A CGE Analysis of the Employment Double Dividend Hypothesis –

Substitution Patterns in Production, Foreign Trade, and Labour Market Imperfections

Inaugural-Dissertation zur Erlangung der Doktorwürde
an der Wirtschaftswissenschaftlichen Fakultät
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Heidelberg, Mai 2001

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1 Introduction

This work deals with the double dividend hypothesis and the macroeconomic impacts of ecological tax reforms – a topic that has become very prominent during the last ten years. The double dividend hypothesis claims that environmental taxes not only reduce pollution (first dividend), but raise tax revenues that can be used to cut other distortionary taxes in order to enhance the allocative efficiency of the (non-environmental) tax system (second dividend). In the European countries, which suffer – more or less – from long-lasting unemployment, the second dividend is mainly interpreted as a reduction in the tax burden on labour and as having positive employment effects. In this context, the hypothesis of the 'employment double dividend' (EDD) was established. While the theory of the EDD has been widely developed during recent years, there is still a lack of empirical research that quantitatively evaluates the employment effects of ecological tax reforms and analyses potential trade-offs between the first and second dividend.

This empirical study intends to close this gap partially by using different methods of applied economics. The essential focus of this thesis is the evaluation of the macroeconomic (mainly employment) effects of a shift from labour to energy taxes in a computable general equilibrium (CGE) framework. The underlying model is GEM-E3, a multi-country, multi-sector CGE model developed by the ZEW, Mannheim, together with other European research institutes by order of the European Commission (DG XII).

Basically, CGE models are outstanding in quantitatively evaluating tax policies since they consider (i.a.) the interrelations between energy and labour market distortions. CGE model results, however, are only as good as the theoretical assumptions and the empirical data base on which they rest. Hence, the main task of this work is to theoretically respecify some of the functional forms, to substantiate important parameters used in GEM-E3 by applying econometric methods, and to test whether these modifications affect the EDD outcome.

The GEM-E3 model can be applied either in the EU-14 model version, covering 14 EU countries that all are linked via bilateral trade flows, or in the single-country version, e.g. for Germany. Two ecological tax reform scenarios are applied in this work. Both consider a shift from social security contributions to the tax on CO_2 emissions for producers and consumers. One scenario assumes an EU-wide co-ordinated tax policy and is applied to the GEM-E3 EU-14 version. The other scenario simulates a unilateral ecological tax reform in Germany and is thus applied to the single-country version for Germany.

The remainder of this work is divided into five chapters:

In Chapter 2 I review the theoretical literature on energy taxes and ecological tax reforms. I turn first to an assessment of energy taxes with respect to ecological effectiveness, cost effectiveness, and innovation incentives; the question of whether such an instrument can raise revenues is another evaluation criterion. I then survey the theoretical literature on ecological tax reforms and identify the conditions under which an EDD can emerge in models with perfectly competitive labour markets and in models that consider involuntary unemployment. Generally, one will find that positive employment effects can occur only on the condition that the ecological tax reform induces tax shifting effects from labour to other sources of private income that are sufficiently high to offset the negative tax burden effect on labour.

Chapters 3 to 5 concentrate on the impact that substitution elasticities, foreign trade elasticities, and labour supply elasticities have on the EDD outcome.

In Chapter 3 I focus on the possibilities of tax shifting processes from labour to other factor income and test the sensitivity of the GEM-E3 single-country version for Germany with respect to substitution patterns in production. Today there are only a few empirical studies available that deal with detailed substitution patterns in the German economy, refer to both producing and service sectors, and account for disaggregated energy inputs. Therefore, I estimate price and substitution elasticities between capital, labour, material, electricity, and fossil fuels for four sector aggregates: energy supply, energy- and nonenergy-intensive manufacturing, and service sectors. The data basis consists of pooled time series and cross sections for nearly fifty sectors over the period 1978-90. I provide sectoral estimates for both the non-nested and the three-level nested translog cost function, where the latter fits into the nested production structure of the GEM-E3 model. Estimations are completed by econometric tests on returns to scale of the sectoral production functions and tests for weak homothetic separability. I introduce the estimates of the nested translog cost function into the GEM-E3 single country version for Germany and conduct sensitivity analyses.

The focus of Chapter 4 lies on the impact of terms-of-trade effects on the EDD outcome in the GEM-E3 EU-14 model. Since terms-of-trade effects depend on the specification of import and export demand and supply functions of both the EU-14 and the rest of the world, I first review the general options for a foreign closure. A world closure is necessary in the GEM-E3 EU-14 model since the behaviour of the rest of the world is kept exogenous in large parts. After describing the foreign trade system of the GEM-E3 EU-14 model, I propose three changes in the foreign trade system: First, I relax the small-country assumption for the EU and assume that trade activities of the EU affect world prices. Second, I introduce a feedback mechanism between macroeconomic developments in the EU and the foreign sector. Finally, I reparameterise the upper-level Armington elasticities in both foreign and EU's import demand functions, thus changing the own-price elasticities of sectoral import demand functions. The sensitivity of the GEM-E3 EU-14 model with respect to the employment effects of an EU-wide co-ordinated ecological tax reform is tested for all these specifications.

Chapter 5 deals with the labour market and concentrates on empirical modelling of the wage setting process in Germany. First, I characterise the institutional structure of the German labour market and analyse the role of trade unions in the German wage formation process. The main interest of this chapter is the derivation of a wage setting equation from a monopoly union model, in which it is assumed that the trade union has sufficient power to unilaterally set the wage (given labour demand). This wage setting equation, as well as an exogenous wage model, are introduced into the single-country version of the GEM-E3 model. I analyse whether employment effects of a shift from energy to labour taxes are strengthened or diminished (compared to the neo-classical labour market specification) in the cases of exogenous real wage rigidities and a monopoly union. Moreover, I consider two policies of unemployment compensation: a fixed replacement ratio of unemployment benefits to wages and nominally fixed unemployment benefits.

Finally, in Chapter 6 I summarise the main results, draw a conclusion, and identify areas where future research is needed.

2 Energy taxation and the employment double dividend

2.1 Introduction

Since the beginning of the 90’s, energy taxes, either based on the energy and/or the carbon content of energy products, have been unilaterally introduced in a number of Western European countries in order to reduce energy consumption and CO_2 emissions (cf. Ekins and Speck 1999, Scholz 1999, Smulders and Vollebergh 2000). Compared to other commonly-used climate policy instruments, such as energy efficiency standards or voluntary agreements, energy taxes are (in general) advantageous for various reasons; in particular they minimise overall abatement costs and provide long-term incentives to introduce energy-saving technologies.

Currently, tradable permits (emissions trading) are another much-discussed climate policy instrument, which is frequently considered to compete with taxes.[1] While the allocative outcome under both instruments is the same in a static, neo-classical framework, permits and taxes are far from being perfect substitutes in reality where transaction costs and other market imperfections exist, but show specific advantages for use in different sectors or at different levels of application.[2] Thus, even if Germany and other European countries may someday participate in a global emissions trading system, energy taxes will remain important instruments in national or EU-wide climate policies. After all, the supplementarity principle established in the Kyoto Protocol requires that flexible mechanisms such as emissions trading may only be used to supplement domestic actions, which, in turn, must be promoted by domestic policies such as energy taxes.[3]

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[1] See Fisher et al. (1996) for a comprehensive overview of policy instruments for greenhouse gas mitigation.

[2] The role of transaction costs for the assessment of environmental policies has gained importance during recent years. Considering transaction costs, Brockmann et al. (1999) discuss the appropriateness of different climate policy instruments for different sectors. If there are transaction costs, Stavins (1995) finds that the initial allocation of tradable permits may affect the final equilibrium, i.e. transaction costs may reduce the information advantage of tradable permits over emission taxes (cf. Section 2.2.2.2). Thus, Stavins rightly emphasises the importance of the effects of transaction costs and the necessity of case-by-case examinations. See Krutilla (1999) for a broad overview of the transaction costs literature.

[3] The Kyoto Protocol within the United Nation Framework Convention on Climate Change of December 1997 (UNFCCC 1997) represents the main basis for present global climate policy. It

In a second-best world with tax distortions, a further difference between taxes and (grandfathered) permits concerns fiscal aspects.[4] During the last few years, European politicians have seen an important advantage of energy taxes in that these may generate a double dividend.[5] Among economists, however, the double dividend hypothesis is controversially disputed and is the object of a series of recently published papers.

The remainder of this chapter is organised as follows: Section 2.2 briefly introduces the functioning of national and international tax systems and the main characteristics of energy taxes. Section 2.3 takes up in more detail the revenue-recycling issue in the context of energy taxation, reviews the theoretical and empirical literature on ecological tax reforms and clarifies the main mechanisms that may trigger an employment double dividend. The results of this chapter and the implications for CGE modelling are summarised in Section 2.4.

2.2 Comparative advantages of energy taxes in climate policy

Section 2.2.1 discusses the general appropriateness of taxes for use in national and international climate policy. In Section 2.2.2 I assess energy taxes with respect to their environmental effectiveness, cost effectiveness, and ability to provide innovative incentives and compare them to tradable permits. In a second-best world with distortionary factor and commodity taxes, where the availability of instruments is limited, a fourth criterion for instrumental choice refers to revenue-recycling issues.

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fixes legally binding quantified greenhouse gas emission limitations and reduction objectives for Annex I Parties. An aggregate reduction of six greenhouse gases by 5.2% from 1990 levels in the budget period 2008 to 2012 is prescribed for all industrialised countries.

[4] This difference disappears when permits are initially distributed to emitters by an auction. I assume that permits are initially allocated free-of-charge. Indeed, as confirmed by the U.S. experience with the Acid Rain Program, tradable permits which are not initially distributed by grandfathering but are auctioned off do not seem to be politically feasible today (cf. Koschel et al. 1998).

[5] Koschel and Weinreich (1995) present a survey of the popular arguments in favour of an ecological tax reform.

2.2.1 Current practice and practicability of national and internationally co-ordinated tax systems

The literature distinguishes between three types of tax systems operating at different levels: domestic taxes, international taxes, and internationally harmonised domestic taxes (cf. Hoel 1992). When considering institutional problems regarding international transfer payments, the following discussion indicates that energy taxes are mostly appropriate for use at the individual domestic country level.

