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NEMO: Netherlands Energy demand MOdel
A top-down model based on bottom-up information

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Contents Page

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où les .. signes algébriques ne manquaient pas.
Jules Verne, Vingt mille lieues sous les mers

1 Introduction[*]

As the Dutch government is strongly concerned with energy saving and reducing greenhouse gas emissions, there is a need for a model linking energy use to energy prices and economic growth (Koopmans, 1997). This type of macro/meso model is often called ‘top-down’, as opposed to ‘bottom-up’ information, i.e. lists of technical possibilities for, and costs of, energy saving in each economic (sub)sector. Generally, assessments based on bottom-up information predict much more energy saving than top-down models based on time series. Consequently, bottom-up modellers often suggest that energy use will increase less rapidly than top-down modellers predict. This difference is related to the so-called ‘energy-efficiency gap’, an important issue in environmental economics. The presence of two widely differing predictions of energy use has a confusing effect on policy preparation.

The energy-efficiency gap has been the subject of much debate in the literature. This has provided a host of possible explanations for the existence of this gap. Many authors emphasize market failures and conclude that energy use is inefficiently large. Others point at non-market hurdles, which make seemingly inefficient outcomes efficient after all. For overviews, see Jaffe and Stavins (1994, 1994a), Scheraga (1994), Sanstad and Howarth (1994), Metcalf (1994), Huntington (1994), Hasset and Metcalf (1993), Howarth and Sanstad (1995). Velthuijsen (1995) and Gillissen et al. (1995) discuss the Dutch situation in particular. Although many of these publications provide useful empirical information, the size and composition of the energy-efficiency gap still remains to a large extent a 'black box' in quantitative terms. In this Research Memorandum we bridge the energy-efficiency gap by presenting a top-down energy demand model (NEMO) in which bottom-up information is used to estimate most parameters.

Existing models of production factor use tend to be of either the putty-putty or the putty-clay type. In putty-putty models, price changes can be absorbed immediately. In putty-

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clay models, in contrast, long-run price elasticities are much higher than the corresponding short-run elasticities. The full impact of a price change occurs only after capital stock has been completely renewed.

In NEMO, we assume a ‘putty-semiputty’ (Fuss, 1977) production structure; factors are substitutable both ex-ante and ex-post, but ex-post substitution possibilities are smaller than ex-ante possibilities. In a putty-semiputty model, part of the response to price changes is instantaneous (ex-post substitution in existing capital stock), and part of it is gradual (ex-ante substitution for new vintages). Long-run price elasticities exceed short-run elasticities, but the difference can be either small or large, depending on ex-post adjustment possibilities.

The empirical literature suggests that energy price changes induce asymmetric impacts on energy use. In particular, rising prices appear to generate larger effects than falling prices (Mork, 1989). These asymmetric responses are often ascribed to the impact of high prices on the development of new technology (Gately, 1993) or on the scrapping of obsolete capital (Tatom, 1988). Gradual penetration of new, more efficient technology can also explain these asymmetric effects. This gradual penetration reinforces the effect induced by higher energy prices, while it reduces the effect of lower energy prices. In aggregate empirical data, the effects of technology penetration and prices get mixed up. We are able to separate these effects by using disaggregated bottom-up data.

In chapter 2 we derive the model equations. Chapter 3 describes how we computed most model parameters using bottom-up information. In chapter 4 we perform some price and policy simulations, to show how NEMO works. Chapter 5 concludes.

2 The model

Section 1 of this chapter describes the production structure of energy demand. Section 2 derives the ex ante energy efficiency of new vintages; in section 3 we look at ex post changes of energy efficiency. The subject of section 4 is policy evaluation. Section 5 concludes.

2.1 Production structure

We start with a KLEM-type[1] production function for each vintage of capital, in which two energy inputs are combined with capital, labour and materials:

$$Y = F(I, L, F, E, M) \tag{2.1}$$

where: Y = Output of new vintage of capital
I = Investments
L = Labour
F = Fuel use
E = Electricity use
M = Materials (or other physical input) use

Total investments and total labour are split up into inputs that mainly affect fuel use (I_f, L_f), inputs that mainly affect electricity use (I_e, L_e) and inputs that do not affect energy use at all (I_0, L_0)[2]:

$$I = I_f + I_e + I_0 \tag{2.2a}$$

$$L = L_f + L_e + L_0 \tag{2.2b}$$

The production function is assumed to be separable in 'fuel-investment-labour-combinations' Z_f, 'electricity-investment-labour-combinations' Z_e and other inputs. We

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[1] KLEM= capital (K), Labour, Energy and Materials. We note that this production structure can also be assumed for households.

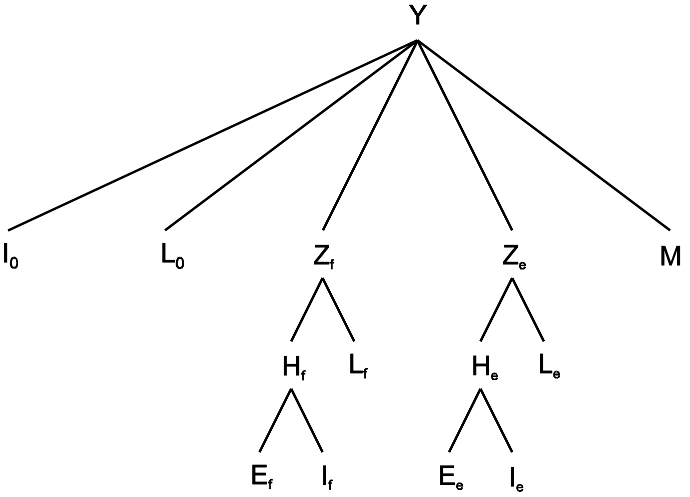
[2] Our data include only a few options that save both fuel and electricity.

abstract from direct substitution between fuel and electricity[3]; however, substitution between Z_f and Z_e is possible. The energy inputs in Z_f and Z_e are called E_f (fuel) and E_e (electricity), respectively. Energy combines with investments to H_f and H_e; these combine with labour to Z_f and Z_e:

$$Y = G\ (\ I_0\ ,\ L_0\ ,\ Z_f(\ H_f(E_f,I_f),L_f)\ ,\ Z_e(H_e(E_e,I_e),L_e)\ ,\ M\ ) \qquad (2.3)$$

where $H_f(.)$, $H_e(.)$, $Z_f(.)$ and $Z_e(.)$ are homogenous of the first degree in both arguments. The production structure is shown in figure 2.1.

Figure 2.1 Production function structure



The energy-investment-labour-combinations Z_f and Z_e are assumed to be proportional to (and therefore complements of) other inputs (M, L_0) or to output (Y), depending on the characteristics of the economic sector[4] involved. The volumes of materials, labour and production are computed in other CPB models (STREAM, Athena). Our model is designed to be used together with these other models. We analyse only substitution within Z_f and Z_e.

[3] Bottom-up information supports this assumption; there are no options in which saving fuel implies considerable increases in electricity use or vice versa, without investments in capital (De Beer et.al., 1995).

[4] For instance in industrial sectors, Z_f is assumed to be proportional to materials use M. The use of 'electricity services' Z_e in households is linked to (but grows faster than) the volume of consumption (Brink, 1997).

Rebound-effect

An interesting effect occurs if the (relative) price of energy-saving investments (I_f or I_e) falls. This would obviously result in substitution of investments for energy within H_f or H_e. However, also the relative price of H_f or H_e will fall. This will lead to more use of H_f or H_e, and thus less use of energy-saving labor (also the price of Z_f or Z_e will fall, causing more use of Z_f or Z_e; this effect, however, is outside the scope of NEMO). Thus, the amount of energy saving due to a lower price of energy-saving investments will be smaller than could be expected if one looks only at energy-investments substitution. In fact, the phenomenon of smaller-than-expected energy saving from investments is often observed in empirical data; among physical scientists, it is known as the 'rebound-effect.' Of course, economists immediately recognize familiar substitution effects and income effects.

2.2 Ex ante efficiency

This section treats the ex ante energy efficiency of new vintages of capital. This efficiency is determined when a new vintage is installed. We assume that ex-ante substitution possibilities are described by CES functions (deleting obvious time indices):

$$H_f(I_f,E_f) = \left[A_{E_f}\, E_f^{\rho} + A_{I_f}\, I_f^{\rho}\right]^{1/\rho} \qquad A_{E_f},\, A_{I_f} > 0 \qquad \rho < 1 \qquad (2.4a)$$

$$Z_f(H_f,L_f) = \left[A_{H_f}\, H_f^{\nu} + A_{L_f}\, L_f^{\nu}\right]^{1/\nu} \qquad A_{H_f},\, A_{L_f} > 0 \qquad \nu < 1 \qquad (2.4b)$$

The production functions for electricity are analogous. From now on, we will present only the equations for fuel use.

Bottom-up information reflects improvements of energy-saving technology over time leading to substitution of capital for energy. We interpret these improvements as a decreasing price of energy-saving investments:

$$p_{I_f,\tau} = p_{I_f,t_0}\, e^{-\kappa_f(\tau - t_0)} \qquad (2.5)$$

where: τ = year in which the new vintage is installed
t_0 = base year

Cost minimisation

Cost minimisation with respect to E_f, I_f and L_f for a given level of Z_f yields the demand equations (again deleting obvious time indices):

$$E_f = H_f \, A_{E_f}^{-\frac{1}{\rho-1}} \, p_{E_f}^{\frac{1}{\rho-1}} \left[A_{E_f}^{-\frac{1}{\rho-1}} \, p_{E_f}^{\frac{\rho}{\rho-1}} + A_{I_f}^{-\frac{1}{\rho-1}} \, p_{I_f}^{\frac{\rho}{\rho-1}} \right]^{-\frac{1}{\rho}} \qquad (2.6a)$$

$$I_f = H_f \, A_{I_f}^{-\frac{1}{\rho-1}} \, p_{I_f}^{\frac{1}{\rho-1}} \left[A_{E_f}^{-\frac{1}{\rho-1}} \, p_{E_f}^{\frac{\rho}{\rho-1}} + A_{I_f}^{-\frac{1}{\rho-1}} \, p_{I_f}^{\frac{\rho}{\rho-1}} \right]^{-\frac{1}{\rho}} \qquad (2.6b)$$

$$H_f = Z_f \, A_{H_f}^{-\frac{1}{\nu-1}} \, p_{H_f}^{\frac{1}{\nu-1}} \left[A_{H_f}^{-\frac{1}{\nu-1}} \, p_{H_f}^{\frac{\nu}{\nu-1}} + A_{L_f}^{-\frac{1}{\nu-1}} \, p_{L_f}^{\frac{\nu}{\nu-1}} \right]^{-\frac{1}{\nu}} \qquad (2.6c)$$

$$L_f = Z_f \, A_{L_f}^{-\frac{1}{\nu-1}} \, p_{L_f}^{\frac{1}{\nu-1}} \left[A_{H_f}^{-\frac{1}{\nu-1}} \, p_{H_f}^{\frac{\nu}{\nu-1}} + A_{L_f}^{-\frac{1}{\nu-1}} \, p_{L_f}^{\frac{\nu}{\nu-1}} \right]^{-\frac{1}{\nu}} \qquad (2.6d)$$

where p_{E_f} = net present value of future energy prices

and $p_{H_f} \equiv s_{E_f} \, p_{E_f} + s_{I_f} \, p_{I_f}$ $\qquad s_{E_f} \equiv \dfrac{E_f p_{E_f}}{E_f p_{E_f} + I_f p_{I_f}}$ $\qquad s_{I_f} \equiv \dfrac{I_f p_{I_f}}{E_f p_{E_f} + I_f p_{I_f}}$

Using (2.6a) and (2.6c) we can write:

$$\begin{aligned} dlog\frac{E_f}{Z_f} &= \frac{1}{\rho-1}(1-a_{E_f})\, dlog\frac{p_{E_f}}{p_{I_f}} \\ &\quad + \frac{1}{\nu-1}(1-a_{H_f})\, s_{E_f}\, dlog\frac{p_{E_f}}{p_{L_f}} + \frac{1}{\nu-1}(1-a_{H_f})\, s_{I_f}\, dlog\frac{p_{I_f}}{p_{L_f}} \qquad (2.7) \end{aligned}$$

where

$$a_{E_f} = A_{E_f}^{-\frac{1}{\rho-1}} \left(\frac{p_{E_f}}{p_{I_f}} \right)^{\frac{\rho}{\rho-1}} \left[A_{E_f}^{-\frac{1}{\rho-1}} \left(\frac{p_{E_f}}{p_{I_f}} \right)^{\frac{\rho}{\rho-1}} + A_{I_f}^{-\frac{1}{\rho-1}} \right]^{-\frac{1}{\rho}-1}$$

$$a_{H_f} = A_{H_f}^{-\frac{1}{\nu-1}} \left(\frac{p_{H_f}}{p_{L_f}} \right)^{\frac{\nu}{\nu-1}} \left[A_{H_f}^{-\frac{1}{\nu-1}} \left(\frac{p_{H_f}}{p_{L_f}} \right)^{\frac{\nu}{\nu-1}} + A_{L_f}^{-\frac{1}{\nu-1}} \right]^{-\frac{1}{\nu}-1}$$

As we do not have information on H_f, I_f and L_f, we cannot compute the cost shares (s) and estimate the host of parameters in (2.7)[5]. Instead, we linearise (2.7)[6]:

$$dlog\frac{E_f}{Z_f} = -\beta_f\ dlog\frac{p_{E_f}}{p_{I_f}} - \xi_f\ dlog\frac{p_{E_f}}{p_{L_f}} - \eta_f\ dlog\frac{p_{I_f}}{p_{L_f}} \tag{2.8}$$

where β_f, ξ_f and η_f are constants. Substituting (2.5) we can now write:

$$\frac{E_{f,\tau}/Z_{f,\tau}}{E_{f,t_0}/Z_{f,t_0}} = e^{-\alpha_f(\tau-t_0)}\left(\frac{p_{E_f,\tau}}{p_{E_f,t_0}}\right)^{-\beta_f}\left(\frac{p_{E_f,\tau}}{p_{E_f,t_0}}\right)^{-\xi_f}\left(\frac{p_{L_f,\tau}}{p_{L_f,t_0}}\right)^{\zeta_f} \tag{2.9}$$

where: $\alpha_f = -\kappa_f\,(\beta_f - \eta_f)$, $\zeta_f = \xi_f + \eta_f$

The first factor on the right-hand side of (2.9) gives the effect of a decreasing price of fuel-saving investments over time. The second factor shows the energy price effect on substitution between E_f and I_f. Substitution between E_f and L_f (through H_f) is reflected in the third factor. Finally, the fourth factor contains the effect on E_f of substitution between I_f and L_f (through H_f). Time trend α_f and elasticity β_f can be estimated using bottom-up information, because bottom-up information concerns substitution possibilities between energy and investments. The elasticities ξ_f and ζ_f, which pertain to labour-energy substitution through 'good-housekeeping' (or 'bad-housekeeping'), are treated in the next section. For now, we define ex ante efficiency exclusive of labour-energy substitution:

$$F^{ea}_{f,\tau} \equiv \frac{E^{ea}_{f,\tau}/Z_{f,\tau}}{E_{f,t_0}/Z_{f,t_0}} = e^{-\alpha_f(\tau-t_0)}\left(\frac{p_{E_f,\tau}}{p_{E_f,t_0}}\right)^{-\beta_f} \tag{2.10}$$

where $F^{ea}_{f,\tau}$ = Ex-ante fuel efficiency of the vintage added in year τ ($F^{ea}_{f,t0}=1$), exclusive of good-housekeeping effects.

