Technological Choices and the Eco-efficiency of the Economy:

a dynamic input-output approach

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Annemarth M. Idenburg
National Institute of Public Health and the Environment
P.O.Box 1
3720 BA Bilthoven
The Netherlands
phone: +31-30-2742626
fax: +31-30-2744417
e-mail: Annemarth.Idenburg@rivm.nl

Abstract

The Dutch government has taken on the challenge of pursuing an economic growth of 3%, while at the same time decreasing environmental degradation. Although emissions of most pollutants in the Netherlands have been reduced in recent years they are expected to increase again after the year 2000. This applies particularly to CO_2. By stimulating the development and application of new technologies, the government expects to increase the eco-efficiency of economic production. Although this confidence in technological innovations is appealing to policy makers, the environmental implications of new technologies are, on second thought, not that obvious. For this reason we have started the development of a model to investigate the environmental implications of new technologies. Furthermore, with this model we should also be able to investigate the effects of policy intervention on the penetration of new technologies. The model will be a dynamic input-output model, with the description of new technologies based on technical data. The choice for a certain technology will be made on the basis of costs related to its application. Total material and energy uses will be used as indicators for environmental degradation. Environmental policy will be defined in terms of (increased) prices of labor, material and energy.

1. Introduction to the study

Increasing economic production while decreasing environmental stress is a key issue for the present Dutch government, as presented in the memorandum on Environment and the Economy and the ICES (Interdepartemental Committee on Economic Structural policy) mission letter. Although Dutch environmental policy has been successful in reducing emissions for many substances in recent years, it will be difficult to continue this success. As shown in Figure 1, SO_2 and NO_x emissions decreased in the Netherlands during the 1985-1995 period, while GDP and CO_2 emissions increased. Figure 2 shows the use of energy in the Netherlands during the 1980-1996 period; here the difference between an increase in energy use by the rate of development of GDP (reference line) and actual energy use is explained. The reduction in energy use per unit GDP is due to an increase in efficiency (insulation of houses, increased performance of power stations). At the same time changes in life-style, a shift from shipping to road transportation and increased quality of products led to a demand for more energy per unit GDP. Overall, the gain in energy efficiency has not been enough to reduce the effects of growing production. Recent surveys by the National

Institute of Public Health and the Environment show the present environmental policy to be insufficient if the recent success is to be continued (see Figures 3 and 4).

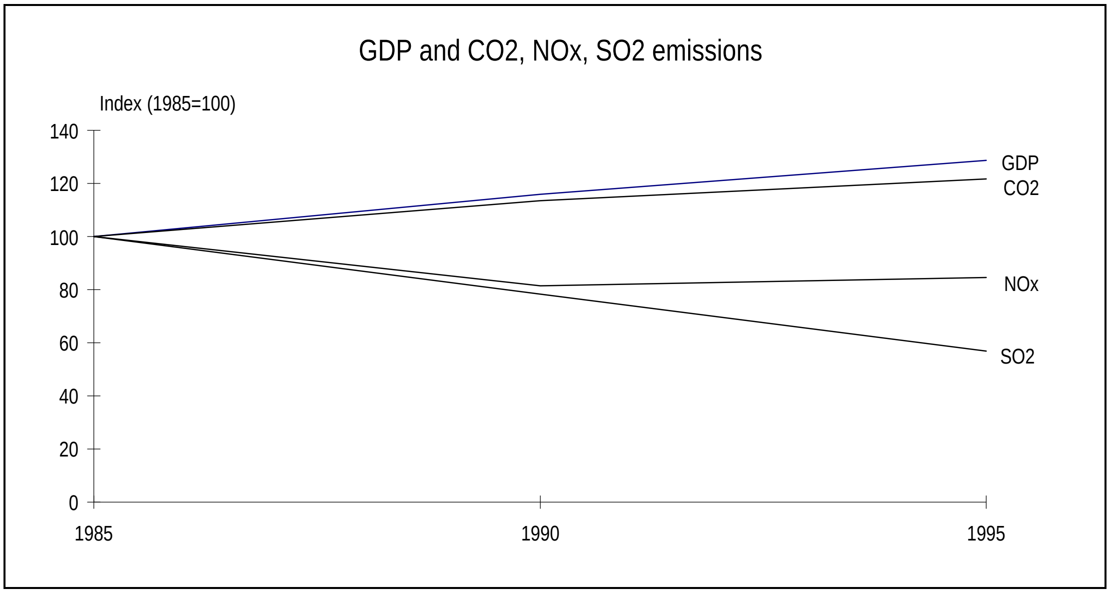

Figure 1 GDP, CO_2, NO_x and SO_2 emissions in the Netherlands, 1985-1995 (National Institute of Public Health and the Environment - RIVM, 1997a).

