount of periods ahead depending on the type of capital good. This distinction is made, since the planning and realization of new buildings generally takes longer than the ordering and introduction of new machines or means of transport. We assumed that the installation of new buildings requires five periods and that the acquisition of machines and new means of transport takes two periods. The new capacity per type of capital good i is:

$$c_i^{\Delta,k}(t) = \max\left[0, \min\left\{\frac{\alpha_i^k\ r_i(t)}{\sum_j B_{ji}^{N,k}(t)}, \frac{c_i^{*,\theta_k}(t) - c_i^k(t) + \sum_{\tau=0}^{\theta_k - 1} S_i^{dep_{i,k}-\tau,k}(t)\, c_i^k(t)}{\theta_k}\right\}\right] \tag{4}$$

with:

$c_i^{\Delta,k}(t)$ newly installed capacity of capital good k in sector i in period t;

$\alpha_i^k$ sector-specific value constraining the amount of available resources for capital good of type k;

$r_i(t)$ available resources for new investments (see formula 5);

$c_i^{*,\theta_k}(t)$ capacity of sector i planned in period t for period t+$\theta_k$ (see formula 6);

$c_i^k(t)$ capacity of capital good k in sector i in period t;

$\theta_k$ number of periods required to realize capital good of type k, $\theta_k$ is 5 for buildings and 2 for machinery and means of transport*;*

$S_i^{\tau,k}(t)$ the share in period t of the capacity of capital good type k installed in period t-$\tau$ (which will be depreciated in period t+$dep_{i,k}$-$\tau$+1); formula (8) describes the calculation of the depreciation shares;

$dep_{i,k}$ sector-specific depreciation period of capital good of type k.

According to formula 4, the extension of capacity is modeled on the basis of the difference between the planned capacity and the existing capacity taking depreciation during the planning period into account. Assuming that this amount will be installed in equal shares over the planning period, next year extension will be one fifth for buildings and a half for machinery and means of transport[1].

The capacity to be installed new is limited twofold. First, the amount has to be positive, which means that a lowering of the capacity, e.g. by selling part of the capital stock to other sectors is not allowed. So, capital stock can only be decreased by depreciation. Secondly, the available resources for new investments per sector restrict the capacity to be installed. These resources on their turn are restricted to the costs of intermediate and primary inputs (value-added). So, the second restriction brings about that, in case a sector suffers losses, the possibilities for new investments will be limited. Formula 5 gives the derivation of $r_i(t)$:

$$r_i(t) = \left\{1 - \sum_j A_{ji}(t) - \sum_j V_{ji}(t)\right\} x_i(t-1) \tag{5}$$

[1] Notice that the remaining four fifth or halve will not be installed. The extension of capacity is planned regardless of last years planning.

Formula 5 sums over all value-added categories except for the operating surplus (inclusive depreciation). The present version of DIMITRI calculates the available resources on the basis of the gross profits in the previous period, but this approach may be refined by determining the available resources on the basis of the profits in a series of previous periods.

*Planning of future capacity*

As already discussed, sectors have to plan their capacity for subsequent periods in order to determine how much new capacity has to be installed each period. As usual in dynamic input-output modeling, the planned capacity per sector depends on the developments in the production of that sector in previous periods. Each period, the capacity for the next periods is planned on the basis of the developments in the production in the preceding periods. Very often dynamic input-output models show unstable behavior that originates from the way capacity is planned. Fleissner (1990), e.g., studied the stability and sensitivity properties of the Leontief-Szyld-Duchin model. The modeling of capacity planning is weak in production models in general partly due to the lack of (good) data on capacity and capacity utilization.

We based the planning of capacity as implemented in the MESEMET model (van Bergeijk, 1995) in which sectoral decisions for expansions are based on the growth rate of production in the last four periods. Furthermore, the growth rates for the most recent periods have the highest weights. In DIMITRI, the planned capacity in period t for period t+τ (τ >0) is:

$$c_i^{*,\tau}(t) = \left\{ \begin{array}{l} 1 + 0.4 * gx_i(t-1) + 0.3 * gx_i(t-2) + \\ \qquad 0.2 * gx_i(t-3) + 0.1 * gx_i(t-4) \end{array} \right\}^{\tau+1} x_i(t-1) \qquad (6)$$

with:

$gx_i(t)$ growth rate of total output in sector i in the period between t and t-1; i.e. $(x_i(t) - x_i(t-1)) / x_i(t-1)$;

$x_i(t)$ total output of sector i in period t.