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[5] Our bottom-up information (see chapter 3) only provides the *additional* investments and labour costs associated with energy saving; the *levels* of energy-related investments and labour are unknown.

[6] We could have obtained (8) more directly by assuming Cobb-Douglas production functions. However, we consider the Cobb-Douglas as very restrictive, as it implies that the elasticity of substitution is 1. By starting with CES functions we stress that we believe in more flexible forms. Only data limitations force us to revert to Cobb-Douglas-compatible demand equations.

2.3 Ex post efficiency

The ex ante energy efficiency of new vintages as determined by (2.9) can be changed in two alternative ways during the lifetime of these vintages. First, additional capital aimed at energy saving (so-called ‘retrofit capital’) may be added. Second, additional labour (‘good housekeeping’) can be substituted for energy. For ex post substitution we replace (2.5) by

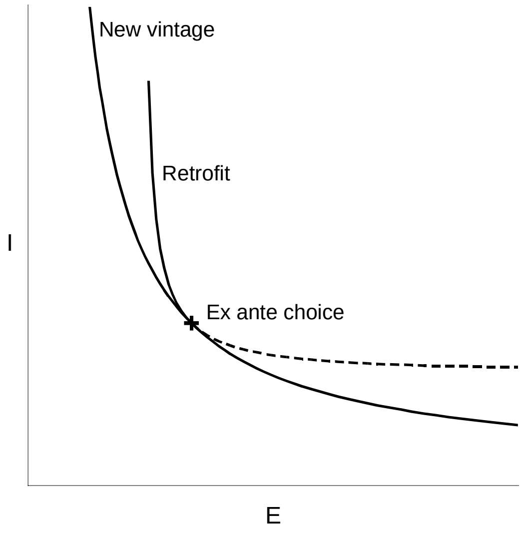
$$p_{I_f,t} = p_{I_f,\tau}\, e^{-\lambda_f (t-\tau)} \qquad (2.11)$$

and (2.4a) by

$$H_f(I_f,E_f) = \left[A^*_{E_f} E_f^{\omega} + A^*_{I_f} I_f^{\omega}\right]^{1/\omega} \qquad A^*_{E_f},\ A^*_{I_f} > 0 \qquad \omega < \rho \qquad (2.12)$$

and we assume that (2.4b) is still valid. In (2.11) we assume that ex-post substitution possibilities through investments (‘retrofit’) (reflected in ω) are smaller than ex-ante possibilities (reflected in ρ). Figure 2.2 shows this graphically. It also shows that decreasing the amount of investment (dotted line) is not possible. In fact, if a point on the (non-dotted) retrofit line has been chosen, going back to less retrofit investments is also impossible. We start by computing the ‘ideal’ amount of retrofit ignoring this restriction. Next, we will include the restriction when we treat the actual amount of retrofit investments.

Figure 2.2 CES isoquants for new vintages and for retrofit investments



The derivation of 'ideal' ex post energy demand is analogous to the derivation of ex ante energy demand in section 2.2 above. The log-linearised equation for fuel efficiency in year t of a vintage installed in year τ becomes, analogous to eq. (2.9):

$$\frac{E_{f,\tau,t}/Z_{f,\tau,t}}{E_{f,\tau}/Z_{f,\tau}} = e^{-\gamma_f(t-\tau)} \left(\frac{p_{E_f,t}}{p_{E_f,\tau}}\right)^{-\delta_f} \left(\frac{p_{E_f,t}}{p_{E_f,\tau}}\right)^{-\chi_f} \left(\frac{p_{L_f,t}}{p_{L_f,\tau}}\right)^{\mu_f} \tag{2.13}$$

where $\gamma_f = -\lambda_f\,(\,\delta_f - \chi_f\,)$

Elasticity δ_f and trend γ_f can again be derived from bottom-up information. We would expect γ_f to be smaller than α_f because ω is smaller than ρ. Again, we 'set apart for later' the good-housekeeping effect, and define:

$$F^{ir}_{f,\tau,t} \equiv \frac{E^{ir}_{f,\tau,t}/Z_{f,\tau,t}}{E_{f,t_0}/Z_{f,t_0}} = F^{ea}_{f,\tau}\; e^{-\gamma_f(t-\tau)} \left(\frac{p_{E_f,t}}{p_{E_f,\tau}}\right)^{-\delta_f} \tag{2.14}$$

where: $F^{ir}_{f,\tau,t}$ = Ideal ex post fuel efficiency in year t of the vintage installed in year τ, exclusive of good-housekeeping effects

In practice we observe the 'energy-efficiency gap': investments that seem profitable are often not implemented. In our model, the energy-efficiency gap is partly reflected in the presence of old vintages that are not adapted to new prices and new technologies. However, the energy-efficiency gap also applies to profitable retrofit investments, which could - in principle - be implemented immediately. To account for the retrofit energy-efficiency gap we assume a simple 'partial adjustment' process. The restriction that the amount of investment cannot be reduced is included:

$$\begin{aligned} F^{ar}_{f,\tau,t} \equiv \frac{E^{ar}_{f,\tau,t}/Z_{f,\tau,t}}{E_{f,t_0}/Z_{f,t_0}} &= F^{ea}_{f,\tau} && t=\tau \\ &= F^{ar}_{f,\tau,t-1} + \psi_f \left(\frac{I^{tot}_t}{K_t}\right)^{\epsilon_f} [F^{ir}_{f,\tau,t} - F^{ar}_{f,\tau,t-1}] && F^{ir}_{f,\tau,t} \le F^{ar}_{f,\tau,t-1} \\ &= F^{ar}_{f,\tau,t-1} && other \end{aligned} \tag{2.15}$$

where: $F^{ar}_{f,t,\tau}$ = Efficiency of fuel use in vintage τ in year t after actual retrofit
I^{tot}_t = Total investment volume in year t
K_t = Capital stock

The speed of adjustment to more efficiency (lower F) depends on the rate of replacement of capital stock I^{tot}_t/K_t, so that retrofit investment is influenced by the general propensity to invest. Adjustment to lower levels of efficiency (higher F) is not possible for individual vintages, but retrofit investment in capital stock is reduced by scrapping of retrofitted vintages (see ‘*Total capital stock*’ below).

Good housekeeping

The third and fourth factor of equations (2.9) and (2.13) show the effects of good housekeeping, which are determined by energy prices and labour costs. As we do not have enough (time series) information to estimate the good-housekeeping parameters ξ_f, ζ_f, χ_f and μ_f separately, we log-linearise the (ex ante ànd ex post) good-housekeeping effect:

$$\frac{E_{f,\tau,t}/Z_{f,\tau,t}}{E_{f,t_0}/Z_{f,t_0}} = \left(\frac{p_{E_f,t}/p_{L_f,t}}{p_{E_f,t_0}/p_{L_f,t_0}} \right)^{-\theta_f} \qquad \theta_f > 0 \tag{2.16}$$

Also, good housekeeping can in part ‘compensate’ for vintages which are ‘too efficient’ or ‘too inefficient’ after the ‘restricted partial adjustment’ described in (2.15). We account for this compensation effect by adding an extra ‘compensation factor’ and defining ex post efficiency as:

$$F^{ep}_{f,\tau,t} \equiv \frac{E^{ep}_{f,\tau,t}/Z_{f,\tau,t}}{E^{ea}_{f,t_0}/Z_{f,t_0}} = F^{ar}_{f,\tau,t} \left(\frac{p_{E_f,t}/p_{L_f,t}}{p_{E_f,t_0}/p_{L_f,t_0}} \right)^{-\theta_f} \left(\frac{F^{ar}_{f,\tau,t}}{F^{ea}_{f,\tau}} \right)^{-\lambda_f} \qquad \lambda_f > 0 \tag{2.17}$$

The ‘relative efficiency’ effect λ_f is linked to the so-called ‘rebound-effect’ observed in empirical data: the results of investments in terms of energy saving are smaller than could be expected on technical grounds. The relative efficiency effect implies, for instance, that very efficient vintages will be used in a less efficient way. Hence, the theoretical savings from investments will not be realized in practice, because they are partly offset. This offers a partial explanation for the ‘rebound-effect’[7].

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[7] Our model only describes substitution effects within Z. The effect of efficiency improvements on Z itself, which is exogenous to our model (it is derived from other CPB models), might also add to the explanation of the rebound effect.

Total capital stock

For simplicity, we assume that capital scrapping takes place over an age interval $[a_{min},a_{max}]$[8]. In this interval, cumulative scrapping is linear:

$$
\begin{aligned}
c_{t-\tau} &= 0 && t-\tau<a_{\min} \\
&= \frac{(t-\tau) - a_{\min}}{a_{\max} - a_{\min}} && a_{\min}\leq t-\tau\leq a_{\max} \qquad (2.18) \\
&= 1 && t-\tau>a_{\max}
\end{aligned}
$$

where: $c_{t-\tau}$ = Cumulative scrapping (perunage) after τ years

Relative efficiency of total capital stock becomes:

$$
F_{f,t} = \frac{\sum\limits_{\tau=t-a_{\max}}^{t} [1 - c_{t-\tau}] Z_{f,\tau}\, F^{ep}_{f,\tau,t}}{\sum\limits_{\tau=t-a_{\max}}^{t} [1 - c_{t-\tau}] Z_{f,\tau}} \qquad (2.19)
$$

As we do not have information about the volume of the fuel-capital-labour bundle $Z_{f,\tau}$ per vintage, we use I_{τ} (total investment volume) instead of Z in the weights of (2.18)[9].

Table 2.1 summarises the mechanisms through which energy efficiency is determined in NEMO by trends, elasticities and adjustment.

Table 2.1 Mechanisms and determinants in NEMO

	Effect of:					
Effect on	Vintage trend	Age trend	Price elasticity	Investment elasticity	Partial adjustment	Rebound elasticity
Initial efficiency	α		β			
Theoretical retrofit		γ	δ			
‘Real’ retrofit				ϵ	ψ	
Good housekeeping			θ			λ

---

[8] For transport and for fuel use in households, however, we use data from Netherlands Statistics (CBS) on scrapping of vehicles and houses, respectively. We assume that scrapping is independent of energy prices.

[9] For households, we use total consumption volumes per year.

2.4 Policy evaluation

An important goal of the model is to evaluate policies aimed at energy saving and/or reducing energy-related emissions. This section describes the way we include policy instruments in the model. For practical applications of the methods described here, see chapter 4.

The inclusion of *taxes and subsidies on energy use* is straightforward. The tax or subsidy rate is used to compute after tax prices; these are used in the model. The effects of taxes and subsidies *on energy-saving investments* can be assessed by using equivalent energy price changes (e.g. a 10% subsidy on energy-saving investments corresponds to a 10% energy price increase). Subsidies for the development or demonstration of *new technologies* could be included in the technological time trends α and γ. The trends could be increased in proportion to the additional profitable energy saving potential provided by the subsidy.

Efficiency standards often apply to new capital goods. The vintage approach allows us to impose such standards, starting in any given year. In these cases, the computed efficiency for new vintages is compared to the obligatory efficiency; if the latter implies more efficiency, that one is used. Usually, instruments aimed at specific (types of) capital goods will not ‘cover’ all the energy used in an economic sector. In these cases, the efficiency improvement implied for these capital goods will be multiplied by the share of the capital goods in sectoral energy use.

Persuasion instruments such as voluntary agreements or information campaigns are not easy to implement in an economic model. However, there are two ways to obtain indications of possible effects. The first approach considers persuasion instruments as ways to speed up the use of profitable energy-saving options, thereby reducing the energy-efficiency gap. An implicit assumption of this approach is that persuasion will induce firms to realize only profitable energy-saving options. As our model assumes that new vintages and good housekeeping are fully optimized, persuasion would then affect only retrofit investment, through an increase in the ‘partial adjustment’ parameter ψ. This approach would provide a ‘upper limit’ for the potential of persuasion.

The second, somewhat related approach is to compute the equivalent price changes needed to reach the goals connected to persuasion instruments. If these price changes are small, the increased (‘virtual’) prices can be maintained. If the price changes are large, the goals are not likely to be reached using relatively ‘soft’ instruments. In this case, using smaller price changes might provide a rough indication of more likely results. If this approach is used, the effects of persuasion are more evenly distributed over new vintages, retrofit investments and good-housekeeping. Of course it is also possible to mix the two methods.

2.5 Conclusion

We have presented a model that describes energy efficiency from a top-down (macro/meso time series) point of view. However, the use of bottom-up information in estimating the model and the concomitant design of the model allow us to describe energy efficiency more extensively and adequately than would have been possible by using only top-down information. This also offers more possibilities for policy evaluation.

3 Parameter estimation

3.1 Introduction

This chapter discusses how we used bottom-up information to estimate most of NEMO's parameters. The bottom-up information we used is called ICARUS (De Beer *et al.*, 1994). ICARUS contains a list of energy-saving techniques that can be implemented before 2015. It serves as an important basis for policy-making; accordingly, it is regularly updated. ICARUS describes the supply side of energy-saving techniques, while NEMO describes energy demand by a set of behavioural equations. Obviously, linking ICARUS to NEMO requires some assumptions regarding investment behaviour.