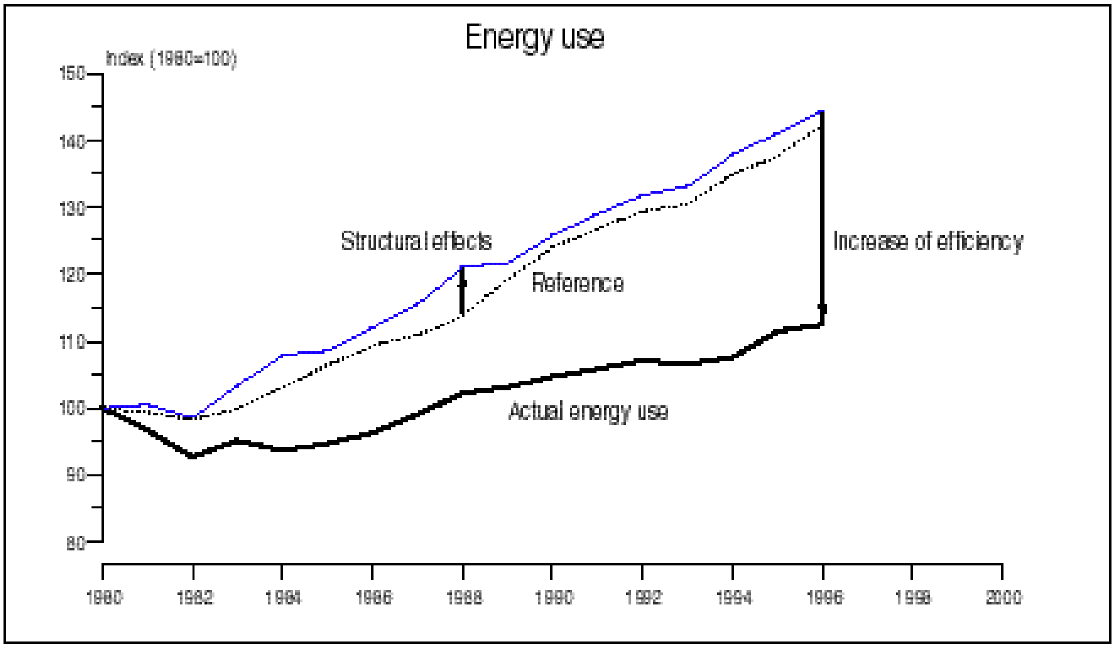

Figure 2 GDP and primary energy use in the Netherlands, 1980-1996; (National Institute of Public Health and the Environment - RIVM, 1997a).