2.2.1.1 Domestic tax systems

Within domestic tax systems national governments specify the tax rate and collect the tax revenue. Domestic energy taxes, partly based on the carbon content of fossil fuels, have been unilaterally introduced during the last ten years in a number of EU countries, such as Sweden, Norway, Denmark, Finland, and the Netherlands (cf. Ekins and Speck 1999, Scholz 1999). Austria also introduced an energy tax on electricity and natural gas in 1996; in Germany an energy tax on mineral oil, gas, and electricity was imposed in April 1999. In most of these countries, the revenues of the energy tax are somehow recycled back to private households and firms, keeping overall tax payments constant. In order to limit impending competitive losses of domestic industries in international trade and to protect the economy against the outflow of physical capital into foreign countries and carbon leakage,[6] governments frequently created tax exemptions for the country's industry or reimbursement schemes for energy-intensive industries[7] (cf. Ekins and Speck 1999).

Theoretically, countermeasures against carbon leakage in the form of sectorally differentiated environmental tax rates may be the second-best solution if the use of trade instruments, such as import and export tariffs, is ruled out by international trade agreements, e.g. the GATT (cf. Hoel 1996, 1999).[8] In reality, however, the practical

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[6] Carbon leakage appears when, in reaction to a carbon abatement policy taken unilaterally by one or a group of countries, the emissions in other non co-operating countries (other things being equal) rise.

[7] In practice, refunding schemes typically limit the maximum amount of the energy tax payments in relation to firm specific figures, such as production costs or savings from reduced rates of social security contributions. They aim less at increasing the firms' investment effort (cf. Gersbach and Requate 2000 for an analysis of the optimal design of refunding schemes) than at protecting the economy against undesired distributional effects.

[8] Applying the GTAP-EG model, Paltsev (2000) shows that welfare always decreases when sectors are absolutely exempted from carbon taxation. Based on the emission reduction targets laid down in the Kyoto protocol, he calculates the sectoral contributions of individual Annex B

implementation of the appropriately differentiated tax rate system is difficult and runs the risk of being abused. The European Commission (1997a) recently issued an urgent warning that sectoral tax exemptions may constitute state aid as defined by Art. 92(1) of the EC Treaty. It thus strongly recommends that any tax relief or compensation should only be temporary and should not provide the exempted sector with a net benefit. Consequently, the Commission did not accept the first German proposal in 1998 for an ecological tax reform (Deutscher Bundestag 1998) in which several energy-intensive sectors were completely exempted from the tax while they profited fully from the reduction of the employers' share in social security contributions.[9]

2.2.1.2 International tax system

Within an international tax system the participating countries agree on a uniform tax rate and an intergovernmental reimbursement rule for tax revenues. The reimbursement rule determines the international cost sharing in much the same way as the initial allocation for carbon quotas within an international emissions trading system.

Similar to an international emissions trading system, every signatory country is free to choose, under an international tax, policy instruments so as to meet the allowed amount of emissions (covered by permits or tax payments) in the country. As Hoel (1992) argues, in the absence of any market distortions, a domestic (carbon) tax with a tax rate equal to the international tax rate would be the optimum solution for a country. Alternatively, the national government can implement a national market for carbon permits and distribute the amount of carbon entitlements in a way that leads to a national permit price equalling the international tax rate.

The practical implementation of an international tax regime is difficult as it requires the establishment of an international authority which administers the collection and international reallocation of tax revenues. Under an international permit system, the sovereignty of governments is less affected. Here the initial (free-of-charge) allocation of permits to countries primarily determines the burden sharing, and ex-

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countries to carbon emissions leakages into the non-Annex B countries and finds that any sectoral exemption increases welfare costs.

[9] A sectoral differentiation in the tax rate could also be justified by administrative costs. In practice, however, energy-intensive industries, which can be taxed with the lowest transaction costs per unit emission, are typically exempted (cf. Smulders and Vollebergh 2000:30).

post side payments, if at all, are only needed in order to correct undesired distributional outcomes due to unforeseen general equilibrium and terms-of-trade effects. Montgomery (1972) was the first to point out that the initial permit allocation has no consequences for the allocative efficiency of abatement costs because it represents a lump sum endowment. The possibility to resolve international burden-sharing issues by the initial permit allocation is in fact a comparative advantage that an international tradable permit system has over an international tax system.

2.2.1.3 Multilateral agreement to harmonise domestic taxes

Multilateral agreements to harmonise domestic taxes are a second approach to create internationally co-ordinated tax systems. Within such an agreement, national tax rates are determined for a group of countries, i.e. countries commit themselves to apply a uniform, negotiated tax. As the tax revenues are collected and reimbursed by the national governments, no international reimbursement rules need to be specified in the agreement.[10] Hence equity issues that become significant if countries differ substantially from another with respect to abatement costs or real income can only be addressed by a separate agreement on transfer payments.

2.2.2 Evaluation of energy taxes

The previous section explained that tradable permits are superior to environmental taxes in international climate policy as they regulate the burden sharing between countries through the initial permit allocation, thus avoiding complicated financial transfers between sovereign countries. At the national level, however, this comparative advantage of tradable permits disappears, and taxes seem to be at least as suitable as tradable permits. A more detailed comparison of both instruments is required, which I present in the following sections.[11]

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[10] Two examples of (never implemented) multilateral agreements to harmonise national taxes on energy products are the European Commission’s proposal for an EU-wide carbon/energy tax system (European Commission 1992) and the proposal for a common EU-wide excise tax duty system on energy (European Commission 1997b, see Jansen and Klaassen 2000 for further details).

[11] In Rennings et al. (1996:78-105) and Capros et al. (1999:27-60), I provide a comparison of environmental taxes not only with tradable permits, but also with other environmental policy instruments, such as voluntary agreements or technological standards.

2.2.2.1 Environmental effectiveness

In practice, emission taxes are less environmentally effective than tradable emission permits which can guarantee the attainment of a given quantified emission target (if properly monitored and enforced).[12] If the regulator has insufficient information on the aggregate abatement cost function, this may lead to uncertainties in setting the accurate tax rate level (cf. Hoel 1998:81, see also Weitzman 1974). Adjustments of the tax rate at a later point of time in a trial-and-error process delay the attainment of the environmental goal if the tax rate is set too low. On the other hand, if the firm's adjustment to the tax rate needs time and if the regulator reacts too quickly, the emission tax may go too far and lead to unnecessarily high costs of attaining the desired emission reduction target (Siebert 1998:118).[13] The regulator's information deficits carry weight particularly if environmental policy aims at realising an precisely predetermined emission reduction target in order to avert dangers. They are, however, of minor importance in real-world climate policies in which tax rates frequently increase only slowly over time and are set at reasonable levels (for which overshooting is unlikely).

A further characteristic of taxes is that the tax rate, theoretically, must be adjusted to changes in economic conditions, such as cost-saving technical progress, in order to maintain a given (optimally set) emission level. Under a permit system technological progress results in a drop of the permit price, whereas technical progress is directly translated into further emission reductions under an emission tax (cf. Section 2.2.2.3).

2.2.2.2 Cost effectiveness

By sending a uniform price signal to all emitters, emission taxes theoretically equalise source specific marginal abatement costs and lead – in an ideal world without transaction costs – to a cost-effective attainment of a given emission reduction goal. In theory, emissions trading also represents a cost-effective option to implement emission reduction goals, provided that transaction costs are negligible,

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[12] For a comprehensive survey on tradable permits see Koschel et al. (1998).

[13] This is confirmed by empirical experience gathered in the U.S. Acid Rain Program for sulphur-dioxide (SO_2) permits. There is a significant discrepancy between the ex-ante estimation of aggregate marginal abatement costs (around 1000 \$/t SO_2) – which would have served as the basis for setting the tax rate in an equivalent tax system – and the actual permit price (around 100 \$/tSO_2). This reflects, on the one hand, the impact of unforeseen technical progress, and, on the other hand, the impossibility of obtaining true information on private marginal abatement costs of firms (cf. Koschel et al. 1998).

markets are perfectly competitive,[14] and emissions are chosen to minimise abatement costs (cf. Montgomery 1972). At the level of the individual emitter, both instruments offer more scope for behavioural choice than technical standards, as the emitter can choose between reducing emissions – by output reduction, input substitution, or the implementation of advanced additive or integrated environmental technologies – or paying the tax (or buying permits, or abstaining from selling permits respectively).

When emissions are taxed directly, the emitter has the broadest scope for action and private (individual and aggregate) abatement costs reach the lowest level. If there are transaction costs, however, it might be more cost-effective sometimes to control emissions indirectly by taxing the excise of inputs.[15] In this context, Smulders and Vollebergh (2000) examine the potential trade-off between administrative costs and the incentives of environmental protection and propose general conditions under which an excise tax will result in less total costs when internalising environmental externalities. These include a close linkage of emissions with inputs, the existence of only a few and expensive additive technologies so as to abate emissions directly, and relatively high administrative costs of emission taxes. As the authors demonstrate, these conditions are satisfied in the case of carbon taxation. Accordingly, the taxation of the excise of energy products instead of emissions is the current strategy that most countries use which introduced a carbon tax.

2.2.2.3 Incentives for innovations

Apart from its ecological and cost effectiveness, an instrument's ability to provide incentives for innovations has become a popular criterion in environmental policy assessment. This growing interest is, not least, related to the popular, but heavily

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[14] The problem of strategic manipulation and oligopolistic interaction in tradable permit markets has been addressed in several studies, as in Hahn (1984), Misiolek and Elder (1989), Tietenberg (1990), Mørch von der Fehr (1993) and others. Indeed, when competition is not perfect, for instance, if a single firm has some market power, it may use this to manipulate the permit market to its own advantage. Thus it is important to guarantee in particular cases that a sufficient number of firms is involved. This is often the case in carbon abatement policy, where a restriction of the market region for ecological reasons is not necessary (cf. Koschel et al. 1998).