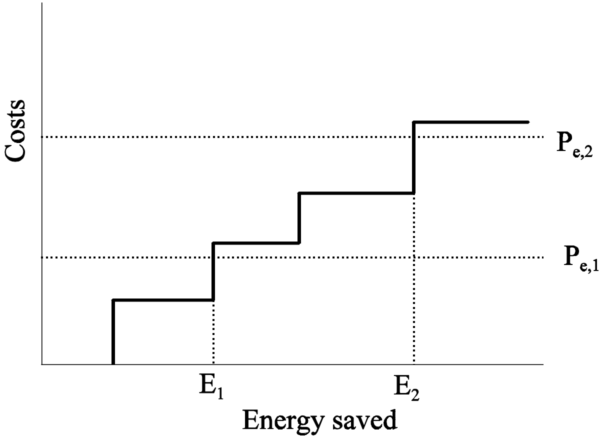
The structure of this chapter is as follows. In section 2 we compare the bottom-up and top-down approaches to energy efficiency analysis. Section 3 provides a description of the bottom-up database ICARUS. Then, section 4 addresses the parameter estimation methods, while section 5 discusses the results of estimation. Finally, section 6 concludes this chapter.

3.2 The bottom-up approach and the energy-efficiency gap

Bottom-up scientists investigate costs and performance of technologies. They have usually argued that significant unexploited opportunities exist for cost-effective investments in energy-efficiency. This seemingly sub-optimal behaviour of decision makers is often labelled the energy-efficiency gap. This section analyses the energy-efficiency gap, an issue that lies at the heart of the debate between bottom-up and top-down modellers of energy-efficiency.

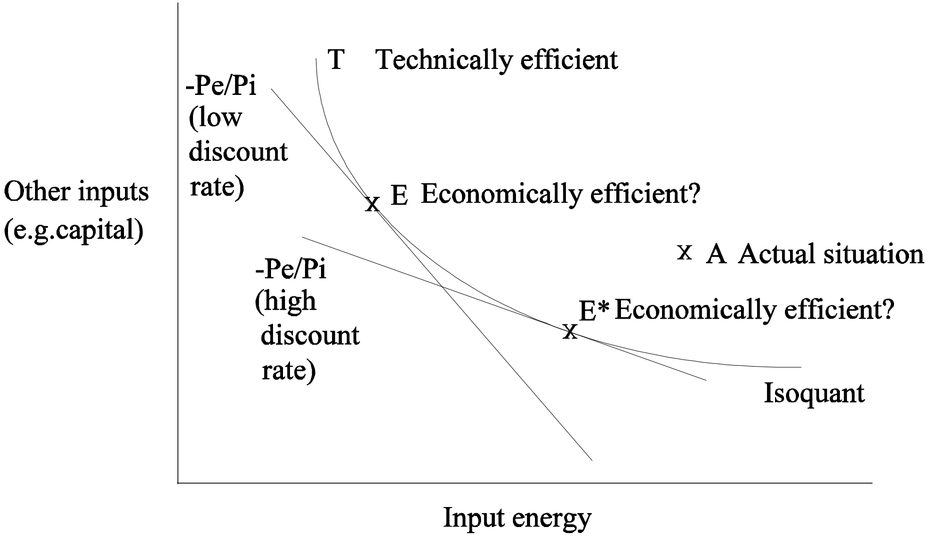
An analysis of bottom-up information usually involves drawing energy conservation supply curves (CSCs) on the basis of individual energy saving techniques (CSCs were introduced by Meier *et al.*, 1983). Figure 3.1 depicts an example of a CSC. Each step in the figure represents an energy saving technique, that improves the energy-efficiency without changing the level of output. Each technique saves an amount of energy per year against certain investment and maintenance costs. As costs and benefits are spread over more than one year, a discount rate is required to discount future costs and benefits. Bottom-up scientists often propose a real discount rate of 5 to 8%, based on market rates for loans. The figure shows a clear price sensitiveness of energy conservation and hence, of implied energy-efficiency: if the price goes up from $P_{e,1}$ to $P_{e,2}$, the amount of energy saved goes up from E_1 to E_2.

Figure 3.1 Energy conservation supply curve



We can link 'bottom-up' CSCs to 'top-down' production functions (Blumstein and Stoft, 1995; Huntington, 1994). A CSC depicts combinations of capital and energy use producing a standardised energy service. An isoquant derived from a production function essentially shows the same. In figure 3.2 the isoquant or best-practice frontier depicts combinations of energy and other inputs that provide the same energy service. Point T represents the technical optimum for energy saving, but achieving this requires a lot of the other inputs, mainly capital. Given the input prices (e.g. P_e and P_i for the price of energy resp. the price of other inputs), micro-economic theory can derive the cost-minimising combination of inputs (point E).

Figure 3.2 Isoquant representation



The position of point E depends on the ratio of the energy price to the price of other inputs. If the other input is capital, using more capital implies saving energy over a number of years in the future. In this situation, P_e is the mean discounted price of future energy use. For low discount rates, as often used by bottom-up modellers, P_e is high and point E is optimal. If a higher discount rate is used, P_e is lower and the optimal choice becomes point E*.

Bottom-up modellers argue that profitable opportunities to improve energy-efficiency are not implemented. In terms of figure 3.2, this would mean that the present situation is above the isoquant (point A). Top-down modellers, however, maintain that the present situation is optimal, because bottom-up modellers do not account for certain factors. In figure 3.2, this would mean that point A is the point of contact between another ('real') isoquant and/or another price line. The difference between 'ideal' behaviour according to bottom-up information (E or E*) and actual behaviour (A) is called the *energy-efficiency gap*.

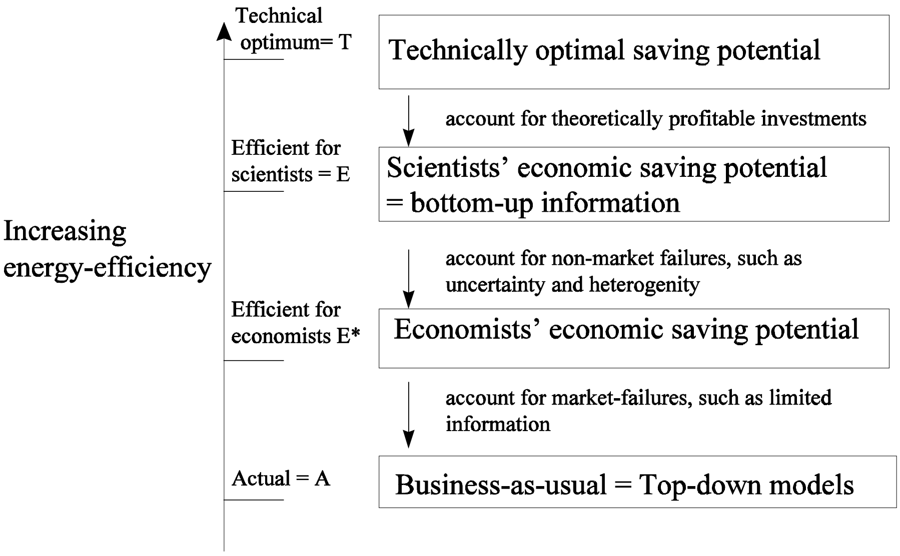
There is a rich literature on possible explanations for the energy-efficiency gap (see introduction). Here, we follow Jaffe and Stavins (1994, 1994a) who distinguish between *market failure* and *non-market failure* explanations of the energy-efficiency gap.

Market failures relate to limited information. Information about energy-efficiency is underprovided by ordinary market activity, due to the public goods nature of information. This may lead to a level of energy efficiency which falls short of the optimum. Also, if the potential adopter does not share in the energy costs, useful information in his hands remains unexploited. Such principal-agent problems may arise for instance if tenants, and not the landlord, pay the energy bill.

Non-market failure explanations reflect why observed behaviour is optimal, explaining why it is rational to use a high discount rate or to wait and see. The benefits of investments in energy-efficiency depend on uncertain, future energy prices. Metcalf (1994) argues that the ability *not* to invest in energy-efficiency until more information is available increases the net present value of the investment (option value). Another non-market failure explanation is that technologists' estimates of costs of techniques often fail to incorporate transaction costs. Another non-market failure explanation is that most bottom-up calculations are based on the average firm. In fact, a technique may be profitable for an average firm in the sector, but not for *all* firms facing heterogenous cost functions. Finally, imperfections in capital markets may impede investments. Some firms must pay substantial premia to obtains loans.

Figure 3.3 summarises the discussion by pointing out which hurdles need to be overcome when incorporating bottom-up information on energy saving techniques in top-down models (a move from E to A). Bottom-up analysts argue that a certain number of investments in energy-efficiency are technically possible (level T), a part of which is profitable (level E). However, adjusting for non-market failures (rational use of high discount rates), means that less investments in energy-efficiency are profitable (level E*). Finally, after accounting for market failures, e.g. limited information, less investments will be achieved than are economically efficient (point A).

Figure 3.3 Concepts of energy-efficiency



One final notion about the energy-efficiency gap is worth mentioning. Some argue that neither point A nor points E and E* could be socially efficient. Such a social optimum can be attained if energy prices fully internalise environmental damages of energy use and after abolishment of subsidies on energy use. However, in this Research Memorandum we abstract from the socially optimal level of energy-efficiency. We do not state which of the explanations of the energy-efficiency gap call for government intervention. Here, we are merely interested in the behavioural modelling of investing in energy-efficiency.

3.3 ICARUS

Description

This section describes the bottom-up information in ICARUS.[10] ICARUS contains engineering data on energy-saving techniques. These techniques are mentioned in the literature in 1990, but have not been implemented in that year. However, they have been through the process of development and can be implemented before 2015.

The engineering data provide costs per energy-saving technique. The costs include the initial investment and maintenance costs. Costs are given for the year 2000 or 2015 in 1990 guilders. A technique saves a given amount of energy, either fuel or electricity, per year during the entire lifetime. It may also entail the additional use of an alternative energy-carrier.[11] One can compute energy saving potentials per technique, and hence per sector, for the year 2000 or 2015, with reference year 1990.

The makers of ICARUS followed a bottom-up approach (De Beer *et al*., 1994, p. 5-6). First, they computed a break-down of sectoral energy consumption in 1990 into its end-use components (process heat, heating, cooling, lighting, etc.). Fuel use for feedstock has been incorporated. Next, they identified energy-saving techniques commercially available before 2000 and 2015. Finally, they determined the maximum share of these techniques in total energy services (for 2000 and 2015), thereby taking into account mutually exclusive techniques.

ICARUS does not impose constraints on penetration of techniques (given prices and a discount rate, profitable techniques will be installed) in the agriculture and industrial sectors. A different approach has been undertaken in the household, government and services sector, where the penetration of techniques (aimed at reducing fuel use) has been limited by assuming that new techniques are implemented at the end of the economic lifetime of existing equipment.

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[10] We use version 3 of ICARUS. Version 0 was published in 1988. It provided a basis for the formulation of the National Environmental Policy Plan (NEPP) in 1989. Version 1 was published in 1990. Version 2 was used for the evaluation of NEPP+ in 1990. Version 3 was published in 1994 (see De Beer *et al.*, 1994).

[11] For instance, replacement of electric boilers by gas boilers: this saves electricity but leads to a higher fuel use. ICARUS accounts for the extra costs of the other energy carrier.

The makers of ICARUS warn for the uncertainty surrounding the engineering data, for three reasons. First, all data are averages with possible variation. Second, costs do not include transaction costs of, e.g., decision making and information gathering. Third, it was difficult to compute which share of investment costs is aimed at energy saving only. Accordingly, the data should be used with a ±25% uncertainty margin.

Predicting energy use with ICARUS

Using ICARUS, scientists at the University of Utrecht have projected the energy use of 1990 on to 2000 and 2015 for given production growth per sector at ‘frozen efficiency’ (1990 energy-efficiency levels). Next, they calculated for an average firm in each sector which techniques are profitable in 2000 and 2015 at given energy prices and discount rates. This provides an estimate of energy use in 2000 and 2010 if all profitable techniques are implemented.

This bottom-up projection has two serious limitations. First, there is only one forecast of the future availability and costs of techniques, while economists would argue that these depend on market conditions. Second, ICARUS compares the actual situation in 1990 (point A in figures 3.2, 3.3), reflecting a partial implementation of cost-effective techniques, with a situation of full implementation of cost-effective techniques in 2015 (point E)[12]. Hence, predicting the location of point A for 2015 using only bottom-up information seems highly problematic in practice.

Estimating the energy-efficiency gap with ICARUS

By comparing ICARUS with actual practice, we can obtain a rough estimate of the magnitude of the energy-efficiency gap. Suppose that investors use a 15% discount rate in analysing energy-saving techniques and assume that real energy-prices have been at the 1990 level. Then, ICARUS shows that 9% energy-efficiency improvement (excluding good-housekeeping measures) would have been profitable in the Netherlands in 1995 compared to 1990. However, empirical analysis shows that only some 5% has been achieved in practice, implying an energy-efficiency gap of some 4%. Thus, either investors (implicitly) use discount rates higher than 15%, or ICARUS understates costs or overstates performance of techniques, or both.

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[12] An exception applies to the government, services and households sector, where ICARUS accounts for partial implementation in the end year.

Supplementing ICARUS

ICARUS does not exhibit all of NEMO’s features. The makers of ICARUS at the University of Utrecht (UU) have further specified the techniques in ICARUS to account for some of these features (Van Vuuren, 1996). First, UU has characterised each energy-saving technique by type of technique: replacement, retrofit or good-housekeeping. A replacement technique can be installed only if the existing capital stock is replaced. This in contrast to a retrofit technique, which is added to the existing capital stock. Good-housekeeping techniques reflect changes in energy management. Expert-judgement by UU was used in situations that were difficult to interpret.

The second extension is an alternative sector-classification. NEMO describes 19 sectors, while ICARUS exists of more than 19 sectors. Appendix A describes the linkage between NEMO sectors and ICARUS sectors.

The third extension concerns the time of implementation. At our request, UU has characterised in which of the following periods (or combination of periods) a technique becomes available: 1990-1995, 1995-2000, 2000-2008 or 2008-2015. UU (Van Vuuren, 1996) notes that the characterisation of techniques over the period 2000-2015 is sometimes difficult (see also section 3.3).