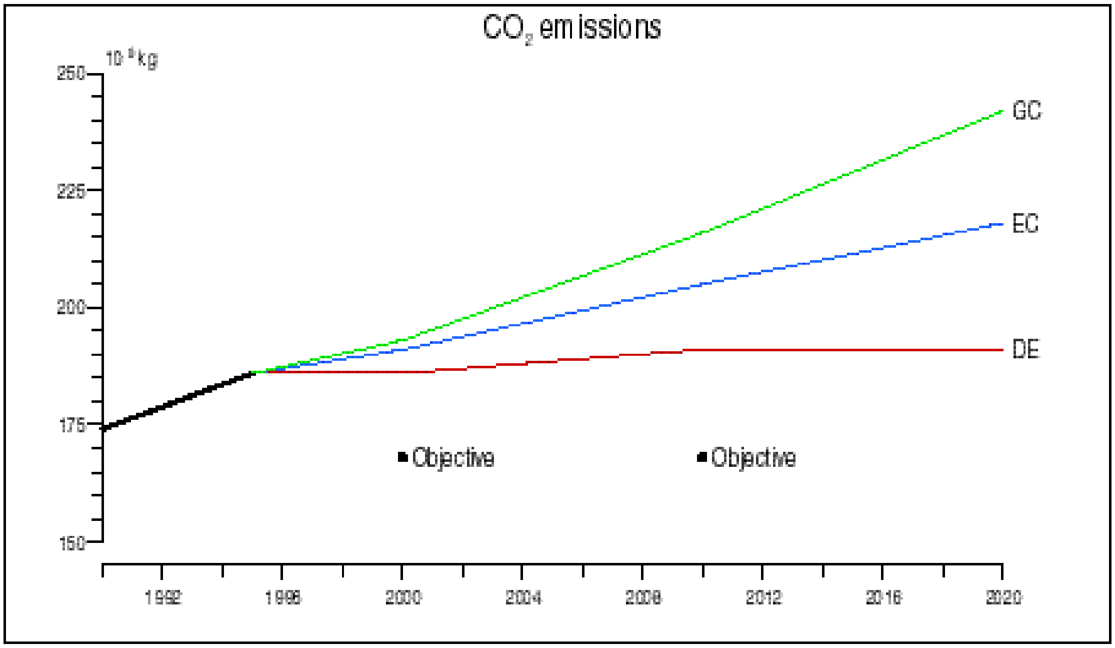

Figure 3 Survey of CO_2 emissions according to three economic scenarios related to policy goals, 1990-2020; GC-Global Competition, EC-European Coordinated, DE-Divided Europe (National Institute of Public Health and the Environment - RIVM, 1997b).

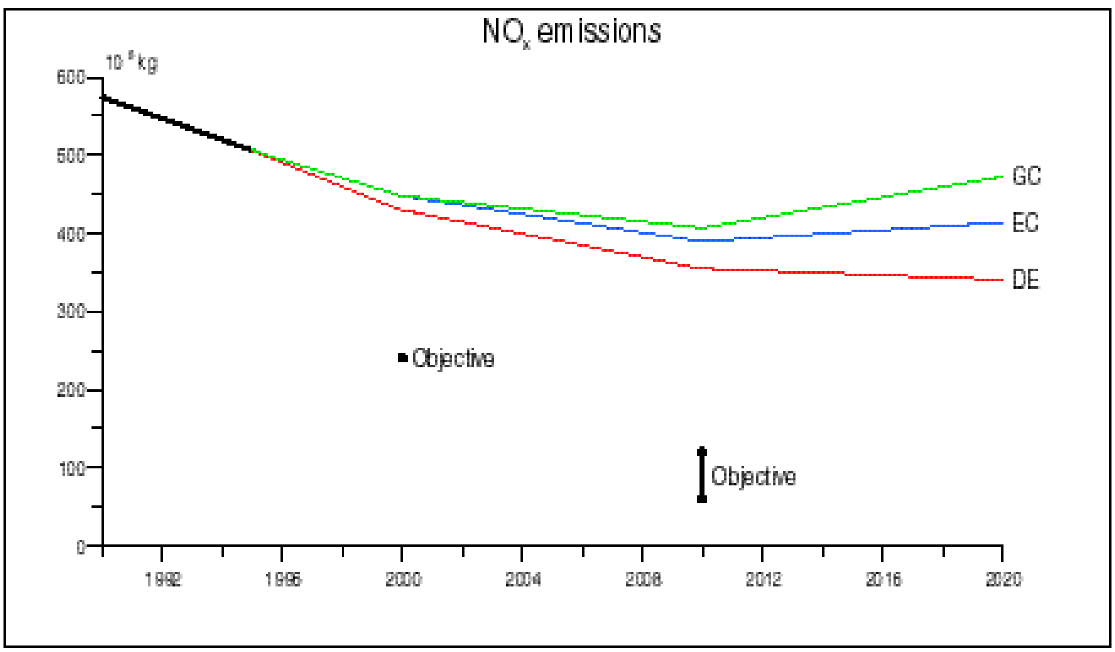

Figure 4 Survey of NO_x emissions according to three economic scenarios related to policy goals, 1990-2020; GC-Global Competition, EC-Coordinated, DE- Divided Europe (National Institute of Public Health and the Environment - RIVM, 1997b).