Each period, the planned capacity is compared with the actual capacity (see formula 4). In this way, previous prognostications for future capacities may be adjusted.

*Present capacity*

The capacity in period t+1 is the sum of the present capacity minus depreciated capacity and the newly installed capacity in period t for each type of capital good i:

$$c_i^k(t+1) = \left[1 - S_i^{dep_{i,k},k}(t)\right] c_i^k(t) \ + \ c_i^{\Delta,k}(t) \tag{7}$$

*Depreciation*

Capacity is depreciated on the basis of depreciation periods per type of capital good. In general, the share $S_i^{\tau,k}(t)$ describes the share of the capacity of capital good k in sector i implemented in period t-τ (and for the first time in use in period t-τ+1):

$$S_i^{\tau,k}(t) = 0 \text{, if } \tau > dep_{i,k}, \tag{8}$$

$$S_i^{\tau,k}(t) = \frac{S_i^{\tau\text{-}1,k}(t-1)\, c_i^k(t-1)}{c_i^k(t)} \text{, if } 1 < \tau \updownarrow dep_{i,k},$$

$$S_i^{\tau,k}(t) = \frac{c_i^{\Delta,k}\ (t\text{-}1)}{c_i^k(t)} \text{, if } \tau = 1,$$

So, $S_i^{dep_{i,k},k}(t)$ is the share of the capacity of capital good type k installed in period t-$dep_{i,k}$, for the first time in use in period t-$dep_{i,k}$+1, and that will be depreciated in period t+1.

All capital goods placed in a certain period are depreciated entirely at the end of the economic life of the capital goods. In this way, intermediate falling-out of capital goods is left out of account. One might consider a more smoothly method of depreciation, but such a method would make the model much more complicated not resulting in a dramatic change of the periodic amount of depreciated capacity.

*Technology matrix*

The installed technology is a mix of technologies implemented in previous periods. As a result of depreciation and new investments, the installed technology in all sectors will change every period. After installing new technologies, the technological matrix should depict the new installed mix of technologies. This is achieved by the following formula:

$$A_{ji}(t) = \sum_{\tau=1}^{dep_{i,\kappa_i}} A_{ji}^{N}(t-\tau)\, S_i^{\tau,\kappa_i}(t) \qquad (9)$$

with:

$\kappa_i$ type of capital good which specifies the technology per sector (means of transport for the transport sector, machines for other sectors);

$A_{ji}^{N}(t)$ technical coefficients belonging to the technology of sector i installed in period t.

Formula (9) enables a dynamical calculation of the technological matrices for each period. Carter (1967) already proposed such a dynamic adjustment of the input coefficients. This approach is different from the procedure employed by Leontief and Duchin (1986) who constructed a technological matrix for a certain future period. For the intervening periods with the base year, technological matrixes were determined by interpolating.

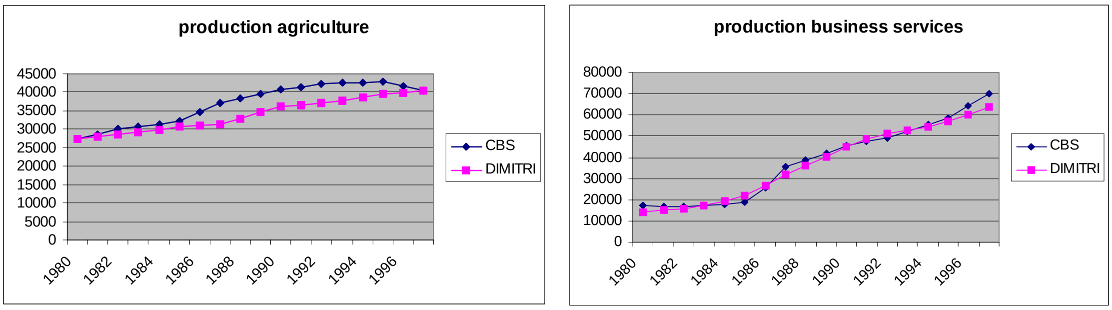
Since the value-added per unit of production also depends on the installed technology, the derivation of the coefficients of V(t) is similar to the derivation of coefficients of the technological matrix in formula 9.