[15] In the case of carbon taxation, second-best taxation of inputs requires that fossil fuels (coal, oil, and gas) are taxed according to their specific carbon content and not according to their energy content. In desired substitution processes the latter discriminates between carbon-intensive and less carbon-intensive fossil fuels and leads to additional distortions. Note, however, that the optimum design of a carbon tax changes if other goals are considered, such as the protection of scarce energy resources. Measures regarding CO_2 reduction and natural resource protection, however, should not be combined in practice since their efficient design has to be based on different criteria.

disputed Porter hypothesis which states that “properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them“ (Porter and van der Linde 1995:98). A central question in the recent literature is whether environmental taxes are more appropriate to give incentives for the development and/or adoption of new technologies than other environmental policy instruments. In addition, optimisation models analyse the dynamic efficiency of these incentives, i.e. the efficiency of resource allocation after the innovation has taken place.[16]

At present there is no final consent in the theoretical literature whether taxes, in terms of dynamic efficiency, are superior to other climate policy instruments or not.[17] Different rankings of environmental policy instruments are mainly the outcome of differences between the underlying modelling frameworks.[18]

Economic instruments typically dominate direct controls in the majority of the (earlier) perfectly competitive, partial equilibrium models, which are frequently based on graphical argumentation (cf. Downing and White 1986, Milliman and Prince 1989, Jung et al. 1996, Malueg 1989). Disagreement exists as to whether auctioned permits and free permits provide different innovation incentives and whether auctioned permits are superior to emission taxes or not. Requate and Unold (1997, 1999), for instance, discover that permits never induce higher incentives to adopt new abatement technologies than emission taxes do and that auctioned and grandfathered tradable permits are equivalent in terms of their innovative incentives. In addition, the authors demonstrate that a permit policy may be superior to a tax policy from a social welfare perspective. The reason for this is that if the policy (tax rate or amount of permits) was set optimally before starting innovation and if partial adoption of the new technology is socially optimal, taxes may give firms innovation incentives that are too high while tradable permits induce too few firms to adopt the new technology. When considering the possibility of ratcheting, i.e. the optimal policy adjustment after innovation, a permit system is superior to an emission tax, as the government can reduce the number of permits at a later point in time in order to

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[16] Note that ‘dynamic efficiency’ and ‘innovative incentives’ have two different meanings. An instrument with the highest incentive to innovate does not necessarily provide the highest dynamic efficiency (cf. Requate and Unold 1997).

[17] Unfortunately, empirical evidence is weak as well due to the very limited use of economic instruments in actual real-world policies, (cf. Jaffe and Stavins 1995).

[18] The following discussion is a summary of Koschel (1998).

reach the social optimum ex post. Under a tax system, however, the social optimum can be realised only by an ex-post tax rate reduction, which is associated with a devaluation of installed physical capital.

Recently, the perfectly competitive innovation models have been widely questioned because of the restrictive assumptions they rely on.[19] Experts criticise most frequently the fact that such models assume perfect competition and full information and consequently neglect strategic market behaviour. In addition, they ignore product market feedbacks but maintain the level of output quantity and output prices. In response to this criticism, recent literature has been concerned with analysing the incentives to innovate if some of the assumptions listed above are relaxed.

Giving up the assumption of perfect competition and considering 'strategic incentives' as an essential force for innovation has led to the development of a host of game-theory, fixed-number duopoly or oligopoly model approaches (cf. Beath et al. 1995).[20] The studies in this area concentrate mainly on the analysis of emission taxes, environmental standards, and subsidy schemes. They take into account that R&D activities of an individual firm cannot be analysed out of context but are considered as being dependent on the R&D activities of its competitors. In addition, they no longer ignore product market effects, such as an instrument's impact on the firm's output and the effect of an output reduction on R&D expenditure. Under specific conditions, for example with respect to the degree of product market competition, this negative output effect (which tends to be relatively high under a cost-raising tax) may dominate the direct incentive effect on R&D. Therefore, as technological standards lead to higher industry output, they may – in specific cases – promote more R&D spending.

Since the endogenous growth theory gained prevalence, several studies have been published analysing the interconnection between environmental policy instruments, R&D spending and innovation in general equilibrium endogenous growth models. Hung et al. (1994), Verdier (1995), and Elbasha and Roe (1996), for instance, all

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[19] Common model assumptions are as follows: 1. firm incentives to innovate are measured as the savings in the firms' abatement costs, 2. innovation in emission control is modelled as a downward exogenous shift in the marginal abatement cost curve, 3. abatement costs increase continuously with emission reductions, 4. polluters maximise profits, and 5. the regulating agency has perfect information on the marginal cost curves and the marginal damage function (cf. Kemp 1997).

[20] See also Carraro and Soubeyran (1996), Katsoulacos and Xepapadeas (1996), and Ulph (1997). For a presentation of these studies see Koschel (1998).

consider monopolistic competition in commodity markets by employing the product variety approach. Fixed production costs are represented by industrial R&D costs, and free-entry of firms is assumed. Taking into account not only environmental externalities, but also static distortions in the product market and dynamic distortions related to R&D activities,[21] a central question in these studies is how policy intervention should be designed in order to achieve the optimum growth rate of innovation. Unfortunately, none of the available studies compares different types of instruments with each other. Elbasha and Roe (1996) come to the conclusion that there is a range of second-best policy options (including emission taxes or R&D subsidies) to bring both competitive and optimum growth rates of innovation into line with each other. The model of Verdier (1995) indicates that an emission tax leads to a higher growth rate than a technical standard. The extent to which emission taxes may or may not dominate technological standards from a dynamic welfare perspective depends, however, on the strictness of the emission target. All in all, the endogenous growth theory gives new insights into the ranking of environmental policy instruments. The results, however, do not seem to completely oppose existing (partial equilibrium) analyses but rather complement them.

2.2.2.4 Revenue-raising issues

As already mentioned, in a second-best optimal world, a further criterion for instrumental choice is an instrument’s ability to raise public revenues. Tax revenues can be used (alternatively or side-by-side) to:

- support distributive and social equity goals, e.g. alleviating undesired negative economic or social side-effects. This refers to tax revenue refund systems for energy-intensive firms or households.
- increase the incentive effect of the environmental tax or create additional environmental incentives. This includes public financing of environmentally

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[21] The latter may include three further distortion effects (cf. Verdier 1995:192): 1. the consumer surplus effect, which arises when innovators do not take into full account the increase in the consumer surplus associated with the innovation, 2. the profit destruction effect, which reflects that innovators decide only on the basis of their own private profits without considering the profit destruction of other firms, and 3. the research spillover effect, which results from the fact that innovators are not able to appropriate returns to R&D completely; it is frequently assumed that innovators can only appropriate the returns to product-specific knowledge, whereas general knowledge spills over and increases the public knowledge stock, which, in turn, facilitates subsequent innovation (cf. Grossman and Helpman 1991:44).

friendly infrastructure and public services as well as the support of R&D and investments in energy saving measures.[22]

– finance the cut in the marginal rates of other existing distortionary taxes in order to reduce the excess burden associated with these taxes. Considering the high unemployment figures in most European countries, the most-discussed option in this context is the cut in labour tax rates in order to reduce the excess burden in the labour market.

The third option of revenue recycling has led to a growing interest in energy taxes over recent years. In this context, the double dividend argument was brought into discussion: The first dividend is related to lower pollution levels, whereas the second dividend generally reflects an increase in the efficiency of the non-environmental tax system which may be realised if the revenue of the environmental tax is returned through cuts in distortionary pre-existing taxes such as labour taxes. Particularly if the government is unable to run alternative policies to reduce the excess burdens associated with certain taxes (e.g. for political-economy reasons), the ability to raise revenues might be a strong argument in favour of environmental taxes (cf. Bovenberg 1995:119).

2.3 The employment double dividend: a literature survey

In this section, I summarise the main findings in the literature on revenue-neutral ecological tax reforms. The literature on the double dividend can be divided broadly into two branches (cf. Bosello et al. 1999).[23] The first branch interprets the second dividend in terms of welfare and distinguishes between a weak and a strong double dividend.[24] The second branch defines non-environmental benefits in terms of macroeconomic indicators, such as GDP or employment. Following the European

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[22] Strand (1999) is a recent example for a double dividend paper in which revenues from the pollution tax are used to subsidise capital investments of firms.

[23] Further surveys of recent double dividend literature and results are Majocchi (1996), Ligthart (1998), Pezzey and Park (1998), Bovenberg (1999), and Perry (1999).

[24] The weak double dividend requires that the recycling of tax revenues through cuts in distortionary taxes lead to less welfare costs (i.e. a lower excess burden), compared to the case where revenues are returned in a lump sum way. The strong double dividend hypothesis claims that the revenue-neutral introduction of environmental taxes, which partially or completely replace other distortionary taxes, involves zero or negative non-environmental gross costs (cf. Goulder 1995). Most literature concentrates on the strong form. Actually, the evidence of a strong double dividend would imply that an ecological tax reform is equal to a no regret strategy, thus increasing political acceptance considerably.

research line and motivated by the increase in long-term unemployment in Europe,[25] the main focus of this survey is on the employment effects of ecological tax reforms. This interpretation of the double dividend is known in literature as the employment double dividend (EDD) (cf. Carraro et al. 1996).

The theoretical literature indicates that an EDD can emerge only if the ecological tax reform successfully shifts parts of the tax burden from wage earners to non-workers. In this context, three ways of tax shifting are discussed, namely tax shifting to non-labour production factors (e.g. owners of capital), to recipients of transfer income (e.g. pensioners or the unemployed), and to the foreign sector (e.g. foreign owners of fossil fuels or foreign users of intermediates).

Section 2.3.1 specifies some common assumptions on which most analytical EDD studies are based. Section 2.3.2 summarises the basic transmission channels through which employment is affected in models with perfectly competitive labour and commodity markets, where only environmental and tax distortions exist. Section 2.3.3 then reviews the more recent literature, in which the neo-classical framework is extended by non-tax market imperfections due to price and wage setting behaviour of agents. I focus on models with production externalities, in which a polluting tax on intermediate inputs, such as energy, is levied on producers and where revenues are recycled through a cut in the labour tax.

2.3.1 Typical model assumptions

Nearly all models analysing the EDD outcome rely on a general equilibrium framework in order to account for energy and labour market interactions. Most models employ comparative static analysis and examine only marginal changes in the tax structure. Frequently, different initial equilibria with either zero or positive energy taxes are considered, whereby initially positive energy tax rates are supposed to approximate the impacts of large environmental taxes.[26] The labour market is

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[25] According to Friedmann (1998), the EU-15 unemployment rate has risen from 1.9% in 1964 to almost 11% by mid-1996. Unemployment rates, however, differ considerably between countries. In mid-1996, the EU-countries with the highest unemployment rates were Spain (23%), Finland (18%), and Ireland (15%). France and Italy prevail with rates around 12%. Germany is, along with Belgium, Austria, Sweden, Greece, and the UK, in the middle with 9-10%. Unemployment is lowest in Denmark, the Netherlands, Portugal (around 7%), and Luxembourg (less than 3%).