So how does the government expect to reach its ambitious goals? Perhaps this can be done by stimulating technologies which increase the eco-efficiency of production. The relationship between environmental stress and economic production can be expressed in a very simple equation originating from Barry Commoner[1]:

$$ES = P \times W \times M$$

in which:
ES is Environmental Stress,
P is Population;
W is Welfare per person and
M is Metabolism or environmental stress per unit of welfare.

According to this equation the three options for reducing environmental stress are population, welfare per person and metabolism/environmental stress per unit welfare. However, reducing the size of the population, and welfare per person are no real options for the Dutch government. Without explicitly addressing these issues, the government is striving for a 3% annual growth in economic production (= PxW), which will mean a production increase in the year 2020 of almost twice the volume of the year 1998. Consequently, metabolism will have to be reduced by a factor of 2 to keep environmental stress at its present level. A reduction by a factor of 4 will be required to halve environmental stress. There are roughly two ways to decrease the metabolism of economic production: first, by technological improvements and, secondly, by increasing the service component of production. The Dutch government wants to pursue both by starting up projects for the development and application of promising technologies, increasing energy prices and reducing the direct costs of labor. Will these projects be sufficient to close the gap between ambitions and actual problems in areas where emissions are expected, as shown in Figures 3 and 4? To get a better idea about the potential of pricing policies and new technologies we started with the development of a dynamic input-output model for the Netherlands. Although still in the definition phase of this development, we can present our initial ideas on the formal model through this paper. In places, the model is still a simplification of what it could be but, hopefully, important relations have been included. Since the model has not yet been empirically tested, comments and suggestions for improvements are therefore more than welcome by the author.

2. Introduction to the theoretical model

The objective of the model is to study:

1. the effects of changing technologies on material and energy use by production and
2. the consequences of changing energy, material and labor prices for the penetration of new technologies.

Technologies to reduce the environmental stress in production can be grouped into four categories (Kemp, 1995):
1. Pollution control or add-on technologies;
2. Off-side re-cycling and treatment of waste;

[1] Dutch readers are referred to Weterings and Opschoor (1992) for further reading on this equation.

3. Process-integrated changes in production technology, input material changes and good housekeeping;
4. Product changes.

The implementation of add-on technologies, re-cycling, waste treatment and good housekeeping have formed a major contribution Dutch environmental stress reduction. However, the RIVM outlook of 1997, has shown the expected future effects of these types of technologies to be limited (National Institute of Public Health and the Environment-RIVM, 1997b). Since technological changes that are expected to be succesful often require major adjustments of products and production processes (material inputs and process design; see, for instance, the report by the Interdepartmental Research Programme Sustainable Technological Development, 1997), we are interested in these types of technology for our model. The implementation of these technologies will often result in changes in process operation (changes in inputs of material, energy etc.) and different process equipment (machinery). Our model should be able to study both. At the same time it will only have to focusing on major changes in technologies. Reductions of material and energy inputs resulting from good housekeeping measures are not included. For reasons of simplification, we will treat product changes as process-integrated changes, assuming here that environmentally sound products can compete with the traditional products issued by the same sector.

Because of the major adjustments required for the implementation of process-integrated technologies, industry is reluctant to use them. Kemp, in his examination of the technological effects of environmental policy instruments (emission standards, pollution and energy taxes, tradeable emission quota and subsidies) in several case studies for the Netherlands, concludes that no single instrument is optimal (Kemp, 1995). Knowing that the costs of implementation is just one criterion, we will use it in our model only to study the penetration of new technology. Governments influence these costs by taxation and subsidies. In our model taxation and subsidies on materials, energy and labour will affect the costs and subsequent the implementation of technologies .

There is no one indicator for environmental stress; usually emissions of a few pollutants are used. For the time being, we will use material and energy use as indicators for environmental stress, for two reasons. First, since emissions of many major pollutants are directly linked to (fossil) energy and material use, it will not be difficult to add emissions if materials and energy use are already included. Second, since discussions on technological options for sustainable development focus increasingly on energy and material use (see, for instance, Von Weizsäcker et al., 1997), we will not talk about kilotons (material use) versus milligrams (emissions of pollutants) here, but for the time being, will assume that material and energy use are sound indicators of environmental stress.