From the research by UU it also becomes clear that a change in the discount rate does not affect the costs of techniques considerably. The bulk of the costs consists of the initial investment, while operational and maintenance costs are relatively small. The initial investment is not discounted. Hence, the discount rate does not play an important role at the cost-side of techniques.

NEMO: high discount rate, gradual penetration

NEMO partly reflects the energy-efficiency gap by assuming that firms and households require a high rate of return. Based on an investigation by Velthuijsen (1995) about firms’ behaviour of investing in energy-saving techniques, NEMO assumes that firms use a 15% discount rate for the evaluation of the costs and benefits of energy-saving techniques. We use the same assumption for private households. Section 3.5 includes a sensitivity analysis of the discount rate.

Even at this rather high discount rate, ICARUS contains large profitable energy saving potentials. NEMO accounts for an ‘additional’ energy-efficiency gap, assuming that profitable energy-saving techniques do not penetrate immediately into existing vintages, for two reasons. First, techniques which can be applied in new vintages (replacement) are often not applicable or more expensive in existing vintages (retrofit). Second, NEMO claims that existing vintages adjust slowly to available and profitable retrofit techniques[13].

Heterogeneity within sectors

ICARUS predicts no profitable techniques for some sectors over the period 1990-2015 with constant energy prices. NEMO, on the other hand, claims that there will always be *some* firms investing in energy-saving techniques. The rationale behind this is the firms' heterogeneity (different cost-structures) in reality, whilst ICARUS provides data for the average firm in each sector. Consequently, we assume a minimum trend and elasticity in NEMO (see Appendix D for the minimum values we used).

Time horizon

ICARUS has been updated in 1994. We think it provides a good estimate for the technical energy saving potential until 2000. However, we doubt that engineers have perfect foresight over the entire period until 2015. The adapted version of ICARUS shows that 393 techniques are commercially available before 2008 and 406 techniques before 2015. We think that the availability of 13 new techniques over the period 2008-2015 is too low a number. The idea that ICARUS underestimates the energy saving potential for 2015 is supported by the makers of ICARUS themselves (De Beer *et al*., 1994, p.14) and by Gillissen *et al*. (1995, p.13). We assume that the ICARUS energy saving potential for 2015 applies to 2010. We may note that this is an optimistic assumption.

While ICARUS considers retrofit investments in the 1990 capital stock only, NEMO also incorporates retrofit investments in vintages installed after 1990. Consequently, ICARUS predicts a decreasing retrofit energy saving potential over time. In estimating retrofit parameters for NEMO, we use the retrofit potential for 2000, as the potential for 2015 would produce too low an estimate (Van Vuuren, 1996, p.10).

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[13] The underlying assumption is that firms pay more attention to new vintages than to existing vintages. As a consequence, firms have imperfect information with respect to investments in existing vintages.

Retrofit and replacement

ICARUS can predict a retrofit potential which is higher than the replacement potential. We consider this hard to defend, as retrofit techniques can in principle also be installed as replacement techniques. Therefore, we restrict the retrofit potential to be lower than the replacement potential. Similarly, since the replacement potential may not include all possible techniques (retrofit techniques) it serves as a lower bound. The upper bound of the replacement potential is the sum of the retrofit and replacement potentials (see Van Vuuren, 1996, p.9).

Corrections to ICARUS

We changed some figures in ICARUS because of new information, consistency or trends observed in time series. For details, we refer to Appendix B.

3.4 Parameter estimation methods

This section describes the methods we employed to estimate parameters for NEMO. Given the assumptions about investment behaviour in the previous section, ICARUS can provide estimates for trends and elasticities, notably α, β, γ, δ and θ[14]. In chapter 4, we determine the other parameters. This section discusses the methods of estimation; the next section presents the estimation results.

Replacement investments

Replacement investment parameters are among the crucial parameters in NEMO, as they affect long-term energy intensity substantially. Section 3.3 argued that it is useful to compute a lower and upper bound with regard to trends and (energy-price) elasticities of replacement investments. The lower bound includes replacement investments, whilst the upper bound includes replacement *and* retrofit investments. Below, we discuss lower bounds, unless otherwise stated. Upper bounds are derived in a similar way.

ICARUS can be used to compute the energy efficiency improvement *trend* caused by penetration of replacement investments in the period 1990-2015, at constant 1990 energy prices (see Table A.2 in Appendix A for energy prices). The profitable energy

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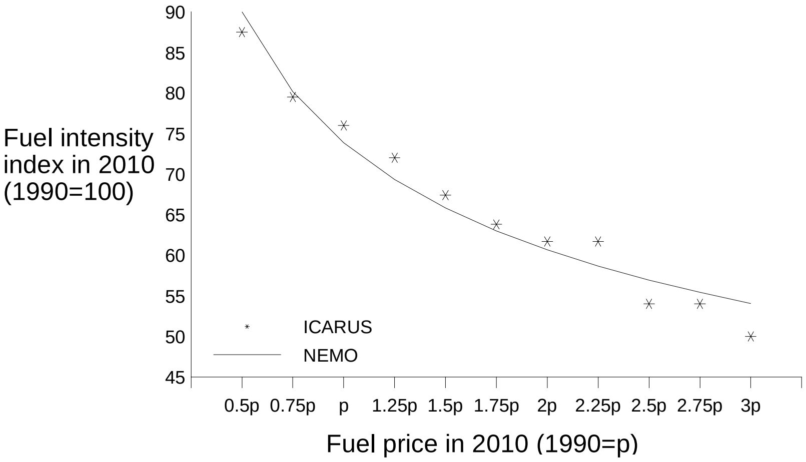
[14] Parameters are computed for both electricity and fuel demand.

saving potential follows from the sum of the saving potentials of profitable techniques. A technique is profitable if, given a discount rate of 15%, the net present value of the costs is smaller than the net present value of savings on energy.

We want to set the replacement trend in NEMO at a value that will reproduce the efficiency improvement in ICARUS. This, however, requires two adaptations. First, the ICARUS energy intensity index in 2015 should be interpreted as a value for 2010 (see section 3.3). The second adaptation is more drastic. For most types of energy use, ICARUS compares a situation of *full implementation* of techniques in 2015 to a situation of partial implementation in 1990[15]. By contrast, NEMO compares situations of partial implementation in 1990 *and* 2010. It assumes that not all vintages are replaced in the period 1990-2010. Consequently, NEMO is compatible with ICARUS if it assumes for 2010 *full* penetration of vintages characterized by a 2010 energy intensity index.

ICARUS can be used to compute *price elasticities* by comparing the energy efficiency improvement caused by replacement investments in the period 1990-2010 at various constant real energy prices. Obviously, it is possible to determine a price-sensitivity of the energy intensity index. Figure 3.4 provides an illustrative example for prices in the range (½*p_{1990}, 3*p_{1990}) where p_{1990} is the fuel price in 1990.

Figure 3.4 Fuel intensity as a function of energy prices in 2010; households



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[15] For fuel use in the services, government and households sectors, ICARUS does take account of partial implementation in 2015. Therefore, NEMO is directly comparable with ICARUS for fuel in these sectors.

NEMO assumes a constant price elasticity over the interval (½*p_{1990}, 3*p_{1990}). Eleven steps, each with magnitude ¼*p_{1990}, yield 11 constructed observations. It is easy to fit a constant price-elasticity curve through the ICARUS asterisks:

$$F_{2010} = \alpha * p^{\beta} + \epsilon \tag{3.1}$$

where F_{2015} denotes the fuel intensity index in 2010, p is the fuel price index in 2010 (p in 1990 = 100), α is a constant and ϵ is the disturbance term. An estimator for β provides an ICARUS based constant price elasticity. The estimation results in Appendix C point at a good fit.

The energy intensity index in the above formula is not corrected for the difference between partial penetration and full penetration in 2010. Whether there is full implementation or not, this will not change the estimated price elasticity considerably.

An alternative method is required to determine the lower bound of parameters in sectors in which the retrofit energy saving potential is higher than the replacement potential. By definition, the replacement potential must be higher than, or equal to, the retrofit potential as explained in section 3.3. If ICARUS does not reflect this feature (at 1990 energy prices), we assume that the replacement potential is half of the total potential of retrofit and replacement (the other half of the total potential is the retrofit potential). As a matter of consistency, this assumption applies to the calculation of both the trends and the elasticities.

Retrofit investments

In principle, estimates of retrofit *trends* need to be based not only on ICARUS data, but also on information about the adjustment parameters ψ and ϵ. Compared to replacement techniques, retrofit techniques in ICARUS account for partial implementation more adequately. Thus, we do not adjust the retrofit potential in 2000 for partial implementation, although we are aware that we might slightly overestimate the retrofit potential. NEMO determines the retrofit trend by equating ICARUS and NEMO energy intensities in 2000 at 1990 energy prices:

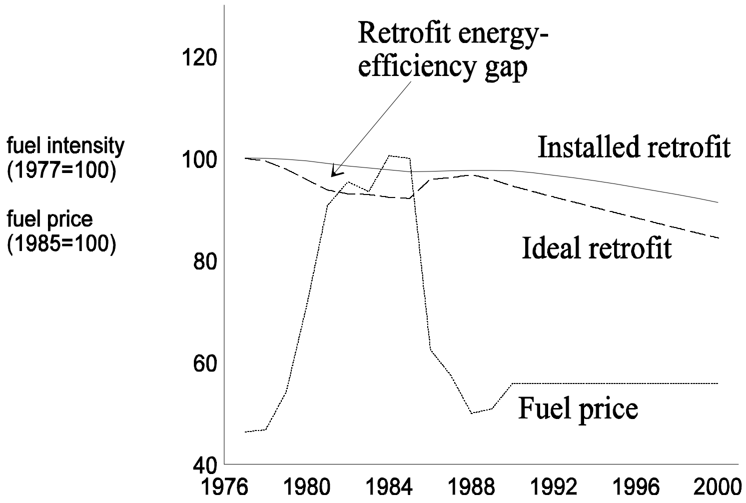
$$\gamma = 1 - (F_{ir,2000})^{1/10} \tag{3.2}$$

where γ denotes the retrofit trend and $F_{ir,2000}$ stands for the ICARUS energy intensity index in 2000 after the installation of profitable (15% interest rate, 1990 energy prices) retrofit techniques in the period 1990-2000.

Retrofit energy-efficiency gap: an example

Figure 3.5 illustrates how NEMO models a persistent retrofit energy-efficiency gap of total capital stock. It shows the predicted fuel intensity index of the vintages installed between 1977 and 1990 in the building materials industry. The fuel price index reflects historical data until 1990. After 1990 we assume constant prices, to show what happens to the energy-efficiency gap in the long run.

Figure 3.5 Illustration of the energy-efficiency gap; building materials sector



We see that the price increase between 1978 and 1980 leads to an immediate fall of the 'ideal' retrofit index. Installed retrofit adapts slowly. The difference between ideal and installed is the retrofit energy-efficiency gap. The price fall in 1986 leads to an immediate rise of the ideal retrofit index. Installed retrofit stabilises near the ideal level. As (assumed) energy prices become stable after 1990, only the time trend remains in ideal retrofit. Installed retrofit again adapts slowly, and a persistent energy-efficiency gap remains.

Retrofit *elasticities* are computed in a similar way as the replacement elasticities described before.

Section 3.3 motivates that the retrofit potential should be bounded by the replacement potential. We assume that retrofit parameters are not larger than 0.7 times the replacement parameters[16].

Good-housekeeping

The costs of good-housekeeping techniques are difficult to determine. What are the costs (in terms of money or utility) of avoiding stand-by of a TV in terms of additional efforts to walk to the TV? Or the costs of switching off lights whenever possible? ICARUS includes for the period 1990-2015 some 20 good-housekeeping techniques, all having negligible or low costs. However, we think that ICARUS neglects the true costs of these techniques. We assume that neglected costs are exactly that high, that good-housekeeping techniques are just not profitable in 1990. Energy efficiency improvements can be achieved only after price increases.

ICARUS does not provide good-housekeeping techniques for each sector. We assume that in all sectors some energy efficiency improvement can be achieved and insert a minimum value for good-housekeeping price elasticity θ.

3.5 Results

Table 3.1 provides our estimates of parameters for NEMO. The table distinguishes 19 sectors, 2 classes of energy-carriers, 3 types of investments (replacement, retrofit and good-housekeeping) and 2 kinds of parameters (trend and elasticities). The estimation results show that the bottom-up database ICARUS can indeed be ‘summarized’ into ‘top-down’ parameters.

The trends in Table 3.1 imply long-run (=replacement) energy-saving rates of 0.2 to 2% per year. NEMO’s replacement price elasticities are 0.1 to 0.5; this accords well with

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[16] In the original version of NEMO this factor was 0.9 (Te Velde, 1997). Later, historical simulations showed that this first version of NEMO predicted energy-‘dis-savings’ in case of sharply falling energy prices. There are no such dis-savings in historical data. The cause of the prediction of dis-savings was that vintages of capital goods being scrapped were (too) heavily retrofitted in the years before. Using 0.7 instead of 0.9 as the maximum retrofit/replacement parameter ratio yielded much better results.

the literature. For many sectors fuel elasticities are higher than electricity elasticities. In most cases, replacement elasticities are greater in sectors where space heating is important than in industrial processes. The main reason is that basic industries use a lot of ‘feedstocks’; as these become part of the product, it is harder to save on feedstock use than on energy use for heat production. Also, it could be that energy-intensive industries have already paid much attention to energy saving, because energy is an important part of their total costs. The estimates in table 3.1 are discussed in more detail in Appendix D.