**Validation of production 1980-1997**

On the basis of the theoretical model we built a first empirical version of DIMITRI for the Dutch economy consisting of 30 economic sectors. We already showed some results from the first runs with the model at the beginning of the paper. The empirical model requires large amounts of data, which are partly available at the Netherlands Bureau of Statistics (CBS). Main part of the data, e.g. concerning capacities, capacity utilization, and capital coefficients, had to be constructed. All economic data were expressed in 1980 prices by using sectoral price indices.

In order to validate DIMITRI, we applied the model to the Dutch economy for the period 1980-97. Several consistency checks on the outcomes were carried out and furthermore, in order to test the performance, we compared the outcomes with data published by the CBS. We simulated the period in question by starting at the base year 1980. All new investments were implemented on the basis of the technological matrix of 1997 (which depicts a mixture of technologies implemented in the periods before 1997). We present some of the outcomes of the validation procedure to start with figures concerning the physical part of the model for illustration. Figure 4 shows actual (CBS) and simulated values (DIMITRI) for production in the sectors agriculture and business services. The outcomes of the model for the period considered come close to the figures published by the CBS.

**Figure 4** *Production (in million Dutch guilders) for the sectors agriculture and business services calculated with DIMITRI and obtained from statistics (CBS) for the period 1980-97.*

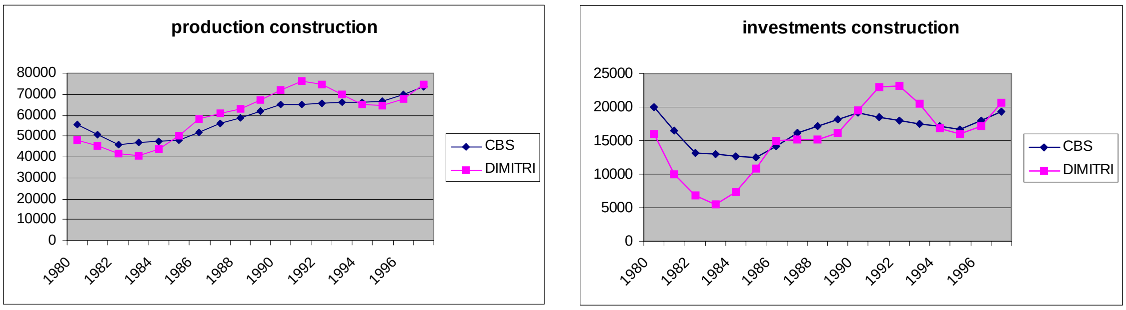



A useful statistic in order to evaluate the simulated values in relation to the actual values is Theil's inequality coefficient, which measures the fit on a scale between 0 and 1 (Pindyck and Rubinfeld, 1981; Theil, 1961). If the coefficient is 0, there is a perfect fit (actual and simulated values are equal for all periods); in case the coefficient is 1, the predictive performance of the model is as bad as possible. The model values for production show a coefficient below 0.05 for all sectors, which is quite reasonable.

Critical sectors in dynamic input-output analysis are the sectors manufacturing capital goods, like buildings, machinery and transport equipment. Since main part of the final demand of these sectors is endogenous, they may indicate the performance of the model. In the Dutch case, the construction sector is more critical in model terms than other sectors manufacturing capital goods, since the manufacturing of machines and means of transport occurs for the greater part in foreign countries, which part of production is exogenous to the model. Figure 5 shows production and investments for construction for the period considered. The production of construction calculated with

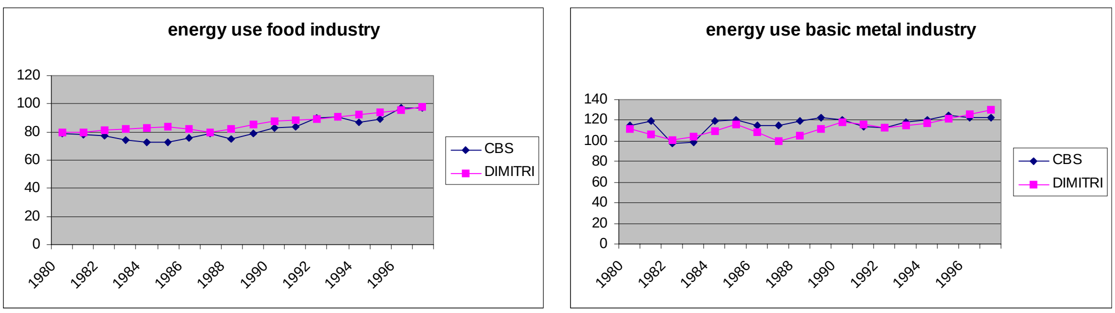
DIMITRI is near to the production published by the CBS (Theil's coefficient is 0.05). The development in investment goods produced by construction shows more differences (Theil's coefficient is 0.09). The means calculated for both data sets differ only slightly, but in the case of the data calculated with DIMITRI the peaks are more extreme.