[26] If the initial energy tax is zero, an ecological tax reform, consisting of a marginal energy tax, produces no additional excess burden. The magnitude of the additional tax burden depends largely on the initial level of the energy tax rate, which determines the marginal costs of reducing energy consumption.

distorted by a positive tax on labour[27] which is imposed – in the absence of lump sum taxes in a second-best world – in order to finance public spending. The labour tax drives a wedge between real producer and real consumer wages and distorts labour supply decisions. In the presence of distortions arising from labour taxation a rise in employment improves welfare (ceteris paribus).[28]

Ensuring (ex post) revenue neutrality, the overall governmental tax revenue is kept constant by fixed public spending. In the majority of studies the tax rate on labour is determined endogenously and balances the public budget.[29] In addition, it is assumed that the economy is on the left hand side of the Laffer curves for both the labour and energy tax, thus ensuring that a marginal increase of the energy tax rate leads to a fall in the labour tax rate.

Frequently, production is modelled on Cobb-Douglas or nested constant-elasticity-of-substitution (CES) functions with (maximally) two clean primary production factors (typically labour and capital) and the polluting input (e.g. energy), while intermediate nonenergy material inputs are neglected. Labour is internationally immobile in nearly all models.

The majority of studies neglects environmental feedbacks on labour supply and labour productivity. Environmental benefits are interpreted as a public good that is weakly separable in the utility function; environmental quality in particular is supposed to be a substitute for leisure. Only a few recent studies show that environmental feedbacks on labour demand (e.g. Bovenberg 1997) and labour supply (e.g. Kahn and Farmer 1999, Schwartz and Repetto 2000) may – in the long run – offset negative effects on the real after-tax wage rate, so that the prospects for a double dividend increase. However, allowing for a complementary relationship

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[27] The tax on labour may consist of either a labour income or a payroll tax. Studies which are closer to reality consider both taxes and introduce non-wage labour costs, such as social security contributions of employers and employees.

[28] Intuitively this can be explained by the fact that the benefit of an additional unit of labour consists of higher output (according to the marginal product of labour) and of additional labour tax revenues. When deciding on leisure and consumption, however, the private household neglects the social benefit of employment in terms of higher tax revenues and takes into account only the private benefit in terms of higher production.

[29] De Mooij and Bovenberg (1998) and Bovenberg and Goulder (1997) are exceptions. They also analyse a cut in capital taxes. In a model with consumption externalities, Scholz (1998) points out that a second dividend is closely attached to the choice of the commodity tax which is reduced in reaction to higher taxes on the polluting consumption good. In this work, I will focus on the substitution of energy for labour taxes.

between leisure and environmental quality may exacerbate the negative impact on labour supply (cf. Bovenberg and de Mooij 1994, de Mooij 2000:219).

Apart from these common features, analytical EDD models differ from each other with respect to the type of environmental externality (consumption or production externalities), the size of pre-existing tax distortions, the production and consumption structure and substitution patterns, foreign trade specifications, and supply elasticities of non-labour production factors. The double dividend outcome also depends on whether or not households receive non-wage income, such as transfers, and whether markets are perfectly competitive or characterised by wage and price setting behaviour of agents.

In the following sections, I use the degree of labour market competition to arrange the EDD studies into two groups. The first encompasses the studies which assume a neo-classical labour market, the second presents the studies which consider non-tax labour market imperfections. I discuss the remaining other determinants for an EDD in the individual context.

2.3.2 Employment effects of an ecological tax reform in a perfectly competitive framework

The earlier literature on ecological tax reforms neglects involuntary unemployment and relies on perfectly competitive labour markets with fully flexible and market-clearing real wages.

2.3.2.1 Introductory graphical analysis

Figure 1 illustrates the impacts of an ecological tax reform on the labour market equilibrium in a partial neo-classical framework with a fully flexible real wage.

Consider a small open economy with a profit maximising representative firm that produces a final output good. Labour demand, represented by the LD curve, depends negatively on real labour costs, i.e. the real producer wage w_P. Furthermore, consider a utility maximising representative household that finances private consumption with after-tax labour income. Labour supply is calculated as the difference between some exogenous endowment of time resources (total time TT) and the endogenous demand of leisure. The latter results from maximising the household's utility function, including leisure and consumption goods. Labour supply depends positively on the real consumer (net or after-tax) wage w. Assume that the government levies an ad-valorem tax on labour income t_L (or, equivalently, a payroll tax). Without consumption taxes, the producer's price index is equal to the consumer's price index and it is $w=w_P(1-t_L)$. In the absence of payroll taxes, such as employers' contributions to social security, w_P is equal to the real gross wage which is defined as the real net wage plus income taxes plus employees' social security contributions (cf. footnote 56). In literature, the difference between the real producer wage w_P and the real net wage w, which can be attributed to all commodity and factor taxes (including social security contributions) that are borne by labour, is called the *tax wedge* (cf. Tyrväinen 1995:13, Steiner 1998:317). According to Nickell and Layard (1999), the total average tax wedge in the period 1989-1994 is approximately 53% in Germany.[30]

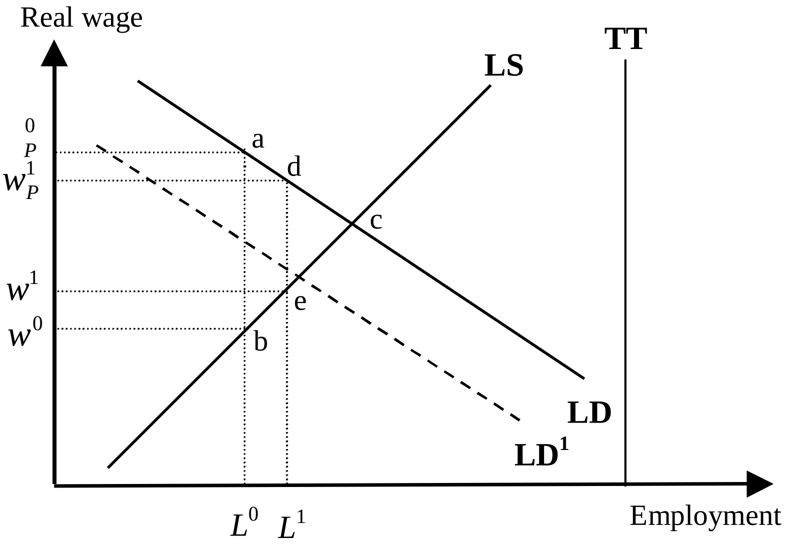

Figure 1: Employment effects of an ecological tax reform, neo-classical labour market

Let us turn to Figure 1. In the initial labour market equilibrium, employment L^0 is supplied by the representative household at the real net wage w^0 and demanded by the firm at the real producer wage w_P^0. The initial tax wedge ($w_P^0 - w^0$) causes an excess burden on the labour market, which is represented by the Harberger triangle *bca*.[31]

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[30] Among the EU-15 member countries, Sweden (70.7%), Finland (65.9%), France (63.8%), Italy (62.9%), the Netherlands (56.5%), Spain (54.2%), and Austria (53.7%) have a higher average tax wedge than Germany for the same period (Nickell and Layard 1999:3038).

[31] The excess burden of a tax system is defined as the amount of welfare that is lost in excess of what the government collects (cf. Auerbach 1985:67). Note that the change of environmental quality (representing the first dividend) is not included in this welfare measure. The excess burden, represented by the triangle *bca*, results from the difference between the aggregate labour tax induced loss of surplus suffered by the employee and the firm ($w^0bcaw_P^0$) and the labour

Now we will assume that the government introduces an ecological tax reform. Consider first the labour market effect of a cut in the tax wedge. If energy tax revenues are reimbursed by a cut in the labour income tax t_L, the tax wedge is reduced to $(w_P^1 - w^1)$ and the Harberger triangle is reduced to *ecd*. The excess burden on the labour market shrinks by the area *beda*. In response to the higher real net wage labour supply rises from L^0 to L^1. The results change if the allocative effects of the energy tax increase are taken into account. On the producer side a higher tax rate on energy inputs in production leads to higher energy costs and to lower energy demand. The rise in the energy tax rate causes not only a reduction in pollution, but simultaneously increases the excess burden in the energy market. The latter is calculated as the balance between the loss in the firm's surplus in response to reduced energy demand and the amount of energy tax revenues.

The following sections will show that the incidence of the tax burden on private income is the crucial factor determining the employment effects of an ecological tax reform. In the simple two-factor model, on which Figure 1 is based (see Section 2.3.2.2), the excess burden of the energy tax is fully borne by real net wage income. Higher energy taxes lead to an increase in energy costs, which, in turn, reduces the firm's energy demand and labour productivity. The loss in labour productivity causes a downward shift of the LD curve, possibly to LD^1. As a result, the positive employment impact of revenue recycling is reduced and overcompensated (at least in the simple two-input model) by the negative allocative effect of the additional excess burden which is associated with the energy tax increase. Both the real net wage and employment decrease, provided that the uncompensated wage elasticity of labour supply is positive: The final equilibrium employment level (not depicted in Figure 1) lies somewhere to the left of L^0. Indeed, in the neo-classical labour market model the sign of the uncompensated wage elasticity of labour supply plays a crucial role for the sign of employment effects. According to the econometric literature, in Figure 1, and in most EDD studies, this elasticity is assumed to be (slightly) positive with respect to the real consumer wage.[32] Consequently, a second dividend in terms of employment can only emerge on the condition that the real net wage increases in response to the ecological tax reform.

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income tax revenues ($w^0baw_P^0$). Gottfried and Wiegard (1995) and Reding and Müller (1999: Chapter 4) explain the concept of the excess burden in greater detail.

[32] The uncompensated wage elasticity of labour supply is positive if the substitution elasticity between leisure and private consumption is above unity (cf. de Mooij 2000:34). See Blundell and MaCurdy (1999) for a review of empirical estimates of the uncompensated wage elasticity.

In the next section I will pick up the simple two-input model framework. Following de Mooij and Bovenberg (1998) and de Mooij (2000) I analyse in greater detail why the EDD hypothesis is rejected. I will then explain, however, that tax shifting effects from labour to other private incomes may occur under specific model assumptions, enlarging the scope for an EDD.

2.3.2.2 Tax shifting across production factors

De Mooij and Bovenberg (1998) and de Mooij (2000) show that a shift from labour to energy taxes reduces employment in a model of a small open economy with only two production factors and production externalities. The authors assume that a representative profit maximising firm produces a single tradable output good with only labour and energy as inputs, using a neo-classical, constant-returns-to-scale production function. The output market is perfectly competitive. While energy and output prices are given by the world market, wages are determined endogenously on the domestic market because labour is immobile. The only income of the representative utility maximising household is after-tax wage income. The pre-existing tax system includes a positive tax on energy input and labour income.