Table 3.1 Trends and elasticities in NEMO[a]

	TRENDS				ELASTICITIES					
	FUEL		ELECTRICITY		FUEL			ELECTRICITY		
	Repl.	Retrofit	Repl.	Retrofit	Repl.	Retrofit	Good-h.	Repl.	Retrofit	Good-h.
	$-\alpha_f$	$-\gamma_f$	$-\alpha_e$	$-\gamma_e$	$-\beta_f$	$-\delta_f$	$-\theta_f$	$-\beta_e$	$-\delta_e$	$-\theta_e$
	% per year				% change of energy use per % change of energy price					
Horticulture	−1.50	−0.47	−2.00	−0.10	−0.23	−0.05	−0.02	−0.10	−0.05	−0.03
Other agriculture	−1.11	−0.10	−1.55	−0.63	−0.27	−0.12	−0.02	−0.29	−0.05	−0.03
Food etc.	−0.48	−0.34	−1.42	−0.99	−0.41	−0.17	−0.02	−0.10	−0.07	−0.07
Textile etc.	−0.20	−0.10	−1.26	−0.30	−0.23	−0.16	−0.10	−0.10	−0.05	−0.03
Paper etc.	−1.12	−0.31	−1.86	−1.30	−0.56	−0.07	−0.02	−0.10	−0.06	−0.03
Organic chemicals	−0.48	−0.34	−1.62	−1.13	−0.10	−0.05	−0.01	−0.10	−0.05	−0.03
Inorganic chemicals	−0.20	−0.10	−0.57	−0.40	−0.10	−0.07	−0.01	−0.10	−0.05	−0.01
Fertilizers	−0.24	−0.17	−1.60	−0.79	−0.10	−0.05	−0.01	−0.10	−0.06	−0.03
Other chemicals	−0.41	−0.29	−1.13	−0.79	−0.16	−0.11	−0.01	−0.19	−0.05	−0.03
Iron and Steel	−0.67	−0.25	−0.26	−0.15	−0.19	−0.05	−0.01	−0.10	−0.05	−0.03
Non-ferrous	−0.36	−0.25	−0.71	−0.10	−0.10	−0.05	−0.01	−0.10	−0.05	−0.01
Metal products	−0.49	−0.34	−0.66	−0.46	−0.18	−0.13	−0.04	−0.10	−0.07	−0.03
Building materials	−1.17	−0.82	−1.08	−0.76	−0.41	−0.20	−0.02	−0.10	−0.07	−0.03
Other industry	−0.53	−0.37	−0.80	−0.56	−0.17	−0.11	−0.02	−0.10	−0.05	−0.03
Construction	−0.20	−0.10	−1.06	−0.74	−0.16	−0.05	−0.02	−0.10	−0.07	−0.03
Services	−0.91	−0.25	−1.34	−0.94	−0.23	−0.12	−0.02	−0.22	−0.11	−0.07
Government	−0.57	−0.40	−1.21	−0.85	−0.24	−0.13	−0.02	−0.34	−0.14	−0.05
Transport	−0.75	0	−2.10	−0.10	−0.40	0	−0.05	−0.10	−0.05	−0.03
Households	−0.90	−0.63	−2.26	−0.63	−0.28	−0.15	−0.15	−0.31	−0.05	−0.04

[a] For background and details see Appendix D.

In table 3.2 we compare NEMO’s long-term elasticities to (implicit) elasticities from Ceneca, NEMO’s predecessor (table V.2 in CPB, 1992; see also CPB, 1984). NEMO’s long term elasticities are the sum of replacement elasticities and good housekeeping elasticities[17]. We may conclude from the table that, apart from the sectors services and government, the elasticities are rather similar between the models.

Table 3.2 Comparison of NEMO’s elasticities to Ceneca

	FUEL				ELECTRICITY			
	NEMO			Ceneca[a]	NEMO			Ceneca[a]
	Repl.	Gd.-h.	Total	Total	Repl.	Gd.-h.	Total	Total
Horticulture	−0.23	−0.02	−0.25	−0.26[b]	−0.10	−0.03	−0.13	0[b]
Other agriculture	−0.27	−0.02	−0.29	−0.26[b]	−0.29	−0.03	−0.32	0[b]
Food etc.	−0.41	−0.02	−0.43	−0.39[b]	−0.10	−0.07	−0.17	−0.10[b]
Textile etc.	−0.23	−0.10	−0.33	−0.39[b]	−0.10	−0.03	−0.13	−0.10[b]
Paper etc.	−0.56	−0.02	−0.58	−0.39[b]	−0.10	−0.03	−0.13	−0.10[b]
Organic chemicals	−0.10	−0.01	−0.11	−0.18	−0.10	−0.03	−0.13	−0.07
Inorganic chemicals	−0.10	−0.01	−0.11	−0.21[b]	−0.10	−0.01	−0.11	−0.16[b]
Fertilizers	−0.10	−0.01	−0.11	−0.12	−0.10	−0.03	−0.13	0
Other chemicals	−0.16	−0.01	−0.17	−0.21[b]	−0.19	−0.03	−0.22	−0.16[b]
Iron and Steel	−0.19	−0.01	−0.20	−0.14[b]	−0.10	−0.03	−0.13	−0.17
Non-ferrous	−0.10	−0.01	−0.11	−0.14[b]	−0.10	−0.01	−0.11	−0.20
Metal products	−0.18	−0.04	−0.22	−0.39[b]	−0.10	−0.03	−0.13	−0.10[b]
Building materials	−0.41	−0.02	−0.43	−0.39[b]	−0.10	−0.03	−0.13	−0.10[b]
Other industry	−0.17	−0.02	−0.19	−0.39[b]	−0.10	−0.03	−0.13	−0.10[b]
Construction	−0.16	−0.02	−0.18	−0.11	−0.10	−0.03	−0.13	0
Services	−0.23	−0.02	−0.25	−0.67[b]	−0.22	−0.07	−0.29	−0.45[b]
Government	−0.24	−0.02	−0.26	−0.67[b]	−0.34	−0.05	−0.39	−0.45[b]
Transport	−0.40	−0.05	−0.45	−0.60	−0.10	−0.03	−0.13	0
Households	−0.28	−0.15	−0.43	−0.25	−0.31	−0.04	−0.35	−0.16

[a] source: CPB(1992, table V.2)

[b] originally in a more aggregated form

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[17] As vintages of capital goods are eventually scrapped, retrofit investments connected to these vintages are also scrapped. Therefore, price-induced retrofit investments do not belong to the long term effect of a price change.

Comparing ICARUS and NEMO: an example

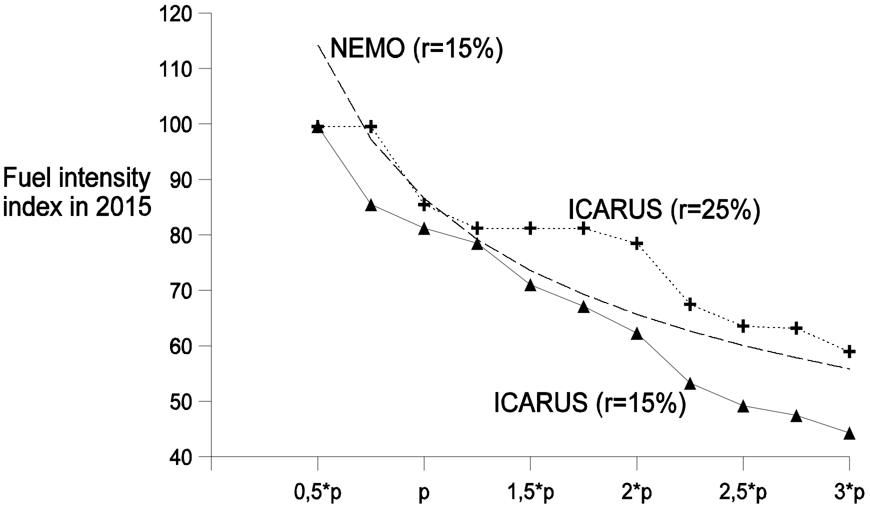
Figure 3.6 sketches the fuel intensity index in the food and drinks sector in 2015 as a function of fuel prices, computed with ICARUS and NEMO. Fuel intensity in 1990 is 100 at fuel price p. Investments are from the 'Global Competition' scenario in CPB (1997).

The slopes of the curves are approximately equal, indicating a similar price-sensitivity. This is a consequence of gearing NEMO's price-elasticities to ICARUS. Also, ICARUS predicts more efficiency improvement than NEMO if we use the same discount rate of 15%. This illustrates that NEMO accounts for an extra energy-gap over and above a high discount rate of 15%, through delayed penetration of new, energy-efficient techniques.

We also see the effect of changing the discount rate in ICARUS from 15 to 25%. The higher the discount rate used, the less energy saving is profitable. Clearly, the curves differ in location, but not in slope. In NEMO terminology: if we analyse ICARUS with alternative discount rates, ICARUS provides different trends but similar elasticities.

For most price levels, the energy saving in NEMO is between the levels generated by ICARUS at a 15% and 25% discount rate. Hence, NEMO assumes an implicit discount rate of between 15% and 25% in the foods and drinks sector. For other sectors, we may apply a similar line of reasoning.

Figure 3.6 NEMO's energy-efficiency gap and discount rates; foods and drinks sector



Aggregated results

Table 3.3 aggregates NEMO’s trends and elasticities over all sectors and over all industrial sectors, respectively, using 1990 energy consumption data as weights. The results point at a long-term efficiency trend of 0.81% per year for total final energy use. This is a mix of a 0.73% per year trend for fuel and a 1.42% trend for electricity. Our estimate of the long-term price elasticity of total final energy demand is −0.29.

Table 3.3 Parameters for NEMO at an aggregated level

	Trend			Elasticity		
	Fuel	Electricity	Total[a]	Fuel	Electricity	Total[a]
NEMO: Total	% per year					
Replacement	−0.73	−1.42	−0.81	−0.25	−0.20	−0.24
Retrofit	−0.33	−0.68	−0.37	−0.08	−0.07	−0.08
Good-housekeeping	0	0	0	−0.05	−0.04	−0.05
Long-term[b]	−0.73	−1.42	−**0.81**	−0.30	−0.24	−**0.29**
NEMO: Industry						
Replacement	−0.49	−1.02	−0.56	−0.17	−0.11	−0.16
Retrofit	−0.31	−0.63	−0.35	−0.07	−0.06	−0.07
Good-housekeeping	0	0	0	−0.01	−0.03	−0.02
Long-term[b]	−0.49	−1.02	−0.56	−0.19	−0.14	−0.18
Other studies						
Total			−1.3[c] , −0.93[d]			−0.30[e], −0.62[f]
Industry						−0.20[e], −0.27[f]

[a] Weighted average of fuel and electricity

[b] Replacement plus good-housekeeping

[c] Ministry of Economic Affairs (1996); 1960-1990

[d] Farla and Blok (1997); 1985-1994

[e] Groot (1988); 1965-1985

[f] Mittelstädt (1983); 1960-1978

Other studies

Table 3.3 also compares aggregated results from NEMO to other studies. As the sectoral weights used to aggregate NEMO’s trends and elasticities over time are constant, the energy-intensity cannot change due to inter- or intra-sectoral shifts. We have included two historical studies on energy intensity trends in the same table, in which sectoral shifts are included. We see that NEMO's parameters are roughly within the range of estimates from other studies; however, NEMO’s aggregate efficiency trend appears to be somewhat low.

3.6 Conclusions

We have shown how to incorporate bottom-up information on energy-saving techniques into a sectoral top-down model. While top-down information would have mixed up replacement, retrofit and good-housekeeping parameters, we are able to disentangle these parameters using bottom-up information. We also gained more insight into the difference between top-down and bottom-up approaches to energy-efficiency. By bridging the gap between both approaches, policy makers get a clearer picture of energy demand in the future.

The parameters obtained are an adequate description of ICARUS. However, as has been noticed in the introductory section, ICARUS cannot provide estimates for all parameters of NEMO. In the next chapter, we use additional assumptions with respect to the other parameters and look at model simulations to see whether this provides plausible results.

4 Model simulations

4.1 Introduction

In this chapter we present model simulations of the effects of exogenous shocks and of government policies. These simulations provide information on NEMO's possibilities to assess the effects of such changes. Also, the reader may use these simulations to judge the plausibility of NEMO's results.

As observed in chapter 3, we cannot estimate all of NEMO's parameters using bottom-up data. We need values for the retrofit adjustment parameters ψ and ϵ, and for the good-housekeeping 'rebound' parameter λ. For the retrofit adjustment parameters we assume ψ=0.9 and ϵ=0.4 for all sectors, such that the total adjustment parameter $\psi_f(I_t/K_t)^{\epsilon_f}$ is around 0.3. These values imply that around half of the profitable retrofit techniques penetrates within two years, around three quarters within four years, etcetera. We set the good-housekeeping 'rebound' parameter λ equal to zero.

As a base line for the simulations in this chapter we use the 'Global Competition' scenario. In this scenario, energy efficiency improvements were computed with NEMO. 'Global Competition' is characterised by a high economic growth, high investments and a lot of new technology (see CPB, 1997; Groot et al., 1997).We may note that the effects of many policies would be up to 40% smaller in a less dynamic base line.

In section 4.2 we analyse the impact of price changes observed historically and of government taxes. Section 4.3 looks at other government policies such as regulations and subsidies. Section 4.4 concludes.

4.2 Energy prices and energy taxes

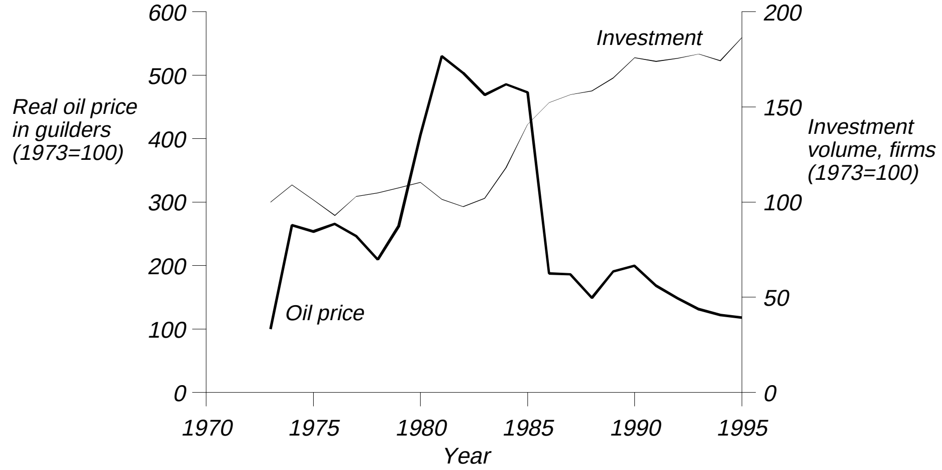
Historical simulation

NEMO is not especially suited to simulate energy use in the past. Most of NEMO's parameters were estimated using technological possibilities for the period 1990-

2010/2015[18]. The parameters we obtained from this do not necessarily reflect technologies available before 1990. In fact, we would need a bottom-up database for, say, the period 1970-1990 to estimate new, possibly other parameters. Such a database is not available. Nevertheless, we analyse the effects on energy efficiency of the energy price shocks of 1973/1974 and 1979/1980, and the price fall of 1985/1986 (see figure 4.1) using NEMO's '1990-2010' parameters.