To be sure that technologies included in the model are realistic potentials for production, their descriptions should be based on technical data. In many economic studies future technologies are generated by the model as a reaction to price changes. Even if the resultant technologies are technically achievable, this fact is often not addressed in these studies. There are also many studies, often limited to one product or production chain, in which technologies are analyzed for their environmental consequences in great technical detail. Although these studies provide interesting tools for the analysis of environmental strategies (Moll, 1993, Van der Voet, 1996), their major drawback is the lack of overall economic effects of technological change (Van Gerwen et al., 1995).

Input-output models have both the advantages of being an economic model (the inclusion of overall economic consequences of technological changes) and of including technical studies (a realistic description of technology). This was shown, for example, in the World Model study carried out by Duchin and Lange (1994). The World Model is a static input-output model designed by Leontief et al. (1977) and re-implemented by Duchin and Lange (1994). The latter study investigates the potential of technological measures to fulfill economic objectives in terms of GDP per capita and environmental objectives in terms of the reduction of CO_2, NO_x and SO_2 emissions. Technological changes in such a static input-output model are included by adjusting input-coefficients (Idenburg, 1993; Duchin and Lange, 1994). Although this type of model can be used successfully to study the possibilities of new technologies to reduce environmental stress, there is an important reason why it is less attractive for our study: i.e. the assumption on the penetration of new technology has to be made by the researcher who adjusts the input coefficients, which means that the model cannot be used for studying the penetration of new technologies, our second objective. Therefore the model we propose is based on the dynamic Input-Output approach.

A physical dynamic Input-Output model with assured positive output was described by Duchin and Szyld (1985). The dynamic price model belonging to it was added by Duchin (1988) and used together with the physical model in several empirical studies (Leontief and Duchin, 1986; Duchin and Lange, 1992; 1993). The model presented in this paper is based on the model described in the last two publications and adjusted to meet the specific demands of our study. This will be clarified in the description of the theoretical model.

As previously mentioned, the model had not yet been implemented at the time of writing this paper, making it impossible to add empirical outcomes of the model.

3. Theoretical model

The structure of the model is shown in Figure 5. For reasons of simplicity, the investment decisions and capital requirements related to these decisions were made just one period before implementation.

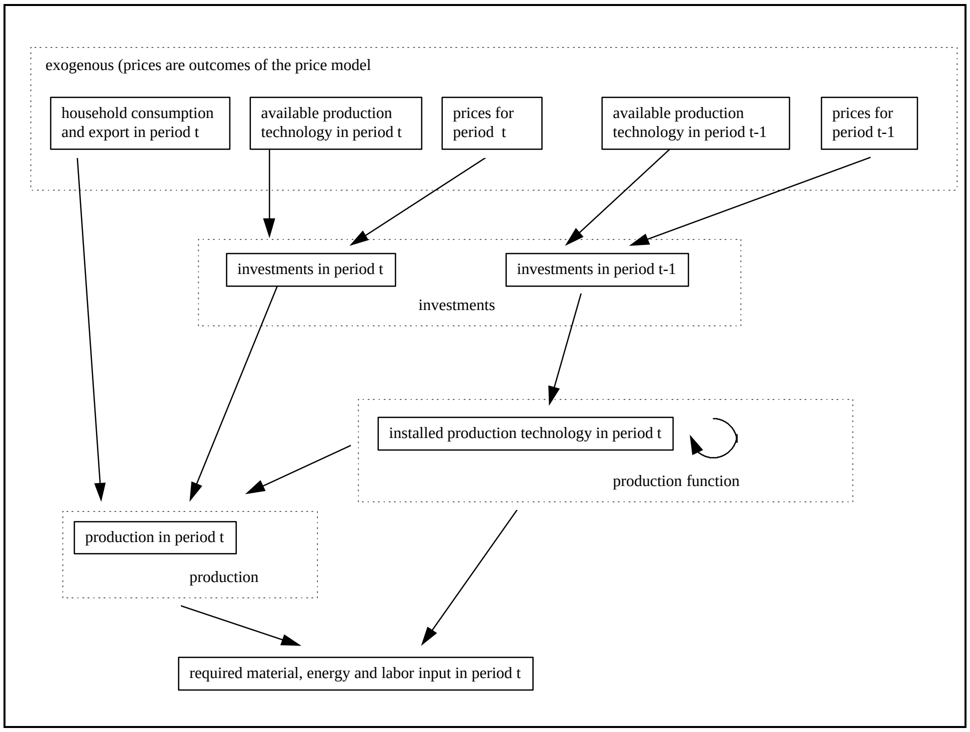

Figure 5: Schematic representation of the physical model.