Two channels can be identified through which an ecological tax reform affects employment. Firstly, the energy tax increases energy and production costs. This cost increase cannot be passed on to consumers as commodity prices are fixed. Higher energy taxes induce firms to reduce energy input in order to avoid tax payments. Labour productivity, labour demand, and the real net wage decrease. The drop in energy demand contributes to environmental protection, but it also lowers the base of energy taxation and the amount of energy tax revenues. The erosion of the energy tax base stands for the additional tax excess burden, which is associated with higher energy prices and abatement costs and is fully borne by the private sector. Secondly, the recycling of energy tax revenues through a cut in the labour income tax alleviates the negative impact on the real after-tax wage. Due to the tax base erosion effect, however, the labour income tax rate cannot be reduced sufficiently to compensate entirely for the decline in the real before-tax wage: the real net wage decreases. Thus both labour supply and equilibrium employment decline and the EDD hypothesis cannot but fail in the two-input benchmark model with a competitive labour market and an upward bending labour supply curve. Obviously, a shift from labour to energy taxes reduces the efficiency of the non-environmental tax system since energy taxes, which are ultimate taxes on labour income, not only increase the labour market distortions, but additionally distort input choice decisions. This sets off a trade-off between the first and the second dividend.

The authors extend their benchmark model by a second clean production factor, (physical) capital,[33] and distinguish between two extreme cases of capital supply: internationally mobile capital or infinitely elastic supply of capital (*Case* 1) and internationally immobile capital or fixed domestic supply of capital (*Case* 2).

In the case of internationally perfectly mobile capital (*Case* 1), the nominal after-tax rate of return on capital is determined by the world market according to the law of one price, i.e. capital supply is infinitely elastic.[34] Since capital owners move their capital (partially) abroad in response to the capital tax in the absence of internationally harmonised capital taxation,[35] the ultimate burden of capital taxation in terms of real income is borne by immobile labour. Actually, as will be shown below, a capital tax only causes a decline of capital demand and leaves the after-tax return on capital unaffected. Assume that both a positive source-based tax on capital income and a positive energy tax are imposed in the initial equilibrium. From a revenue-raising point of view the initial tax system is inefficient not only with respect to energy taxation, but also with respect to capital taxation. Direct taxation of labour income is, in any case, superior to indirect taxation by means of a capital tax that additionally distorts investment decisions. The ecological tax reform affects non-environmental welfare and labour market distortions (employment) through two channels:

– Similar to the two-input model, the increase in the energy tax is associated with a tax burden effect that reflects the costs of a cleaner environment. The tax burden effect grows bigger the larger the initial energy tax rate is and the stronger the energy/labour ratio declines in response to the higher price for energy and the lower price for labour.

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[33] Sometimes the second clean production factor is referred to as land or entrepreneurial talent (cf. Bovenberg and van der Ploeg 1998a:138). Compared with capital, however, both factors are characterised by relatively small production shares and therefore presumably have a relatively lower potential to absorb the tax burden.

[34] A three-input model with internationally mobile capital is also employed in Bovenberg and de Mooij (1994), Bovenberg and Goulder (1997), and Ruocco and Wiegard (1997).

[35] It is assumed that capital owners remain in the domestic country and consume the capital yields at home.

– Since the elasticity of energy supply is infinite and that of labour is finite, a decline in the energy/labour ratio is associated with a negative output effect. De Mooij (2000:73-77) argues that the capital/labour ratio *typically* falls in response to an increased ratio of energy to labour prices since the negative output effect offsets the positive substitution effect.[36] The drop in capital demand reflects a tax shifting effect of the tax burden towards capital, which is, however, in terms of real income, ultimately borne by immobile labour. The capital tax base shrinks (tax base erosion effect) and labour productivity further declines. Given revenue neutrality, the government's scope for cutting the labour income tax rate is further restricted, and the real net wage and the incentive to supply labour are further reduced.

To conclude, in the presence of mobile capital, mobile energy, and immobile labour the incidence of all taxes falls on real labour income in a neo-classical labour market. Employment thus typically decreases when labour taxes are shifted to energy taxes.

In the case of perfectly inelastically supplied (or at least imperfectly elastically supplied) capital (*Case* 2) the prospects for an EDD are enhanced since tax shifting effects towards after-tax profits (i.e. the income of the fixed factor) become possible (at least under specific conditions, see below).[37] It is assumed that profit income accrues to the household, i.e. the household now receives labour and profit income. If, in the case of fixed capital, the initial distribution of taxes over labour and capital is sub-optimal from a revenue-raising perspective (i.e. labour is 'overtaxed', while capital is 'undertaxed'), an ecological tax reform may alleviate initial inefficiencies by shifting the tax burden from labour to profit income (tax shifting effect). This means that an EDD emerges if the following conditions are met which will guarantee that the tax shifting effect to profits is sufficiently large to offset the negative tax burden effect on labour (cf. de Mooij and Bovenberg 1998:24, de Mooij 2000:102):[38]

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[36] De Mooij (2000:76) shows that capital demand increases in response to an ecological tax reform only if the substitution possibilities between capital and energy are high enough to compensate for the negative production effect. This is the case if labour input is separable in production, if the production share of labour is high, and if energy and capital are better substitutes than labour and energy.

[37] A fixed factor was also introduced in Bovenberg (1997) and Bovenberg and van der Ploeg (1998a).

[38] These conditions refer to the case of fixed capital.

- The initial profit tax rate is small (and below unity[39]) and the share of capital in production is large. This ensures that after-tax profits can bear a substantial part in the overall tax burden.
- The elasticity of labour demand is relatively high (compared to the elasticity of energy demand). This implies that labour demand increases strongly in response to a cut in the labour tax,[40] whereas the drop in energy demand and thus the tax base erosion effect is relatively small.
- The supply of labour is sufficiently elastic (it should be neither completely inelastic nor completely elastic) with respect to wages. In this case the tax shifting effect towards capital income is large.
- The initial labour tax is large, while the initial energy tax should be small. This ensures that an increase in employment is associated with high welfare increase, whereas a drop in energy demand leads to relatively small welfare losses.

Summarising the theoretical results, I find that in the case of a fixed (or at least imperfectly elastically supplied) clean non-labour production factor (capital) and initial inefficiencies of the non-environmental tax system[41] tax shifting effects from labour to capital become possible. This may offset the negative tax burden effect on labour. It was shown that the real net wage and employment may rise only if capital supply is not infinitely elastic.[42] Hence the assumptions on the supply elasticity of capital and the degree of international capital mobility are decisive. If it proves to be true that capital moves abroad in the long run due to distortions in domestic factor or product markets, positive employment effects of an ecological tax reform may threaten to disappear in the long run (cf. Bovenberg 1995:123). Recent empirical

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[39] In the case of an initial profit tax rate of unity, tax shifting from labour to profits is impossible. Assuming the (first-best) 100% profit tax, however, is out of touch with reality. In the GEM-E3 model the (calibrated) tax on capital income lies between zero and one in Germany.

[40] De Mooij (2000:101) shows that labour demand typically rises in response to reduced wage costs. It may fall only in an exceptional case: the production function is characterised by separability of labour and a relatively high degree of substitutability between energy and capital.

[41] From a revenue-raising perspective, it would be most efficient to raise all tax revenues by the (first-best) profit tax. If the profit tax rate, however, is predetermined at a given level and if there are insufficient profit tax revenues to finance public spending, the government is forced to impose further (distortionary) taxes. De Mooij (2000:92-98) finds that the optimal ratio of labour to energy taxes depends on the elasticities of labour and energy supply and demand. According to the Ramsey principle for taxation, the input with the relatively lower demand and supply elasticity should be taxed with a relatively higher rate.

[42] Note that in a richer model framework allowing for other ways of tax shifting an EDD may be gained, even if capital is internationally mobile.

work on international capital mobility is ambivalent. This might indicate that capital is neither fully immobile nor perfectly mobile. Obstfeld (1993), who surveys the literature on measuring international capital mobility, ascertains that the mobility of capital between economies has increased markedly in industrial countries in the last two decades but that capital mobility is still lower between countries than within the borders. Gordon and Bovenberg (1996) also conclude that capital is not perfectly mobile and attribute capital immobility to asymmetric information of investors across countries.

The findings of this section imply for CGE modelling that, apart from the benchmark data set used for the calibration of the initial tax system, the assumed degree of capital mobility and the choice of factor demand elasticities is crucial when analysing the impacts of an ecological tax reform. As factor demand elasticities mainly depend on the degree of substitutability between production factors, the objective of Chapter 3 is to substantiate sectoral substitution patterns in the GEM-E3 model empirically and to test the model's sensitivity with respect to variations in substitution elasticities. Within these and other simulations based on the GEM-E3 model, I assume that invested (physical) capital stocks are internationally and sectorally immobile, while investment decisions depend on nationally and sectorally differentiated interests on capital.[43]

2.3.2.3 Tax shifting to non-wage incomes

If households finance private consumption not only with labour income, but also with non-wage (lump sum) incomes, such as social transfers, pensions, or unemployment benefits, the chance for an EDD increases since this creates an additional way of tax shifting, namely tax shifting from labour income towards non-wage income. As is shown by Bovenberg (1997) and de Mooij (2000), tax shifting between both types of income is possible if the non-wage income regime meets specific conditions. In any case, the tax burden of an ecological tax reform is shared by recipients of social transfers in terms of real income losses if transfers are not subject to labour taxation and not indexed to consumption prices. In this case the recipients of social transfers

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[43] Springer (2000) stresses that the incorporation of internationally mobile capital in multi-country, multi-sectoral CGE models may have important implications for the allocative and distributive outcome. She shows that the theoretical equivalence between goods trade and factor movements no longer holds in the presence of country specific production technologies, trade impediments, and factor and product market distortions. She also explains that it is crucial to account for foreign capital ownership and international transfers of capital income.

partly bear the incidence of the higher energy tax but are not compensated by a lower labour income tax.

In more realistic models where some households mainly rely on labour income and others (e.g. the unemployed) finance consumption with transfer income, tax shifting between wage and non-wage income raises equity issues and may be associated with a trade-off between a fair income distribution and higher employment. The current discussion in Germany about the adjustment of pensions and the complaint of pensioners about the energy tax clearly reflects this trade-off.[44]

The impact of an ecological tax reform on the ratio of non-wage incomes (such as unemployment benefits) to after-tax wages plays a special role in the context of wage setting models. This aspect will be picked up in Section 2.3.3 in more detail (see also Chapter 5).