Apart from energy prices, the volume of investments also strongly influences NEMO's outcomes. This captures business cycle effects. Historically, investments are negatively related to oil prices (see again figure 4.1). Together, real energy prices, investment levels and government policies determine NEMO's outcomes with respect to energy efficiency.

Figure 4.1 Real oil price and investment volume, 1973-1995



A first round of simulations did not work out well: predicted energy efficiency improvements were lower than observed improvements. This confirms the result in section 3.5 that NEMO's aggregate energy efficiency trend parameter is lower than in studies based on historical data. The average pace at which new technologies become available appears to be substantially lower between 1990 and 2010 (ICARUS/NEMO)

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[18] Strictly speaking, this would mean that NEMO's parameters are not valid for the period 2015-2020, and we could not give results after 2015. However, if NEMO's parameters are different in 2015-2020, this would not have a large impact on the total results for 1995-2020. Therefore, we do present estimates for 2020.

than between 1973 and 1995 (historical data). To test this hypothesis, we did a second round of simulations in which we increased all trend parameters by 50%.

The outcomes of the second simulation are presented in table 4.1. We see that energy efficiency increases strongly between 1973 and 1985, as a result of the price shocks of 1974 and 1979/1980. The oil price shocks increase the total yearly efficiency improvement between 1973 and 1985 to 2.1% per year. We can compare this to historical data: between 1975 and 1985, the efficiency improvement was 2.0% per year. After the price fall of 1985/1986, the predicted rate of efficiency improvement falls back to 0.6% per year; the observed rate was 0.8% per year. The difference may be caused by government policies aimed at energy efficiency. New policies which were introduced in the 1980s (regulations for new-built houses, subsidies for energy-saving investments) are not included in these predictions; they may have increased observed energy efficiency improvement.

On the whole, the simulations with increased trends appear to be satisfactory. This suggests that the pace at which new technologies become available after 1990 is lower than in the seventies and eighties. Therefore, it may not be adequate to extrapolate historical trends of energy efficiency improvements into the future.

Table 4.1 Energy-efficiency 1974-1995; NEMO simulation and historical data

		1974-1985	1986-1995
NEMO simulation[a]		efficiency improvement per year (%)	
Households	Fuel	3.3	1.4
	Electricity	3.3	2.5
Industry total	Fuel	1.8	0.1
	Electricity	1.5	0.9
Transport	Fuel	1.3	0.6
Other	Fuel	2.3	0.8
	Electricity	2.4	0.9
Total final energy use		2.1	0.6
Historical data[b]			
Total final energy use		2.0	0.8

[a] With trend parameters increased by 50% (see text).

[b] CPB monitoring of energy data from Netherlands Statistics (CBS).

All-user energy tax

Table 4.2 shows the effects[19] of a permanent 50% increase in energy prices which takes place immediately (no gradual introduction). We may interpret this either as an all-user energy tax on final energy prices or as a ‘technical variant’ aimed at showing different effects in different sectors of an equal price change. The total effect in 2020 is almost minus 10%. Fuel in transport and electricity in households are relatively sensitive to price changes[20]. Industrial energy use responds less strongly, because feedstocks, which are relatively hard to substitute, are a substantial part of it.

Table 4.2 Effects on energy use in NEMO of a persistent 50% increase of energy prices

Sector		1995	1996	2000	2010	2020
		PJ	% change compared to baseline			
Households	Fuel	398	−8.9	−10.8	−10.9	−10.4
	Electricity	71	−2.9	−6.2	−11.6	−13.4
Industry total	Fuel	873	−1.2	−3.6	−6.2	−6.8
	Electricity	129	−1.9	−3.5	−5.1	−5.5
Transport	Fuel	416	−3.5	−9.4	−16.9	−16.9
Other	Fuel	406	−2.0	−5.3	−8.1	−9.2
	Electricity	95	−2.3	−2.4	−3.3	−3.6
Total final energy use		2387	−3.2	−6.1	−9.2	−9.6

In figure 4.2 we can see how the effect of the price change on energy use builds up gradually over time. In the first year, the effect mainly consists of good-housekeeping; this takes place immediately. In this first year, the effects of retrofit and replacement are still rather small. The retrofit effect cumulates quickly: in the third year, most of this effect has been reached. At that point in time, the retrofit effect has become almost as large than the good-housekeeping effect, and the replacement effect is still building up. After that, the replacement effect continues to grow while vintages, including the retrofit

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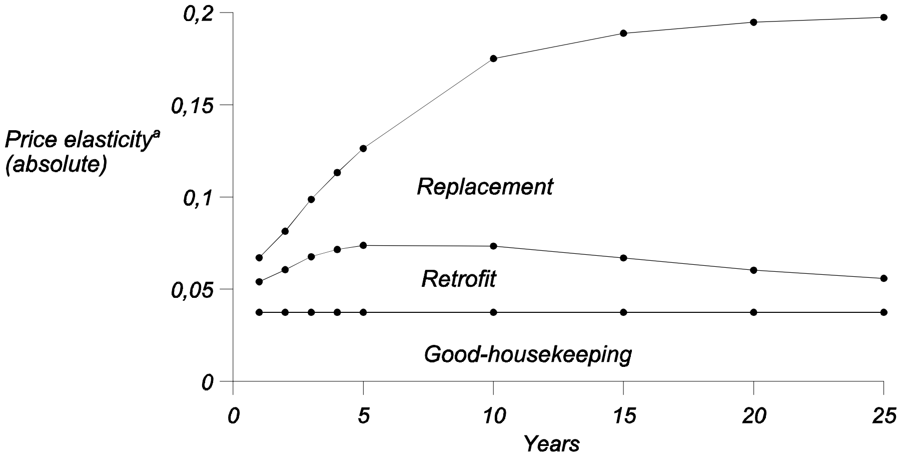
[19] More detailed sectoral effects are presented in Appendix E.

[20] The effect of the price change penetrates relatively fast in household fuel use. This is caused by a characteristic of the baseline. In the baseline, fuel use in new-built houses is regulated. As a consequence, replacement is not determined by energy prices but by standards. Therefore, the price effect shown in Table 4.1 for fuel use in households consists only of retrofit and good-housekeeping. These effects penetrate faster than replacement.

investments added to them, have been replaced. After 25 years, the greater part of the total long-term effect has been reached. The long-term effect consists of replacement and good-housekeeping effects only. Retrofit has only served as a ‘precursor’ to later replacement.

Figure 4.2 Price elasticity of a persistent 50% energy price increase starting in year 1



[a] Elasticity for a 50% price increase. The point elasticity for total final energy use presented in chapter 3 (−0.29; see Table 3.3) only applies to small price changes. Also, for fuel use in households, there is no price effect on replacement here (see above).

Small-user energy taxes

In 1997, we analysed two policy proposals for a Committee installed by the Netherlands government to advise on ‘greening’ the tax system (Vermeend and Van der Vaart, 1998). The first variant involved doubling existing energy taxes which mostly (but not only) pertain to ‘small users’ (private households, small firms). In the second variant, the tax increase was aimed at ‘very small users’ (private households and very small firms) only.

Table 4.3 shows the effects of the tax increases on energy prices and on energy use. The effects on industrial sectors are small, because the tax increases were designed to avoid effects on international competitiveness. For basic industries (base chemicals, base metals), which compete on an international market, the tax does not increase marginal prices at all. The effects on energy use are relatively large in private households: minus 4 to minus 10% in 2020. In variant 1 we also see a clear effect (minus 3%) in the sector ‘other users’, which consists mainly of the services and agriculture sectors. The reduction of total final energy demand is between 1.5 and 2% in 2020 in both variants.

Variant 1 was used by the Netherlands Energy Research Centre (ECN) to analyse a sub-variant in which 15% of the additional tax revenues are not recycled in other taxes, but used to subsidise investment in energy efficiency. To this end, ECN used a bottom-up model based on the same data as NEMO (the ICARUS database). As both models used the same basic data, the combination of NEMO computations with respect to tax increases and ECN’s bottom-up model in one sub-variant was internally consistent.

Table 4.3 Effects in NEMO of increased energy taxes

		Marginal energy price		Energy use	
		2010	2020	2010	2020
Variant 1		% change compared to baseline			
Households	Fuel	17.9	17.5	−4.4	−4.0
	Electricity[a]	12.7	12.4	−5.1	−5.5
Industry	Fuel	3.8	3.5	−0.6	−0.6
	Electricity	4.6	4.0	−0.6	−0.6
Transport	Fuel	2.1	2.9	−0.6	−1.0
Other	Fuel	17.0	16.0	−2.7	−3.3
	Electricity	14.0	13.6	−3.0	−3.5
Total		8.5	8.2	−1.7	−1.9
Variant 2					
Households	Fuel	30.4	29.7	−7.1	−6.5
	Electricity[a]	23.4	24.5	−9.2	−10.5
Industry	Fuel	0.1	0.1	0.0	0.0
	Electricity	0.0	0.0	0.0	0.0
Transport	Fuel	0.0	0.0	0.0	0.0
Other	Fuel	2.9	3.1	−1.1	−1.4
	Electricity	0.0	0.0	0.0	0.0
Total final use		5.6	5.3	−1.5	−1.5

[a] The estimated price effect on electricity use includes, apart from a NEMO-based effect on energy efficiency, a small effect on the presence of electrical appliances.

CPB’s sectoral model Athena showed that the economic effects of these tax increases can be relatively small outside of the energy sphere, provided that the additional tax revenues are recycled to firms and households and that there are no substantial wage increases. In 1998, the Dutch government decided to increase energy taxes (including ‘positive incentives’), using a mix of the two variants presented above.

4.3 Subsidies, regulation and voluntary agreements

Regulation

Since 1996, the Dutch government imposes strict energy-efficiency standards on newly-built houses (‘Energieprestatienormen’), which make new houses about twice as efficient as existing houses. These standards are part of our baseline. By removing them from the baseline, we can analyse the additional effect of the standards. Table 4.4 shows the effects on household fuel use. We see that the effect cumulates only very gradually, as a consequence of the low turnover rate of houses (about 1½% per year). The build-up is slower after 2010, because in this period the expected efficiency levels of new houses which would be reached without standards have fallen so far (mainly because of the autonomous efficiency trend in NEMO) that they come close to the level prescribed in the standards. The effect of the standards on household fuel use in 2020 is −1.9%. As a percentage of total final energy use in 2020, the effect is −0.2%.

Table 4.4 Effects in NEMO of energy-efficiency standards for new-built houses

Sector		1995	1996	2000	2010[a]	2020[a]
		PJ	% change			
Newest vintage of houses	Space heating fuel	3	−6.1	−24.6	−12.3	0
Households	Fuel	398	−0.1	−0.4	−1.6	−1.9
Total final energy use		2387	0	−0.1	−0.2	−0.2

[a] The standards are planned to be tightened until 2000. After that, we did not assume further tightening. In that case, we expect ‘normal’ (NEMO-computed, autonomous) efficiency improvements to catch up with the standards in 2020.

Investment subsidies

Our baseline contains the effects of the ‘Energy investment allowance’ (Energie-investeringsaftrek), a special tax break for firms that invest in energy-efficient technology[21]. Through this allowance, firms can get back around 17% of their investment through lower profit taxes. As the level of allowance has a maximum, this subsidy mainly affects firms with a relatively small energy use. Most of these firms are found in the services sector. The Energy investment allowance has a limited budget.

If the budget would not be limited and if every type of energy saving would be deductible, we could consider this subsidy as an across-the-board 17% cut in the capital costs of energy saving. As energy-saving decisions in NEMO involve comparing the benefits of energy saving to costs which are mainly capital costs, we would expect the effects of a 17% fall in costs of capital to be roughly equal to those of a 17% increase of energy prices. Such an increase would, in the long term, reduce fuel use in the services sector by 3%; for electricity, this would be 4%.

However, given the limited budget of the Energy investment allowance and the fact that it only pertains to specific types of investments, we made a separate computation, with a lower outcome. The result was added to NEMO as an autonomous factor. This example illustrates that NEMO is capable of analysing general subsidies. If, however, the subsidy is specific in terms of target groups or budget, we need to perform separate computations based on additional assumptions.

Voluntary agreements

Most agricultural and industrial sectors in the Netherlands have promised the government that they will substantially increase their energy efficiency between 1990 and 2000. In most of these voluntary agreements (‘Meerjarenafspraken’), the sectors aim at 20% more efficiency (feedstocks are excluded). The government considers these agreements as the core of its energy efficiency policy for the sectors involved. This policy instrument fits well in the Dutch tradition of consultation between government and organised business (‘polder model’).

Of course it is not clear whether the sectors involved will reach their targets. Also, as the agreements have their own monitoring system not connected to official statistics, differences of definitions and measurement can occur. Therefore, we need to assess the additional effect of these agreements.

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[21] Here, we analyse the Energy Investment Allowance as it was in the beginning of 1997. Later, the budget of the Allowance has been expanded and its conditions have been changed.

We note that NEMO is not really suited for this ‘soft’ type of instrument. In NEMO, profitable actions are taken anyway (sometimes after some delay), and actions which are not profitable, are simply not taken. If we would apply NEMO without additional assumptions, voluntary agreements would have no extra effects at all. This might be true if firms only promised improvements they would have carried out anyway. Here, however, we assume that firms are prepared to do things which are not profitable, to avoid a ‘dirty’ image and/or to prevent the government from raising energy taxes or imposing standards.

We assume that firms are willing to make additional investments which are nearly profitable. That is, they are prepared to behave like the energy price is somewhat higher than it is. Table 4.5 shows which – admittedly rather arbitrary – ‘price impulses’ we added to the energy prices in the baseline to reflect voluntary agreements. As most voluntary agreements were made around 1993, and effects on behaviour may lag behind, we started to introduce low impulses in 1996; they reach their full level in 2000. We assume that new agreements with a similar effect will be reached for the years between 2000 and 2020; if not, the disappearance of the price impulse will have an adverse effect on energy efficiency improvement after 2000.