3.1 physical production

$$x(t) = A(t)x(t) + y(t) + B^{N(t+1)}(t)In(t+1) \qquad (1)$$

where:

$x(t)$	production in period t;
$A(t)$	matrix with technical coefficients for period t;
$y(t)$	final demand (consumption and export) in period t;
$B^{N(t+1)}(t)$	matrix with capital requirements per unit of production produced in period 't' to be used for the first time in period t+1;
In(t+1)	investment required for the production in period t+1;

The N at $B^{N(t+1)}(t)$ stands for a 'new' or 'pure' technology. The technical coefficients for intermediary inputs related to this technology are $A^N(t+1)$ (This new technology will be installed in period t+1.) Without N, A(t) stands for the technical coefficients of the mixture of technologies installed in period 't'. This will be further clarified in section 3.4.

Equation (1) can be rewritten as follows:

$$x(t) = \left[I - A(t)\right]^{-1}\left[y(t) + B^{N(t+1)}(t)In(t+1)\right] \qquad (1a)$$

Different from the physical production function taken from Duchin and Lange (1992), this equations lacks a matrix R of requirements for replacing existing capacity. Decisions for extending capacity are, in our opinion, often made at the same time as the decision for the replacement. In both cases, a firm would want to install new technology if this seemed an improvement over the old technology. In addition, we are of the opinion that derivation of old technologies depends on how old the technology is, rather than on how much production there is. Therefore we choose to treat the replacement of dated capacity in the same way as the extension of capacity. This explains also why matrix B is multiplied by the vector containing investment figures instead of the extension of capital.

Not all parts of an installed technology will last as long as the overall technology (up to the moment a business has to decide about the replacement of outdated capacity). Some units and machinery will have to be replaced beforehand, with replacements possibly related to the intensity of use. At the moment we expect that this type of replacement will be able to be implemented into matrix A with intermediary requirements.

3.2 value added

To be able to account for energy, material and labor use by production, these items should be distinguished as separate value-added categories. However, to keep the equations used in this paper from becomming too long, we will limit the value-added categories to two: labor and value-added different from labor. However, note that this last category can be easily split into energy, materials etc. Limitation will be made according to the availability of data, not by the complexity of the model.

$$\begin{aligned} L(t) &= l(t)x(t) \\ V(t) &= v(t)x(t) \end{aligned} \tag{2}$$

with:

$L(t)$	required labor in period t;
$l(t)$	required labor per unit of production in period t;
V(t)	required value-added (different from labor) in period t;
v(t)	required value-added (different from labor) per unit of production in period t.

3.3 the choice of technology

In period t it is defined how much will be invested for the period t+1 (see section 3.5) and in what technology. Capital requirements for this technology are also produced in period t. A subsequent version of the model might distinguish between the capital requirements which have to be made in 1, 2 or even more periods before it can be installed (see Duchin and Lange, 1992).

The choice for a certain technology is based on a minimum cost principle. The model will contain a database of available technologies per sector per period. In period t, the model will select per sector the technology with the lowest present value from this database (3a). A different but easier way to select the same technology is to add the annuity of the required investment to the yearly operational costs (3b).

$$\underset{q\in\Re(i,t)}{\text{MIN}}\left[\sum_j\sum_h^{dep_i}\frac{A_{ji}^{Nq}*p_j(t)}{(1+d_i)^h}+\sum_j\sum_h^{dep_i}\frac{l_{ji}^{N_q}*p_j^L(t)}{(1+d_i)^h}+\sum_j\sum_h^{dep_i}\frac{v_{ji}^{N_q}*p_j^v(t)}{(1+d_i)^h}+\sum_j B_{ji}^{N_q}*p_j(t)\right]\quad(3a)$$

or

$$\underset{q\in\Re(i,t)}{\text{MIN}}\left[\sum_j A_{ji}^{Nq}*p_j(t)+\sum_j l_{ji}^{Nq}*p_j^L(t)+\sum_j v_{ji}^{N_q}*p_j^v(t)+\sum_j\frac{d_i}{1-(1+d_i)^{-dep_i}}*B_{ji}^{Nq}*p_j(t)\right]$$