**Figure 5** *Total production and production for investments (in million Dutch guilders) in the construction sector calculated with DIMITRI and obtained from statistics for the period 1980-97.*




One of the aims of DIMITRI is the calculation of energy use and emissions in individual economic sectors. Figure 6 shows energy use for the sectors food industry and basic metal industry calculated with the model (DIMITRI) and published by the CBS. For most sectors, the differences between actual and simulated values for energy use are small (Theil's coefficient below 0.06). Only construction (0.10) and the transport sector (0.11) show a higher Theil's coefficient.

**Figure 6** *Energy use(in petajoules) for the sectors food industry and basic metal industry calculated with DIMITRI and obtained from statistics for the period 1980-97.*



## Discussion

We presented an input-output model for the investigation of the impacts of technologies on environment and economy. We demonstrated some features of the model by analyzing technological change in the period 1980-97. DIMITRI enables analyses of technological change in the past, but, in fact, the model is intended for examinations of the effects of ongoing technological change as a result of improvements in technologies or the introduction of innovations for future years. In order to investigate the impacts of new technologies, these technologies have to be described in terms of the model. One of our intentions on the short-term is the preparation of a database with at least one new technology for each sector. The availability of a technology database enables investigations of both individual technologies and combined effects. A first step in this direction is taken in Blom (1999) in which coefficients are derived for underground transport with pipelines.

The presented simulation and validation of DIMITRI, which was based on the actual 1997 technological matrix, is rather straightforward and was aimed at testing the dynamical part of the model. In case the model is used for investigating the effects of new technologies, the determination of future technological coefficients is important. Constructing a technological matrix for 1997 on the basis of the 1980 situation and knowledge of the implementation of new technologies in the period 1980-97 could validate the determination of such future coefficients. However, the identification of new technologies installed in individual sectors was far from evident for the period considered.

In the present version of the model, the newly installed technology is fixed, that means that the model has no choice for technologies. However, the technology database of the model can be extended, so that it contains more than one technology per sector, e.g. an old and a new technology. In such a case, the model has to choose technologies from the database to realize investments. These choices can be based on cost minimization per sector by using sectoral prices calculated with a micro-economic price model as described in Idenburg (1998). Furthermore, the price model enables studies on the extent to which levies on energy and material use stimulate the penetration of new technologies.

The technology of a sector as depicted in the column of an input-output table describes all activities of the sector. In case a sector is rather heterogeneous with lots of sideline activities, the coefficients for the core activity should be identified and the implementation of the new technology should only concern this core activity. By enlarging the number of sectors in the model, the sectors in general will become more homogeneous. However, an increase in the number of sectors is accompanied with an increase in the data requirements. Especially, the time consuming derivation of coefficients for new technologies imposes limitations on the number of sectors. So, as usual in input-output modeling, in choosing the number of sectors, a balance has to be found between the desired level of detail of the model outcomes and the required amount of data, which all have their own uncertainties.

One of the main applications of the model in the short-term will be the linking with a model in which future consumption patterns are developed. Such a linking enables the determination of the energy and material requirements of future household consumption. In this approach, the combined impacts of changes in household consumption and changing production structures on energy and material use can be studied. Wilting et al. (1999) carried out such research in a pseudo-dynamic way, but DIMITRI enables a more dynamical investigation of the relationships mentioned. For this purpose, DIMITRI has to be extended with modules concerning production in foreign countries, since the consumption of households in the Netherlands is not restricted to the Dutch production system.

## Conclusions

The model DIMITRI presented in this paper is the first version of a tool for studying the impacts of new technologies on energy and material use. At the moment, the model is still in the stage of development, but the first experiences with DIMITRI are encouraging. The outcomes of the model for the period 1980-97 come close to the figures published by the Netherlands Bureau of Statistics.

The empirical model based on the theoretical description in this paper will be the basis for our further research. Although at the detail level several modifications to DIMITRI are possible, as discussed in the text, they will not drastically change the character of the model. Further development and application of the model will give more insights in the usefulness of DIMITRI for our purposes.

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