Table 4.5 Assumed price impulses for voluntary agreements and their effects on fuel use

	Price impulse	Effects on energy use		
		2000	2010	2020
Variant 1	%	% change		
Horticulture	10	−0.9	−1.9	−2.4
Other agriculture	5	−0.6	−1.3	−1.4
Industry	5 to 15	−0.5	−1.1	−1.3
Transport	10	−0.2	−0.3	−0.4
Other	5	−0.4	−0.9	−1.1
Total		−0.4	−0.8	−0.9

[a] There is no voluntary agreement for energy used in transport.

The size of the price impulse depends on the structure of the sector. If the number of firms in a sector is small, as is the case in basic industry, the voluntary agreements have either been made with individual firms or with a trade organisation with just a few members. In this case, the behaviour of the firms involved is very visible. We assume that this leads to a relatively strong effect of voluntary agreements. In other words, we assume a relatively large price impulse in these sectors. If, on the other hand, the number of firms in a sector is large, we would expect less commitment from individual firms to the sectoral goal. This consideration leads to a relatively small price impulse.

Table 4.5 shows the effects of these price impulses, starting in 1996. The estimated long term effect on final energy use is –0.9%; for the year 2000 this effect is –0.4%. Adding the effects by sector to autonomous energy efficiency improvements, we may expect that the goals of most voluntary agreements will probably be reached. We note, however, that the greater part of the improvement is autonomous. These autonomous improvements are determined by the relatively high economic growth (and concomitant high investment levels) the Netherlands have achieved in the 1990s. Without this high growth, the goals of the voluntary agreements would possibly not have been reached.

4.4 Conclusion

In this chapter we have shown that NEMO can be used to perform scenario analysis and to assess the effects of many types of policy instruments. NEMO's bottom-up foundation helps to combine it with 'pure' bottom-up analysis. NEMO is particularly suited to analyse effects of energy prices and taxes. For specific measures or 'soft' instruments, additional assumptions and computations are often needed. Still, for these instruments as well, NEMO offers a systematic way to analyse effects.

5 Conclusions

We have presented a top down energy demand model, estimated most parameters using bottom-up information, and showed that it can be used to analyse energy price changes and different types of government policies.

However, research on NEMO is not finished. We see three areas for further research. First, we need to have a closer look at the demand for energy services. More and more, electricity using techniques replace fuel using techniques. In terms of the model, we need to investigate substitution between Z_e and Z_f. Second, the development of energy efficiency over time seems to depend on the types of techniques that are available: retrofit and/or replacement techniques. As ICARUS was not designed to distinguish between these types of techniques, definition questions as to what is retrofit and what is replacement still need to be addressed. We expect that a new version of ICARUS, being planned now, will address this issue more thoroughly. Third, ICARUS does not enable us to estimate all parameters of the model, notably the speed of adjustment of actual ex post to ideal ex post efficiency and the ‘rebound effect’ on good-housekeeping. More empirical research measuring investors' demand side behaviour is required. Such research could also include (determinants of) discount rates used in investment decisions.

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Appendix A Sector classifications and sectoral data

Table A.1 Sector classifications: Statistics, NEMO and ICARUS

Netherlands Statistics (CBS) (1994)	NEMO	ICARUS (Van Vuuren, 1996)
Horticulture	Horticulture	Horticulture
Other agriculture	Other agriculture	Agriculture
Food,beverages and tobacco industry	Food etc.	Food, beverages & tobacco
Textile-, clothing- and leather industry	Textile etc.	Textile
Paper industry, printing and publishing	Paper etc.	Paper (including Paper converting)
Organic chemical industry	Organic chemicals	Petrochemicals
Anorganic chemical industry	Inorganic chemicals	Inorganic chemistry
Fertilizer industry	Fertilizers	Fertilizer
Other chemical industry Chemical products industry	Other chemicals	Other chemicals
Iron and steel basic metals industry	Iron and Steel	Iron and Steel
Non ferro basic metals industry	Non-ferrous	Non-ferro
Metal products industry	Metal products	Other metal
Building materials industry	Building materials	Building materials
Plastics-, rubber- and other manufacturing industry Manufacturing industry not specified by branch	Other industry	Other industry (including Wood-products and Printing&Publishing[a])
Construction	Construction	Building industry
Services	Services	Services (Commercial offices, Catering and Retail)
Government	Government	Government (Non-commercial offices and Health-care)
Transport	Transport	Transport
Households	Households	Households

[a] In Van Vuuren (1996) Printing&Publishing is a part of ‘other industry’; in NEMO, it belongs to ‘paper etc.’. As the energy use of the Printing&Publishing sector is relatively small, this inconsistency does not influence our results strongly.

Table A.2 Sectoral data

Sector	Energy prices (1990)[a]		Scrapping ages[b]		Energy use (1990)[c]	
	Fuel	Electr.	a_{min}	a_{max}	Fuel	Electr.
	guilders/GJ				PJ	
Horticulture	8.3	42.2	15	25	144.5	4.7
Other agriculture	8.3	42.2	10	20	22.9	2.0
Food etc.	6.5	33.8	25	35	65.2	16.7
Textile etc.	6.7	34.0	30	40	5.0	1.6
Paper etc.	6.7	27.8	18	28	21.2	8.5
Organic chemicals	6.6	20.4	18	28	369.6	13.1
Inorganic chemicals	6.6	20.4	18	28	43.1	13.9
Fertilizers	4.8	26.1	18	28	118.9	4.0
Other chemicals	6.6	20.4	18	28	30.5	7.9
Iron and Steel	8.0	23.3	18	28	82.0	9.3
Non-ferrous	8.0	23.3	18	28	14.7	18.2
Metal products	8.8	34.7	30	40	24.7	12.9
Building materials	6.8	35.6	18	28	35.5	5.4
Other industry	6.8	35.6	30	40	8.9	6.4
Construction	8.4	42.2	14	24	10.0	1.6
Services	12.9	42.2	37 [d]	47 [d]	90.7	35.1
Government	12.9	42.2	37 [d]	47 [d]	87.0	25.7
Transport	44.7	42.2	[e]	[e]	370.6	4.6
Households	12.9	42.2	10[f]	15[f]	399.2	59.4

[a] Energy prices are taken from Netherlands Statistics (1991).

[b] 'Guesstimates', based in most cases on average lifetimes computed as a weighted average of lifetimes of buildings, appliances and processes from ATHENA, a CPB model.

[c] Energy consumption data are taken from ICARUS (De Beer *et al.*, 1994 and 1994a).

[d] For fuel use (mainly related to office buildings); for electricity a_{min}=15, a_{max}=25.

[e] For the transport sector, we use data on scrapping of vehicles by age.

[f] For electricity; for fuel, we use data on putting out of use of houses by age.

Appendix B Changes to ICARUS

Organic chemicals: fuel

In the organic chemicals sector we used new insights with respect to fuel saving gained by the makers of ICARUS, which have not been accounted for in ICARUS-3. We have extended their insights for the period 1990-2000 to the period 1990-2015. Table B.1 summarizes the new information[22]. The new energy saving potentials are smaller than in ICARUS-3.

Table B.1 Fuel saving techniques in the petrochemical industries ; period 1990-2015

	Technical potential (%)	
	Replacement	Retrofit
overall - 2015	3.75	3.75
olefines - dividing wall column - 2015	1.25	1.25
other petrochemicals - 2015	0	1.60
styrene - 2015	0	0.59
olefines - cracking furnace - 2015	3.28	1.62
aromatics - melt crystallization	4.10	0
MEOH - advanced reactor design	1.22	0

source: Worrell (1996)

Organic chemicals and fertilizers: electricity

In these industries, ICARUS mentions only one technique for saving electricity in the period 1990-2015: a replacement technique in organic chemicals, and a retrofit technique in the fertilizer industry. As the electricity saving potential in both sectors has been divided into retrofit and replacement potentials over the period 1990-2000, we have also divided the techniques over the period 1990-2015 into retrofit (50%) and replacement (50%).

Transport

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[22] The new data contain an uncertainty range for the option ‘process integration’. We chose the lower limit.

In the transport sector we excluded the ICARUS techniques ‘weight reduction of cars’ and ‘idle-off engines’. Weight reduction is a relevant possibility, but the addition of air conditioning, spoilers, more powerful and heavier engines, etc. yields an opposite trend. The technique for ‘idle-off engines’ is available, still far from actual implementation.

Households

In the households sector we classified boilers (‘condensing boilers in new dwellings’ and ‘replacement by gas boilers’) as retrofit instead of replacement, because the house is the relevant capital good for fuel use. Consequently, a new house is replacement, and changes within the house are retrofit.

Appendix C Estimation of price elasticities

We estimated $F_{2015} = c * p^{\beta} + \epsilon$ where F_{2015} denotes the energy intensity index in 2015 computed with ICARUS, taking into account replacement and retrofit techniques (upper bound); p is the energy price index in 2015 (p in 1990 equals 100); α is a constant and ϵ is the disturbance term. An estimator for β provides an ICARUS-based constant price elasticity. For retrofit, we estimated $F_{2000} = c * p^{\delta} + \epsilon$, where F_{2000} denotes the ICARUS-based energy intensity index for 2000 taking into account retrofit techniques only.

Table C.1 Estimation results: fuel elasticities

	Replacement (upper bound)			Retrofit		
	$E(\beta_f)$	$se(\beta_f)$	R^2	$E(\delta_f)$	$se(\delta_f)$	R^2
Horticulture	−0.23*	0.05	0.664	−0.05*	0.01	0.809
Other agriculture	−0.27*	0.04	0.830	−0.12*	0.02	0.800
Food etc.	−0.41*	0.04	0.930	−0.17*	0.02	0.898
Textile etc.	−0.23*	0.06	0.649	−0.21*	0.08	0.607
Paper etc.	−0.56*	0.06	0.887	−0.07*	0.01	0.813
Organic chemicals	−0.02*	0.00	0.771	−0.04*	0.01	0.598
Inorganic chemicals	−0.09*	0.02	0.620	−0.10*	0.03	0.630
Fertilizers	−0.03	0.02	0.175	−0.04*	0.01	0.780
Other chemicals	−0.16*	0.02	0.853	−0.11*	0.02	0.773
Iron and Steel	−0.19*	0.02	0.893	−0.04*	0.01	0.802
Non-ferrous	−0.02*	0.01	0.431	−0.00	0.00	0.427
Metal products	−0.18*	0.02	0.903	−0.13*	0.02	0.767
Building materials	−0.41*	0.05	0.885	−0.20*	0.02	0.883
Other industry	−0.17*	0.02	0.846	−0.11*	0.02	0.847
Construction	−0.16*	0.03	0.814	−0.05*	0.01	0.742
Services	−0.23*	0.02	0.902	−0.12*	0.02	0.736
Government	−0.24*	0.04	0.824	−0.13*	0.02	0.772
Transport	[a]			[b]		
Households	−0.28*	0.02	0.957	−0.15*	0.02	0.882

[a] Not estimated (see Appendix D)

[b] No price-sensitivity was found in the observations

* Significant at 5% level

Table C.2 Estimation results: electricity elasticities

	Replacement			Retrofit		
	$E(\beta_e)$	$se(\beta_e)$	R^2	$E(\delta_e)$	$se(\delta_e)$	R^2
Horticulture	-[a]			-[a]		
Other agriculture	−0.29[*]	0.06	0.716	−0.01	0.01	0.15
Food etc.	-[a]			−0.15[*]	0.02	0.829
Textile etc.	-[a]			−0.02[*]	0.01	0.535
Paper etc.	-[a]			−0.06[*]	0.01	0.799
Organic chemicals	-[a]			-[a]		
Inorganic chemicals	−0.10[*]	0.01	0.852	−0.02[*]	0.00	0.633
Fertilizers	-[a]			−0.06[*]	0.01	0.803
Other chemicals	−0.19[*]	0.06	0.466	-[a]		
Iron and Steel	−0.09[*]	0.01	0.792	−0.00[*]	0.00	0.423
Non-ferrous	−0.00[*]	0.00	0.427	−0.00[*]	0.00	0.325
Metal products	-[a]			−0.08[*]	0.02	0.623
Building materials	−0.02[*]	0.01	0.430	−0.07	0.04	0.281
Other industry	-[a]			−0.05[*]	0.02	0.303
Construction	-[a]			−0.16[*]	0.05	0.507
Services	−0.22[*]	0.02	0.902	−0.11[*]	0.02	0.775
Government	−0.34[*]	0.03	0.939	−0.14[*]	0.03	0.735
Transport	-[a]			-[a]		
Households	−0.31[*]	0.03	0.910	−0.03[*]	0.01	0.433

[a] No price sensitivity was found in observations

[*] Significant at 5% level

Appendix D Trends and elasticities

Tables D.1 and D.2 show ICARUS-based estimates of NEMO's trends (table D.1) and elasticities (table D.2). For replacement elasticities and trends, the tables show lower bounds (computed using ICARUS-replacement only) and upper bounds (sum of ICARUS replacement and retrofit; see section 3.3).