(3b)

with:

$\Re(i,t)$	database with available technologies for sector i in period t;
$A_{ji}^{N_{qr}}, l_{ji}^{Nq}, v_{ji}^{N_q}, B_{ji}^{N_q}$	technical coefficients belonging to the optional technology N_q for sector i;
$p_j(t), p_j^L(t), p_j^V(t)$	prices in period t for products of sector j, labor and other value-added categories;
δ_i	sector-specific disconto rate;

Because future prices are unknown, prices in the present period are used as an estimate for future prices. Sectoral prices are taken into account by the model. Prices for value-added categories are external and can therefore be subject to price policies (see section 3.6).

This model compares available technology only with other available technologies. Some of these might already have been implemented in an earlier period. At the moment, the model will not review the costs of installed technologies in relation to the costs of available technologies. A subsequent version might include this as well. It will then be possible to decide to remove a certain technology before its time if new technology is cheaper (see also section 3.4).

Note too that a sector invests in just one technology in a certain period.

3.4 installed technology

The technology in use is not ‘pure’ technology but an avarage of all ‘pure’ technologies implemented earlier. The matrices A(t), l(t) and v(t) are therefore constructed from different types of technologies. In this first model, we assume technologies are not taken from the production process before they are completely depreciated. This can be adjusted for the next version in two ways. First, one can include a probability term to remove (part of) a technology before the standard depreciated period due to, for example, bankruptcy, neglect of maintenance or just bad luck. Second, technologies can be removed earlier if the costs for new technology are less than if current technology is kept in use. However, for the time being, the technical coefficients of matrix A(t) are derived as follows, the derivation of the coefficients of l(t) and v(t) being similar:

$$A_{ji}(t)=\sum_{\tau=0}^{dep_i-1} A_{ji}^{N}(t-\tau)S_i^{t-\tau}(t) \Rightarrow$$
$$A_{ji}(t)=\left[A_{ji}(t-1)-A_{ji}^{N}(t-dep_i)S_i^{t-dep_i}(t-1)\right]\frac{c_i(t-1)}{c_i(t)}+A_{ji}^{N}(t)\frac{In_i(t)}{c_i(t)} \qquad (4)$$

in which $S_i^{t-\tau}(t)$ is the share in period t of the technology of sector i implemented in period t-τ. This share is calculated as follows[2]:

$$S_i^{t-\tau}(t)=0,\ \text{if } \tau \geq dep_{i;},$$
$$S_i^{t-\tau}(t)=\frac{S_i^{t-\tau}(t-1)c_i(t-1)}{c_i(t)}\ ,\ \text{if } 0<\tau<dep_i, \qquad (5)$$
$$S_i^{t-\tau}(t)=\frac{In_i(t)}{c_i(t)}\ ,\ \text{if } \tau=0.$$

Note that $\sum_{\tau=0}^{dep_i-1} S_i^{t-\tau}(t)=1;$

(The sigma sign in equation 4 sums up to ($\tau=dep_i-1$) because the share of technology for $\tau=dep_i$ equals zero.)

The capacity in period t is determined as:

$$c_i(t)=\left[1-S_i^{t-dep_i}(t-1)\right]c_i(t-1)+In_i(t) \qquad (6)$$

with:

$c_i(t)$	the capacity of sector i in period t;
$A_{ji}^{N}(t-\tau)$	technical coefficients belonging to the technology of sector i installed in period t-τ;
dep_i	sector-specific depreciation period;
$S_i^{t-dep_i}(t-1)$	the share in period t-1 of the technology that will be depreciated in period t

Notice that we have used a sector-specific depreciation period. One might consider a depreciation rate that is not sector-specific but kind of capital-specific. However, this would make the model much more complicated. But even more important is that we regard technology as a fixed set of capital and intermediary inputs which can be used for the production in a sector. If one of these inputs per unit of output is changed, we regard this as alternative technology. The implementation of a new technology then requires the adjustment of the input coefficients of a sector. As long as a unit of capital has to be replaced by a similar unit, we do not consider this to be a change of technology but maintenance of the old technology. This has to be included in matrix A (see the remark on replacement requirements under 3.1).