2.3.2.4 Tax shifting to foreign countries

Whereas tax shifting effects to non-labour production factors and to non-wage income are common in the theoretical double dividend literature, tax shifting mechanisms to foreign countries have been widely neglected.[45]

Tax shifting effects to the foreign sector become feasible when terms-of-trade effects can be observed. In reality, this is only plausible if the ecological tax reform is introduced in a large country (e.g. the USA) or a large group of countries (e.g. the EU-15) which account for a substantial part of the world trade.

Unlike the theoretical EDD literature, which mainly relies on the small-country assumption, terms-of-trade effects are important determinants of the double dividend outcome in CGE models. As will be shown in the following chapters, both the single-country version and the linked version of the GEM-E3 model allow for tax shifting effects towards the foreign sector since the rest of the world’s import demand is assumed to be imperfectly price elastic. I will investigate the impacts of terms-of-trade effects on employment and economic welfare in Chapter 4.

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[44] Strictly speaking, a double dividend is always associated with a change in income distribution. This change, however, may be particularly disapproved by the public when it is implemented at the expense of domestic recipients of income transfers.

[45] Koskela et al. (1998) is an exception. De Mooij (2000: Chapter 5) analyses the importance of terms-of-trade effects for the double dividend in a three-country model in which tax shifting to foreign suppliers of polluting inputs and to foreign users of intermediate inputs is permitted.

2.3.3 Employment effects of an ecological tax reform in the case of labour market imperfections

In a recent series of double dividend papers the EDD was analysed in a modelling framework, where distortions not only arise from environmental externalities and taxes, but also from imperfectly competitive labour and commodity markets. Most theoretical and empirical papers indicate that labour market imperfections may increase the size of employment effects and enhance the scope for an EDD.[46]

The remainder of this section proceeds as follows. I briefly introduce the concept of the wage setting curve in Section 2.3.3.1. Section 2.3.3.2 summarises the results of the literature that simply traces involuntary unemployment back to exogenous real wage rigidities. Section 2.3.3.3 concentrates on studies, in which wage formation is endogenous and founded on the microeconomic theory of trade unions.[47]

2.3.3.1 Introductory graphical analysis

In reality labour market imperfections arise from the presence of several labour market institutions, such as legal employment protection rules, taxes on labour, trade unions and minimum wages, the social security system and unemployment benefit regime, or barriers to regional and sectoral mobility. Economic theory offers a variety of concepts to explain labour market imperfections and the institutional structure of wage setting. Three leading approaches of wage setting behaviour are available from the microeconomic theory of equilibrium unemployment (cf. Layard et al. 1991): trade union/wage-bargaining models, efficiency wage models, and job search/matching models.

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[46] In Section 5.3.2, I will empirically bear out this result. See also Bosello et al. (1999) for a discussion of simulation results obtained from empirical large-scale models with labour market imperfections.

[47] A further approach to modelling temporary unemployment – which is not considered here – is the Phillips curve wage equation which connects the real wage *changes* with the unemployment rate; the real wage rises if unemployment is below its natural rate and falls if unemployment rises above it. The Phillips curve concept, however, is less appropriate for modelling endogenous wage formation for the following two reasons: firstly, its micro-foundation is weak (i.e. it does not explain the determinants of the natural rate of unemployment), secondly, it assumes that unemployment is stationary and fluctuates around a mean value. However, according to empirical evidence from industrialised countries, there are not only temporary effects on equilibrium unemployment, but also persistent shifts in the unemployment rate in the long-run. The Phillips curve is thus suitable for capturing short-term disequilibrium processes but not for explaining long-lasting unemployment (cf. Tyrväinen 1995, Bean 1994). Examples of an application of the Phillips curve in CGE models can be found in Welsch (1996) and Kemfert and Welsch (2000).

All models explain why the actual consumer wage is marked up over the so-called reservation wage of employees (see below), but they differ in the variables that affect this mark-up. At present, there are only a few EDD studies available that employ the efficiency wage approach (e.g. Schneider 1997) or a mismatch model (e.g. Bovenberg and van der Ploeg 1998b, Strand 1999).[48] Most papers addressing European labour market characteristics assume that wage formation is determined by decentralised wage bargaining between the unions and the employers. Considering the evidence on labour market institutions in Germany (cf. Section 5.2), I also follow this approach by assuming that wage setting behaviour originates from the presence of trade unions.[49] I will therefore introduce in Figure 2 an aggregate wage setting (WS) curve that describes the relation between the negotiated real consumer wage and collective labour supply. The WS curve replaces the individual labour supply (LS) curve: Equilibrium employment and wage levels are now determined by the intersection of the WS curve and the labour demand (LD) curve. In the case of labour market equilibrium, the difference between individual labour supply and labour demand at the equilibrium real wage rate determines the level of involuntary unemployment.

De Mooij (2000) theoretically shows that in the case of wage bargaining the wage on the WS curve is determined not only by the unemployment rate, but also by further factors such as the labour tax rate[50] and a labour productivity index (see also Layard et al. 1991:181-189). If the ecological tax reform does affect these factors, this may

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[48] Like the trade union models, the efficiency wage models explain why workers who are willing to supply their labour force at a wage rate below the actual market wage do not find a job. But while involuntary unemployment is explained by the labour supply side in the trade union models, i.e. by the power of insiders, the firms, i.e. the labour demand side, set wages above the market-clearing level in the efficiency wage models. Even if firms maximise profits, they are assumed to have an incentive to voluntarily pay wages above the market-clearing wage rate in order to stimulate labour efficiency and to curb shirking (to motivate workers), reduce fluctuation (to retain workers), or select job candidates (to recruit workers). The mismatch models assume that individual workers and employers bargain over the rents that are associated with hiring costs, leading to a mark-up over the competitive wage (cf. Layard et al. 1991).

[49] See Nickell and Layard (1999) for the empirical evidence on the influence of labour market institutions on wage formation and unemployment in OECD countries. As was already mentioned, trade unions are not the only labour market institution that influences wage formation in Europe, nevertheless they are of great empirical significance, especially in Germany (cf. also Dell' Aringa and Lucifora 2000). In Chapter 5 I will derive a wage setting equation from a monopoly union model.

[50] In more complex models, other factors, such as the tax structure, influence the negotiated wage level. Lockwood and Manning (1993) and Pissarides (1998) analyse the impact of non-proportional tax systems on wage pressure generated by trade unions.

lead to persistent shifts of the WS schedule in (*w*–*L*) space. For a given employment level, an upward shift of the WS curve implies higher wage pressure exerted by the trade unions, and a downward shift leads to wage moderation.

In order to create a better understanding of the impacts of a shift from labour to energy taxes on the wage setting behaviour of trade unions, I briefly explain how the slope and the locus of the WS curve are determined in a wage-bargaining model framework (see Section 5.2.3 for more details and a formal analysis).

According to de Mooij (2000: Chapter 7) the EDD depends mainly on the question whether the ecological tax reform affects the ratio of the reservation wage, $\overline{w}$, to the real net wage, w. If the tax reform reduces $\overline{w}/w$, the bargaining position of the trade union gets worse as potentially unemployed union members face a lower unemployment benefit. Reduced wage pressure widens the scope for an EDD. A policy induced increase in $\overline{w}/w$ reflects that the union's wage claims become stronger, thus reducing the opportunity for an EDD.

The reservation wage $\overline{w}$ (often also termed fallback or outside option of employees) represents the union's utility during unemployment. In decentralised wage-bargaining models, $\overline{w}$ is typically specified simply as the weighted sum of real income during employment, w, and real income during unemployment, b

(2-1) $\overline{w}=(1-u)w+ub$

where the economy-wide unemployment rate, u, is assumed to approximate the probability of being unemployed, and $(1-u)$ stands for the probability of finding a job outside the trade union's coverage.[51] From (2-1) we obtain a positive relationship between $\overline{w}/w$ and b/w (for given u).

Several factors exert an influence on the union's bargaining position which is mainly reflected by changes in $\overline{w}/w$. First of all, I consider the impact of the unemployment rate on the negotiated real net wage, i.e. the slope of the WS curve. The slope measures the degree of *real wage rigidities* in the labour market, i.e. the degree of the sensitivity of real net wage changes to an alteration of the unemployment rate. A flat WS curve indicates strong real wage rigidities, a steep WS curve reveals a low degree

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[51] Note that income during unemployment, b, may refer not only to unemployment benefits, but also to untaxed income from the informal sector. A more complex specification of the trade union's utility during unemployment (and employment) is, for example, adopted by Pissarides (1998), who additionally introduces a coefficient reflecting risk aversion of the trade union.

of real wage rigidities. Considering the definition of the reservation wage (2-1), the positive slope of the WS curve in (w-L) space is explained by the fact that a lower unemployment rate, u, ceteris paribus pushes up the ratio $\overline{w}/w$ (since $b/w<1$). An increase in $\overline{w}/w$ (or equivalently a rise of b/w), however, strengthens the trade union's bargaining position and increases wage pressure.

Furthermore the position of the WS curve in (w-L) space may be affected under certain conditions by changes in the labour tax rate (or the rate of social security contributions, respectively) and/or labour productivity.

The relative bargaining position of the trade union in wage negotiations deteriorates (leading to wage moderation) if a lower labour tax rate reduces the ratio of the reservation wage to the consumer wage. This may occur if nominal unemployment benefits are fixed. In such as case a lower t_L ceteris paribus boosts the net wage, whereas unemployment benefits remain constant (thus b/w and, given u, $\overline{w}/w$ decrease). According to the tax incidence literature, this phenomenon is described as *real wage resistance*. Real wage resistance exists if the real wage partially or fully resists the change in the labour tax rate. This means that the incidence of a labour tax cut does not affect only employees in terms of higher real consumer wages but also employers in terms of lower real labour costs.[52] In a wage-bargaining model framework, real wage resistance generally requires that parts of the income during unemployment, b, be untaxed. Since real wage resistance (ceteris paribus) widens the scope for an EDD, its empirical evidence is an important issue (see Section 5.2.2 for a survey on the econometric literature).[53]

The analogous argumentation holds for the impact of labour productivity on the locus of the WS curve. If lower labour productivity increases $\overline{w}/w$, e.g. because unemployment benefits are nominally fixed, wage pressure of trade unions is reinforced and the WS curve shifts upwards. Note that for a fixed replacement ratio

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[52] Tyrväinen (1995:7) states in his definition of real wage resistance that "If wages do not fully absorb changes in wedge factors (including various tax rates), real wage resistance exists."

[53] Bingley and Lanot (1999) identify three related factors that determine the responsiveness of the real producer wage to labour taxes: firstly, the nature of the tax wedge, secondly, the institutional structure of wage setting and the degree of product market competition, and thirdly, the perceived links between labour taxes and transfers such as unemployment benefits. Pissarides (1998) demonstrates that the impacts of a labour tax policy crucially depend on the specific model underlying the wage setting function, the structure of taxation, and the unemployment benefit system.