Table D.1 ICARUS-based trends (values used for NEMO in bold italics)[a]

	FUEL				ELECTRICITY			
	Replacement			Retrofit	Replacement			Retrofit
	$-\alpha_f$			$-\gamma_f$	$-\alpha_e$			$-\gamma_e$
	Lower	Upper	Mean		Lower	Upper	Mean	
	% per year							
Horticulture	−3.01	−4.60	***−1.50***[b]	***−0.47***	−5.23	−5.27	***−2.00***[b]	***−0.10***
Other agriculture	−1.11	−1.11	***−1.11***	***−0.10***	−0.98	−2.11	***−1.55***	***−0.63***
Food etc.	−0.29	−0.67	***−0.48***	***−0.34***	−1.39	−1.45	***−1.42***	***−0.99***
Textile etc.	−0.20	−0.20	***−0.20***	***−0.10***	−1.18	−1.34	***−1.26***	***−0.30***
Paper etc.	−1.04	−1.19	***−1.12***	***−0.31***	−1.07	−2.64	***−1.86***	***−1.30***
Organic chemicals[c]	−0.34	−0.62	***−0.48***	***−0.34***	−0.95	−2.29	***−1.62***	***−1.13***
Inorganic chemicals	−0.20	−0.20	***−0.20***	***−0.10***	−0.38	−0.75	***−0.57***	***−0.40***
Fertilizers	−0.21	−0.27	***−0.24***	***−0.17***	−0.94	−2.25	***−1.60***	***−0.79***
Other chemicals	−0.32	−0.49	***−0.41***	***−0.29***	−0.75	−1.51	***−1.13***	***−0.79***
Iron and Steel	−0.63	−0.71	***−0.67***	***−0.25***	−0.20	−0.31	***−0.26***	***−0.15***
Non-ferrous	−0.23	−0.49	***−0.36***	***−0.25***	−0.69	−0.73	***−0.71***	***−0.10***
Metal products	−0.35	−0.63	***−0.49***	***−0.34***	−0.43	−0.88	***−0.66***	***−0.46***
Building materials	−0.82	−1.51	***−1.17***	***−0.82***	−0.67	−1.48	***−1.08***	***−0.76***
Other industry	−0.39	−0.67	***−0.53***	***−0.37***	−0.50	−1.10	***−0.80***	***−0.56***
Construction	−0.20	−0.20	***−0.20***	***−0.10***	−0.67	−1.44	***−1.06***	***−0.74***
Services	−0.86	−0.96	***−0.91***	***−0.25***	−0.81	−1.86	***−1.34***	***−0.94***
Government	−0.43	−0.70	***−0.57***	***−0.40***	−0.78	−1.63	***−1.21***	***−0.85***
Transport	−1.50	−1.50	***−0.75***[b]	***0***	−1.99	−2.21	***−2.10***	***−0.10***
Households	−0.71	−1.09	***−0.90***	***−0.63***	−2.00	−2.53	***−2.26***	***−0.63***

[a] ICARUS is based on the average firm in a sector. However, due to heterogeneity of firms, there will always be firms investing in energy-efficiency (see section 3.3). We imposed the following minima on trend parameters: α_f 0.20; γ_f 0.10; α_e 0.20; γ_e 0.10.

[b] See text of this Appendix.

[c] The ICARUS saving potential was adjusted using new insights of the makers of ICARUS (Appendix B).

In table D.1, the margin between the lower and the upper bound for *replacement trends* is more than 1% for electricity use in some sectors. For fuel use, the gap is lower. Two reasons led us to consider the mean of both bounds as the most appropriate value. First, the lower bound understates, whereas the upper bound slightly overstates the actual replacement potential (see section 3.4). Second, the inclusion of neglected costs (e.g. transaction costs of installing techniques) would restrict the replacement potential.

The fuel and electricity *replacement* trends in the *horticulture* sector are unexpectedly high, given historical data (3.80 and 5.25% per year, respectively). This is caused by the energy-saving technique 'production increase - 2015'. This technique implies using 'assimilation lighting' to achieve a much higher production per unit of area. As fuel use is related to the area used, fuel use per unit of output falls strongly. At the same time, the increased lighting would raise electricity use. However, this extra electricity is produced with very efficient cogeneration - an energy supply technique which is not part of what we try to predict with NEMO. In this technique, we cannot filter out the 'unwanted' energy supply part, because it is strongly linked to a supposed energy demand development. However, we do know that a value of 3.80% (5.25%) per year for the fuel (electricity) trend is too optimistic for energy demand alone. As a guesstimate, we substitute a value of 1.50% (2.00%) per year. We note that these new values are still, and by far, the highest replacement trends of all sectors.

The ICARUS-based *replacement and retrofit* trends for fuel use in the *transport* sector are −1.50% and −0.10% per year, respectively. However, if we run NEMO with these parameters we predict much higher efficiency improvements than historical data show. We believe that engines have become more efficient and will continue to do so in the future, but that this is compensated in part by a trend towards engines with more power, heavier passenger cars (for instance because of airbags) and more electrical (=fuel-using) equipment in cars (airconditioning, heated mirrors etc.). We set the replacement trend to 0.75% per year and the retrofit trend to zero. With these values, simulations show a nice fit with historical data (see section 4.2, 'Oil price shocks').

As explained in section 3.4, the *retrofit trends* are bounded by 0.7 times the replacement trends. *Good-housekeeping trends* are assumed to be zero.

Table D.2 ICARUS based elasticities (values used for NEMO in bold italics)[a]

	FUEL				ELECTRICITY			
	Replacement		Retrofit	Good-h.	Replacement		Retrofit	Good-h.
	$-\beta_f$	$-\beta_f$	$-\delta_f$	$-\theta_f$	$-\beta_e$	$-\beta_e$	$-\delta_e$	$-\theta_e$
	Lower bound	Upper bound			Lower bound	Upper bound		
Horticulture	−0.10	***−0.23***	***−0.05***	***−0.02***	−0.10	***−0.10***	***−0.05***	***−0.03***
Other agriculture	−0.11	***−0.27***	***−0.12***	***−0.02***	−0.10	***−0.29***	***−0.05***	***−0.03***
Food etc.	−0.29	***−0.41***	***−0.17***	***−0.02***	−0.10	***−0.10***	***−0.07***	***−0.07***
Textile etc.	−0.23	***−0.23***	***−0.16***	***−0.10***	−0.10	***−0.10***	***−0.05***	***−0.03***
Paper etc.	−0.44	***−0.56***	***−0.07***	***−0.02***	−0.10	***−0.10***	***−0.06***	***−0.03***
Organic chemicals[b]	−0.10	***−0.10***	***−0.05***	***−0.01***	−0.10	***−0.10***	***−0.05***	***−0.03***
Inorganic chemicals	−0.10	***−0.10***	***−0.07***	***−0.01***	−0.10	***−0.10***	***−0.05***	***−0.01***
Fertilizers	−0.10	***−0.10***	***−0.05***	***−0.01***	−0.10	***−0.10***	***−0.06***	***−0.03***
Other chemicals	−0.10	***−0.16***	***−0.11***	***−0.01***	−0.10	***−0.19***	***−0.05***	***−0.03***
Iron and Steel	−0.10	***−0.19***	***−0.05***	***−0.01***	−0.10	***−0.10***	***−0.05***	***−0.03***
Non-ferrous	−0.10	***−0.10***	***−0.05***	***−0.01***	−0.10	***−0.10***	***−0.05***	***−0.01***
Metal products	−0.10	***−0.18***	***−0.13***	***−0.04***	−0.10	***−0.10***	***−0.07***	***−0.03***
Building materials	−0.20	***−0.41***	***−0.20***	***−0.02***	−0.10	***−0.10***	***−0.07***	***−0.03***
Other industry	−0.10	***−0.17***	***−0.11***	***−0.02***	−0.10	***−0.10***	***−0.05***	***−0.03***
Construction	−0.14	***−0.16***	***−0.05***	***−0.02***	−0.10	***−0.10***	***−0.07***	***−0.03***
Services	−0.11	***−0.23***	***−0.12***	***−0.02***	−0.10	***−0.22***	***−0.11***	***−0.07***
Government	−0.11	***−0.24***	***−0.13***	***−0.02***	−0.12	***−0.34***	***−0.14***	***−0.05***
Transport	−0.40[d]	***−0.40***[c]	***0.00***[c]	***−0.05***[c]	−0.10	***−0.10***	***−0.05***	***−0.03***
Households	−0.15	***−0.28***	***−0.15***	***−0.15***[c]	−0.19	***−0.31***	***−0.05***	***−0.04***

[a] Our database ICARUS is based on the average firm in a sector. However, due to heterogeneity of firms, there will always be firms reacting to price changes (see section 3.3). We imposed the following minima on elasticity parameters: β_f 0.10; δ_f 0.05 ; θ_f 0.02; β_e 0.10; δ_e 0.05; θ_e 0.03. For large-scale energy-intensive processes we expect that good-housekeeping is not very price-sensitive because it is profitable even at low energy prices. In these processes we assume θ=0.01.

[b] The ICARUS saving potential was adjusted using new insights of the makers of ICARUS (Appendix B).

[c] See text of this Appendix..

Elasticities

Looking at the *replacement elasticities* in table D.2, we think that the upper bound is the most appropriate for NEMO, for two reasons. First, the inclusion of neglected fixed costs changes the location of the curve (which changes the trend - see above) in figure 3.4, but not its slope (which leaves the elasticities unchanged). Hence, the price sensitivity remains unaltered even if extra costs are added. Second, the estimates of elasticities based on ICARUS are slightly biased downwards. To see why this is the case, think of what would happen to the energy intensity index in 2015 after a large energy price decrease. After such a decrease, only a few techniques are profitable and ICARUS predicts a low energy efficiency improvement, but no worsening. NEMO, however, assumes an energy efficiency worsening if the price decrease is sufficiently big. A worsening would move the first and second asterisks in the left part of the graph to places above the energy intensity index in 1990 (i.e. above 100). As a consequence, the slope of a curve fitted through the changed ICARUS asterisks would be steeper.

For the *fuel* use in the *transport* sector we did not estimate elasticities on ICARUS data, as we have estimates from the literature. More recent literature (Terzif et al, 1995) points at a long term price elasticity of 0.4 to 0.5. We have chosen a value of 0.45, and split this up in 0.40 for replacement and 0.05 for good-housekeeping. As there is little retrofit in this sector (see above), we set the retrofit price elasticity to zero.

The *retrofit elasticities* are bounded by 0.7 times the replacement elasticity. The *good-housekeeping elasticities* reflect in part the 20 good-housekeeping measures in ICARUS over the period 1990-2015, and in part the lower bounds we set (0.02 for fuel, 0.03 for electricity). For the good-housekeeping elasticity of fuel use in *households*, ICARUS yielded a the minimum value (−.02). However, time series research (SEO,1991) leads to short-term (that is, mainly good-housekeeping) elasticities of 0.26 to 0.41. We choose a value of −0.15; this is compatible with NEMO's precursor Ceneca.

Appendix E Simulation results

Table E.1 Effects on (final) energy use in NEMO of a persistent 50% increase of energy prices

	FUEL					ELECTRICITY				
	1995	1996	2000	2010	2020	1995	1996	2000	2010	2020
	PJ	% per year				PJ	% per year			
Horticulture	161	−2.0	−4.8	−8.2	−9.7	3.2	−2 .0	−3.6	−4.7	−5.2
Other agriculture	18	−2.8	−7.2	−10.8	−11.2	9.7	−2.7	−6.6	−11.6	−12.3
Food etc.	70	−2.6	−7.3	−12.8	−15.2	21.0	−3.8	−5.8	−6.6	−6.7
Textile etc.	7	−4.9	−7.7	−11.6	−12.7	2.1	−1.7	−2.9	−4.1	−4.7
Paper etc.	25	−2.5	−7.7	−16.8	−20.9	11.7	−2.0	−3.7	−4.7	−5.2
Organic chemicals	433	−1.9	−3.6	−4.8	−5.2	21.3	−1.9	−3.5	−4.8	−5.2
Inorganic chemicals	18	−1.5	−3.5	−4.8	−4.8	7.9	−1.9	−3.5	−4.8	−5.2
Fertilizers	108	−1.3	−2.9	−4.4	−4.8	3.7	−2.0	−3.7	−4.8	−5.2
Other chemicals	41	−2.0	−5.0	−6.7	−7.1	9.8	−2.1	−4.5	−7.5	−8.6
Iron and Steel	90	−1.5	−3.7	−6.8	−8.2	8.4	−1.8	−3.3	−4.7	−5.2
Non-ferrous	9	−1.4	−2.9	−4.3	−4.8	16.6	−1.8	−3.2	−4.7	−5.2
Metal products	34	−2.9	−6.1	−8.0	−8.4	14.9	−2.1	−4.0	−4.9	−5.1
Building materials	31	−3.9	−10.3	−14.7	−16.1	4.9	−2.2	−4.1	−4.9	−5.2
Other industry	7	−2.1	−4.9	−6.7	−7.2	6.6	−1.9	−3.3	−4.5	−4.9
Construction	33	−1.8	−4.1	−6.4	−7.1	1.9	−2.6	−4.7	−5.1	−5.2
Services	160	−2.5	−5.8	−7.9	−8.8	60.2	−4.6	−8.0	−10.5	−11.3
Government	33	−2.6	3.7	−8.1	−9.0	14.3	−4.0	−8.2	−11.4	−13.0
Transport	416	−3.5	−9.6	−16.9	−16.9	5.3	−2.1	−3.8	−5.0	−5.2
Households	398	−8.9	−10.8	−10.9	−10.4	70.9	−2.8	−6.2	−11.6	−13.4
Total final use	2093	−3.7	−6.7	−9.7	−10.2	294.4	−3.0	−5.6	−8.4	−9.2

Abstract

This Research Memorandum presents the model NEMO, which describes and predicts energy demand in the Netherlands. The model links energy use to other production factors, (physical) production, energy prices, technological trends and government policies. It uses a 'putty-semiputty' vintage production structure, in which new investments, adaptations to existing capital goods (retrofit) and 'good-housekeeping' are discerned. Price elasticities are relatively large in the long term and small in the short term.

Most predictions of energy use are based on either econometric models or on 'bottom-up information', i.e. disaggregated lists of technical possibilities for and costs of saving energy. Typically, one predicts more energy-efficiency improvements using bottom-up information than using econometric ('top-down') models. We bridged this so-called 'energy-efficiency gap' by designing our macro/meso model NEMO in such a way that we can use bottom-up (micro) information to estimate most model parameters.

In our view, reflected in NEMO, the energy-efficiency gap arises for two reasons. The first is that firms and households use a fairly high discount rate of 15% when evaluating the profitability of energy-efficiency improvements. The second is that our bottom-up information ('ICARUS') for most economic sectors does not (as NEMO does) take account of the fact that implementation of new, energy-efficient technology in capital stock takes place only gradually.

Parameter estimates for 19 sectors point at a long-term technological energy efficiency improvement trend in Netherlands final energy use of 0.8% per year. The long-term price elasticity is estimated to be -0.29. These values are comparable to other studies based on time series data. Simulations of the effects of the oil price shocks in the seventies and the subsequent fall of oil prices show that the NEMO's price elasticities are consistent with historical data. However, the present pace at which new technologies become available (reflected in NEMO) appears to be lower than in the seventies and eighties. This suggests that it may not be adequate to extrapolate historical trends of energy efficiency improvements into the future.

We used NEMO to predict energy efficiency improvements in long-term scenario's developed by CPB in 1997. Policy simulations show that NEMO is especially suited to predict effects of energy taxes on energy use. It can also be used to assess other policies; in some cases, this requires additional assumptions. Nevertheless, NEMO offers a systematic way to analyse effects of various policies.