[2] The value of a technology may decrease by its depreciation rate, a factor having no effect on physical production in this model. The (relative) share of a certain technology only decreases if the capacity increases until the technology is removed.

3.5 investments

How much will be invested? What will the volume of $In_i(t+1)$ be? This decision is based on the difference between the present capacity (minus the share of technology that will be depreciated in the next period) and the planned capacity in the next period. The planned capacity is accounted for as being usual in a dynamic input-output model (Duchin and Szyld, 1985), depending on the development of the production in the periods before taking the decision.

$$In_i(t+1) = \max\left\{0, c_i^*(t+1) - \left[1 - S_i^{t+1-dep_i}(t)\right]c_i(t)\right\} \tag{7}$$

$$c_i^*(t+1) = \min\left[1 + g_i, \frac{x_i(t-1) + x_i(t-2)}{x_i(t-2) + x_i(t-3)}\right]^2 x_i(t-1) \tag{8}$$

$$c_i(t+1) = \left[1 - S_i^{t+1-dep_i}(t)\right]c_i(t) + In_i(t+1) \tag{9}$$

with:

$c_i(t)$	capacity of sector i in period t;
$c_i^*(t+1)$	capacity of sector i planned for period t+1;
g_i	rate of maximum yearly growth of the capacity of sector i;

3.6 price model

The prices of a sector output have to equal the costs per unit of production, as is usual in input-output models. The costs for this model are compiled from the operational costs, the return of capital and a revaluation of the capital stock (see also Duchin, 1988 and Duchin and Lange, 1992). Sectoral prices are accounted for by the model. Prices on labor and other value-added categories are external. This provides us the opportunity to investigate the effects of policies which affect the prices of labor, energy and material on sectoral prices, and consequently on the penetration of new technologies.

For this model the price model can be written as follows (equation 10):

$$p_i(t) = \sum_j p_j(t)A_{ji}(t) + p^L(t)l_i(t) + p^V(t)v_i(t)$$

$$+ \sum_j \sum_{\tau=0}^{dep_i} \left\{\left[1 + r_i(t)\right]p_j(t-1-\tau)B_{ji}^{N(t-\tau)}(t-1-\tau)S_i^{t-\tau}(t)\right\} - p_j(t)B_{ji}^{N(t)}(t) \Rightarrow$$

$$p'(t) = p'(t)A(t) + p'^L(t)l(t) + p'^V(t)v(t) + \sum_{\tau}^{\max_i dep_i} p'(t-1-\tau)B^{N(t-\tau)}(t-1-\tau)\left[I + \hat{r}(t)\right]\hat{S}^{t-\tau}(t) \Rightarrow$$

$$p'(t) = \left\{p'^L(t)l(t) + p'^V(t)v(t) + \sum_{\tau}^{\max_i dep_i} p'(t-1-\tau)B^{N(t-\tau)}(t-1-\tau)\left[I + \hat{r}(t)\right]\hat{S}^{t-\tau}(t)\right\}\left[I - A(t)\right]^{-1}$$

with:

$p'(t)$	row vector with sectoral prices, which result from the model;
$p'^{L}(t), p'^{V}(t)$	prices for labor and other value-added categories, which are exogenous to the model;
$r_i(t)$	rate of return on capital for sector i in period t;
$\hat{r}(t)$	diagonal matrix with sector-specific rates of return of capital in period t;
$\hat{S}^{t-\tau}(t)$	diagonal matrix with the shares in period t of the technology installed in period t-τ ;

4. Conclusion

We expect the model presented in this paper to give us the opportunity to investigate the implications of new technologies on material and energy use by production. Moreover , it will be possible to study the effects of price policies on material and energy for the penetration of available technologies. Of course, the model could be improved in a number of ways. Here, we have already discussed the depreciation of technology, the replacement of technology before it is depreciated and the time between an investment decision and the moment of installation of a new technology. The model might also have some limitations at other points. The Dutch economy, for instance, is an extremely open economy. Therefore a fair number of sectors operate more on a West-European or international scale than a Dutch scale. These sectors might decide to leave the Netherlands if energy prices are much higher than elsewhere. This is not included in the model. Nevertheless, we are of the opinion that this model will serve as a feasible tool for our objectives, not withstanding our first concern at the moment, which is to get the model operational with empirical data.

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