(i.e. for a fixed ratio of unemployment benefits to the net wage) neither a change in t_L nor a change in labour productivity affects the locus of the WS curve.

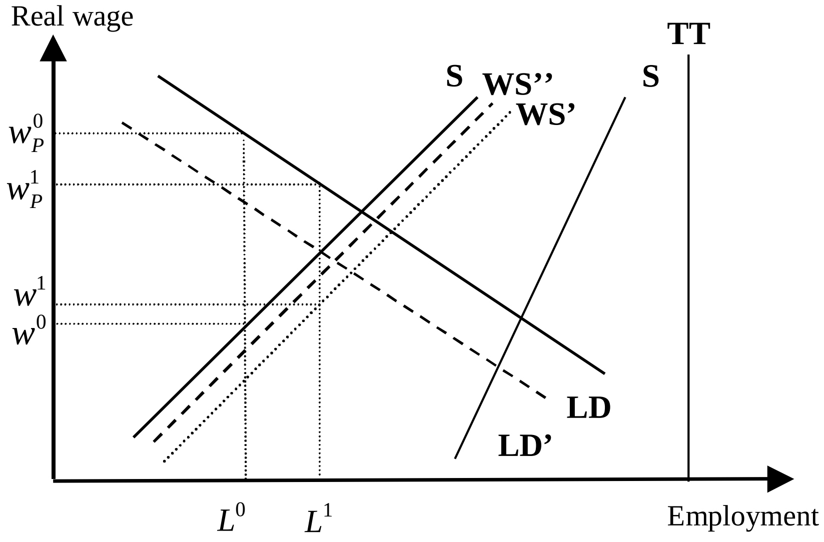

Figure 2: Employment effects of an ecological tax reform, non-competitive labour market and involuntary unemployment

Figure 2 illustrates the possible impacts of an ecological tax reform on employment in a partial equilibrium framework in which involuntary unemployment results from wage bargaining. Just as in Figure 1, the LD curve represents either the traditional labour demand function (if output markets are competitive) or a price setting curve (if output markets are imperfect and prices are set as a mark-up on marginal costs). I already mentioned that in contrast to Figure 1 the labour supply side is now described by a WS curve which is to the left of the (virtual) LS curve.[54] In Figure 2 the initial equilibrium employment level, L^0, is determined by labour demand at the real producer wage, w_P^0; the initial tax wedge is (w_p^0-w^0).

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[54] The LS curve relates the real net wage to the amount of labour that individual households would supply theoretically if all labour market institutions were absent. The equilibrium unemployment rate u (also designated as natural rate of unemployment or rate of structural unemployment) is defined as u=1-L/L^s. It represents the resulting unemployment level if prices and wages are correctly foreseen (cf. Johnson and Layard 1986:921). The empirically observable rate of unemployment does not necessarily correspond to the rate of structural equilibrium unemployment due to cyclical shocks in product markets, such as technology or import price shocks (cf. Franz 1996). If actual employment deviates temporarily from equilibrium unemployment this may have a direct effect on the equilibrium rate of unemployment. This phenomenon of persistence of unemployment (hysteresis) has gained much attention in the literature. Bean (1994), for example, discusses various sources of persistence that refer to the supply side (i.e. the wage setting process), such as insider membership or outsider characteristics, or to the demand side (i.e. the price setting schedule), such as firing costs or capital shortage.

Firstly, I consider a cut in the labour income tax t_L, i.e. a reduction in the tax wedge. I assume that real wage resistance exists. This implies that the WS curve shifts somewhere downwards, for example to WS', in response to the cut in t_L. For given real wage rigidities (i.e. for a given slope of the wage curve) this downward shift reinforces the positive employment impact of revenue recycling since the incidence of the tax cut falls partially on employers in terms of a lower producer wage. On the assumption that the tax wedge shrinks to $(w_P^1 - w^1)$, employment rises to L^1 in Figure 2.

On the other hand, an increase in the energy tax leads to higher energy prices, lower energy demand, and lower labour productivity. The LD curve moves to the left (for example to LD'). If lower labour productivity boosts $\overline{w}/w$,[55] the union's bargaining position in wage negotiation improves, wage pressure rises, and the WS curve shifts upwards (for example to WS'').

Both moves tend to reduce equilibrium employment compared to L^1, however, in the partial equilibrium framework underlying Figure 2, and without a quantitative parameterisation of the wage setting and labour demand equations, the ultimate net labour market effect of an ecological tax reform cannot be discovered. I only attempted to illustrate that, if there is wage-bargaining behaviour, the EDD outcome depends on a number of elasticities in the wage setting equation. The degree of real wage resistance (which in turn depends on the indexation rule for unemployment benefits) and the size of real wage rigidities are particularly important.

2.3.3.2 Fixed real wages

The first few papers analysing the EDD in a framework of equilibrium unemployment simply assume that the real wage – typically the real net wage – is fixed at a level above the exogenous reservation wage. With exogenous real wage rigidities, labour supply is de facto infinitely elastic at the fixed real wage, i.e. the WS curve in Figure 2 transforms into a horizontal line. The incidence of a change in the tax wedge is fully borne by the employers, and there is a maximum degree of real wage resistance.

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[55] As already mentioned, both the elasticity of the wage with respect to the labour income tax and labour productivity depend on the indexation of unemployment benefits (cf. de Mooij 2000:191). If unemployment benefits are nominally fixed, lower labour productivity increases wage pressure, whereas a lower labour tax reduces wage pressure.

Bovenberg and van der Ploeg (1998a), Bovenberg (1998), and de Mooij (2000:196-200) introduce involuntary unemployment that is explained by an exceedingly high fixed real net wage into a small open-economy model with three production factors: labour, energy, and fixed capital (cf. Section 2.3.2.2). The authors suggest that in the presence of fixed net wages the necessary conditions for positive employment effects are very similar to those derived from the fixed factor model with a competitive labour market. A sufficiently small initial pollution tax (ensuring a small tax burden effect), a small initial rate of profit taxation, and a large production share of the fixed factor (both ensuring that after-tax profits can bear a large part of the tax burden) are the prerequisites for a substantial fall in real wage costs and thus for positive employment effects. A further condition is a higher degree of substitutability between labour and energy than between the fixed factor and energy (ensuring that the substitution effect offsets the output effect and that the fixed factor can share the burden of the energy tax to a great extent).

In Koskela et al. (2001) equilibrium unemployment is also traced back to an excessive fixed net wage. A representative firm produces an export good with two production factors – domestic labour and imported energy – in an open economy. In contrast to most other EDD studies, the terms of trade defined by the price of the export good in terms of an import good are assumed to be endogenous and declining in output. The authors come to the conclusion that a moderate ecological tax reform can alleviate the unemployment problem through strong substitution processes between energy and labour in production. Moreover, substitution towards labour increases welfare since energy is priced at its national opportunity cost (which is equal to the fixed world market price) while the wage rate is above its opportunity cost. In addition, the authors find that unit production costs of exports continue to decrease as long as the (ad-valorem) energy tax rate is below the (ad-valorem) labour tax rate, i.e. the economy’s competitiveness increases.

The sensitivity of EDD results with respect to different ways of wage fixing is examined in Kirchgässner et al. (1998) by applying a CGE model for the Swiss economy and in Koschel et al. (1999) by using the single-country version of the GEM-E3 model for Germany. In both studies, the energy/carbon tax revenues are redistributed to the private sector through an equal cut in the employers’ and employees’ social security contribution rate. Both studies support the EDD hypothesis, provided that workers accept a decrease in the real gross wage compared to the benchmark.[56] If, however, employees take advantage of the tax reform and improve their real income position, real labour costs cannot decrease sufficiently, leading to a higher share of unemployment compared to the benchmark (cf. Section 5.3.1).

2.3.3.3 Wage bargaining

The assumption of exogenous real wage rigidities is unsatisfactory because it is lacking in a microeconomic foundation of the wage formation process. Recently, some EDD papers were published that allow for endogenous wage formation. As I mentioned in Section 2.3.3.1, in the majority of EDD studies that refer to European labour markets equilibrium wages are regarded as the outcome of collective bargaining between trade unions and employers. Typically, the right-to-manage approach is chosen, which implies that bargaining only has to do with wages, whereas employment is determined unilaterally by profit maximising employers ex post.[57] The standard approach is to derive wages and employment from the maximisation of a Nash objective function subject to labour demand (cf. McDonald and Solow 1981).

In Section 2.3.3.1 I argue that the introduction of a positively sloped wage curve that attributes real wage rigidities to institutional mechanisms of wage setting opens up a further transmission channel through which employment may be influenced when an ecological tax reform is implemented. This transmission channel is closely related to the tax reform's impact on the ratio between income during unemployment and income during employment. If the ecological tax reform is successful in shifting parts of the tax burden from workers to the unemployed, this ratio decreases, the union's bargaining position deteriorates, and wage claims are moderated.

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[56] Note that the real gross wage and the real producer wage differ from each other if employers' social security contributions are considered. In Germany the real gross wage is usually defined as the real net (after-tax) wage plus labour income taxes and employees' social security contributions. The real gross wage plus the employers' social security contributions then yield the real producer wage, i.e. real labour costs (cf. Steiner 1998).

[57] Alternatively, it can be assumed that the union does not bargain with employers but has the power to unilaterally set the wage level. A monopoly union model is applied in Section 5.2.3 as well as in Jensen et al. (1994) and Nielsen et al. (1995). Bayindir-Upmann and Raith (1999) examine the trade-off between first and second dividend in the context of four alternative bargaining models: efficiency bargaining, monopoly union, right-to-manage, and insider-dominated union model (see below in this section).

In a bargaining equilibrium the net wage is a constant mark-up on the reservation wage of employees. The mark-up represents some rents that are negotiated on. Actually, in models where profits are zero regardless of the negotiated wage level wage bargaining will not take place because there is no incentive for firms to enter into negotiations. In theory there are various sources of rents. Rents may come from market power on commodity markets, leading to product market rents (e.g. in Holmlund and Kolm 1997, Koskela et al. 1998, Marsiliani and Renström 2000). Alternatively, rents may arise from a (quasi) fixed production factor, such as capital (e.g. in Bayindir-Upmann and Raith 1999, Koskela and Schöb 1999, de Mooij 2000) or from search and hiring costs (e.g. in Bovenberg and van der Ploeg 1998b, Strand 1999). Rents can also originate from firm specific human capital or entry barriers (e.g. in Carraro et al. 1996, Bosello and Carraro 1998). As de Mooij (2000:203) indicates, the source of rents is an important issue since it determines whether or not the mark-up and thus the EDD outcome depend on the production structure.

In the following, I review the results of some recent EDD studies which account for wage bargaining.

Carraro et al. (1996) were among the first authors who introduced imperfectly competitive labour and output markets into a large-scale macro-econometric general equilibrium model, the WARM model.[58] Firms are price setters and set a constant price mark-up. Net wages in the primary sector (including all industrial and service sectors apart from agriculture) are the outcome of a sequential bargaining process. In a first step, wages are determined by bargaining between a trade union and a representative firm of the ‘leading’ manufacturing and service sectors; in a second step, wages in all other sectors of the primary sector are derived on the basis of sector specific wage differentials. It is assumed that the union maximises the product of employment and the individual earnings of workers in the unionised sector. Wage formation is described by a share equation in which the ratio between the gross wage and profits per head depends positively on the relative bargaining power and negatively on the unemployment rate, the employment elasticity with respect to wages, and the weight that the union attributes to employment in its utility function.

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[58] The inclusion of technical change and a disaggregated capital stock are two further specific features of the WARM (World Assessment of Resource Management) model (cf. Carraro et al. 1996).

Econometric estimation of the share equation indicates that real wage resistance exists only in the short run, while a cut in payroll taxes only has negligible positive employment impacts in the long run if trade unions enforce higher net wages.[59] In the WARM model, a revenue-neutral ecological tax reform introducing a uniform EU-wide carbon/energy tax and lowering payroll taxes boosts employment and reduces gross wages in the short run. In the long run, however, employment virtually approaches the baseline figures. A further interesting outcome of Carraro et al. (1996) is that an ecological tax reform increases employment; income effects, however, will lead simultaneously to higher pollution.[60]

In a subsequent paper on the WARM model, Bosello and Carraro (1998) segmented the labour market of the primary sector into unskilled and skilled workers. Wages in both segments are separately negotiated according to the sequential process outlined above. Econometric estimations yield that the trade union of skilled workers has more bargaining power and higher preferences for wages than the trade union of unskilled workers. The simulations carried out with the WARM model reveal that the short-term increase in employment is higher when tax revenues are used to cut social security contributions of both unskilled and skilled workers than those of unskilled workers alone. The reason for this is that a unilateral reduction of the gross wage triggers substitution processes between unskilled and skilled labour which cause labour demand of skilled workers to decline. As was outlined in Carraro et al. (1996), positive employment effects arise only in the short run since unions succeed in transferring lower labour costs into higher net wages in the long run.

Holmlund and Kolm (1997) investigate the employment effects of an ecological tax reform using a general equilibrium model of a small open economy with a tradable and a non-tradable sector. In each sector a fixed number of monopolistically competitive firms operates with sector specific production technologies including two production factors: immobile labour and imported (mobile) energy. For given price levels nominal net wages are the outcome of decentralised bargaining of the right-to-manage type. The real net wage is then specified as a constant mark-up on the outside opportunity, which is measured in terms of the weighted average of

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[59] See Brunello (1996) for more details on the estimation results.

[60] At first glance, this result is surprising. Weinbrenner (1999: Chapter 5) and Bayindir-Upmann and Raith (1999), however, prove that in theoretical models with only consumption externalities an ecological tax reform may reduce environmental quality despite substitution effects if efficiency gains lead to higher income and thus to higher consumption of dirty goods.

incomes from unemployment and employment in the tradable and the non-tradable sector.[61] Since Holmlund and Kolm assume that the trade union in the tradable sector has a relatively higher bargaining power, the negotiated wage in the tradable sector is higher than in the protected sector.

The authors conclude from theoretical and numerical analyses that a moderate increase in the tax on imported energy can boost equilibrium employment, provided that the negotiated wage is higher in the tradable sector than in the protected sector. This is due to the fact that the energy tax lowers labour demand in the tradable sector and the real value of outside opportunities. Wages in both sectors are depressed and employment is reallocated from the tradable to the non-tradable sector. Numerical sensitivity tests with respect to the unemployment benefit regime reveal that results hardly differ, irrespective of whether unemployment benefits are indexed to the consumer wage (fixed replacement ratio) or to the consumption price index (fixed real unemployment benefits). Obviously, in the model of Holmlund and Kolm the main driving force of employment effects is the wage differential between the tradable and the protected sector. A tradable sector wage premium, however, requires that there be substantial rents in bargaining, either resulting from strong market power of firms or from quasi-fixed capital in the tradable sector. Both assumptions are questionable in the framework of a small open economy in which firms in the tradable sector are more likely to be price takers and capital is internationally mobile (cf. Section 2.3.2.2). For this reason, the authors themselves conclude that there is little chance of obtaining an EDD.

Koskela and Schöb (1999) expand the EDD debate by emphasising the importance of the institutional arrangements concerning the income tax and the unemployment benefit system. They construct a model of a small open economy consisting exclusively of consumption externalities and right-to-manage wage bargaining. Firms produce a single output good with labour as the only variable input. Households are divided into workers, either employed or unemployed, and shareholders who own profit income which accrues to a fixed factor in production. Trade unions maximise workers' real income which consists of real net wage income and real net unemployment benefits. The negotiated outcome is the nominal net wage.

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[61] The real reservation wage $\overline{w}$ is defined as follows: $\overline{w} = ub + n_C w_C + n_S w_S$, ($u$+$n_C$+$n_S$=1), where u denotes the unemployment rate, b are real unemployment benefits, n_C and n_S are ratios of labour demand to the labour force in the tradable and the non-tradable sector, and w_C and w_S are sector specific real net wages (cf. Holmlund and Kolm 1997:14).

The authors analyse the effects of a revenue-neutral shift of the tax on (labour and profit) income to the tax on dirty consumption goods under four assumptions concerning the taxation and indexation of unemployment benefits and the type of tax exemption. They deduce that employment rises if the benefit-replacement ratio – i.e. the ratio between real net unemployment benefits and the real net wage – decreases. This is the case if unemployment benefits are nominally fixed and taxed at a lower rate than labour income. Employment effects are ambiguous if unemployment benefits are price-indexed and taxed at a lower rate than labour income. Employment definitely falls when benefits are price-indexed and taxed at the same rate as labour income.

Applying four different wage-bargaining models, Bayindir-Upmann and Raith (1999) conclude that a revenue-neutral tax reform on the consumption side is successful in raising employment and shifting the tax burden from workers to profit owners. In their model, competitive firms produce both a dirty and a clean good with a Cobb-Douglas production function. Labour is the only variable production factor. Households are divided into unemployed workers (those who receive only transfer income), employed workers (those who receive both wage and transfer income), and managers (those who receive profit income arising from fixed factors in production). Wages are determined alternatively by efficiency bargaining, right-to-manage, monopoly union and insider-dominated union models.

The authors show that the first dividend can get lost if – in terms of pollution – the substitution effect between clean and dirty commodities does not suffice to overcompensate the income effect associated with higher employment. Positive employment effects lead to increased pollution under the following conditions: The economy is on the left hand side of the Laffer curve for the labour income tax, and the labour income tax rate exceeds a critical value which, in turn, depends on the households' expenditure share for dirty goods, the production coefficient, and the wage share. The authors suggest that, provided that the bargaining outcome is on the labour demand curve,[62] an expenditure share of 0.5 leads to an increase in pollution for any labour income tax at the left hand side of the Laffer curve. This is an interesting theoretical finding; however, I would like to make a comment on it from a more empirical perspective. Consider, for instance, a tax on household energy consumption and right-to-manage bargaining. In this rather realistic case, the initial

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[62] This applies to the right-to-manage, monopoly union and insider-union models.

labour income tax rate for which a revenue-neutral ecological tax reform leads to both higher pollution and higher employment must stay in the narrow range of 0.26 to 0.3 (I calculated the lower bound of 0.26 on the basis of an household expenditure share for energy of 10%[63]). Actually, this shows that the condition for a simultaneous increase of energy-related emissions and employment is very specific and might not be met in reality.

While the last two models ignore production externalities and factor taxation, Koskela et al. (1998) analyse the employment effects of a marginal ecological tax reform affecting the producer side in the presence of wage bargaining. Their model considers a monopolistic firm which only uses labour and imported energy to produce output with a CES production technology. The net wage is negotiated between a trade union and the firm according to the right-to-manage model. Unemployment workers receive a fixed unemployment benefit.

The authors suggest that the condition for an employment dividend is the limited rise of the negotiated net wage. Employment definitely increases if the substitution elasticity between labour and energy exceeds unity, thus leading to a decrease in the negotiated net wage. As soon as the substitution elasticity between labour and energy drops below unity, the net wage increases. Employment may still rise if there are moderate wage increases, however, it will decline if the wages reach a certain level. A further result is that chances for positive employment effects increase simultaneously with the labour tax rate and decrease with the bargaining power of trade unions.

Marsiliani and Renström (2000) develop a general equilibrium model of a closed economy with both consumption and production externalities. In close analogy to Layard et al. (1991) they assume monopolistic competition on product markets and decentralised right-to-manage wage bargaining. The main focus of the authors is to test for the sensitivity of EDD outcomes with respect to the degree of both labour and product market distortions. A large number of price setting local monopoly firms produce a different consumption good with the same Cobb-Douglas production technology using a given capital stock, labour, and energy. Households are divided into three groups: after-tax wage-income earners (employed workers), recipients of

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[63] According to the Federal Statistical Office Germany (1999, Table 21.2), the expenditure shares of households for energy (electricity, gasoline etc.) were even less than 10% in 1998 – i.e. only between 4 and 7%.

unemployment benefits (unemployed workers), and profit-income earners (shareholders). The outcome of bargaining between firms and local unions is the net wage which is a constant mark-up on unemployment benefits. The mark-up rises with increasing bargaining power of unions and decreasing competition in good markets.

Marsiliani and Renström find that a revenue-neutral ecological tax reform, consisting of a newly introduced energy tax and a cut in the (Laffer efficient) labour income tax,[64] generates positive employment effects. This is due to tax shifting effects towards non-labour income such as unemployment benefits and profits; actually, all households bear the additional tax burden associated with the energy tax, but only employed workers are compensated with lower payments of the income tax. Secondly, the authors find that employment rises as the union power and price mark-ups increase. This result is explained by the fact that the share of household income from profits and unemployment benefits in total wage income is higher with less competition on the labour and product markets, and this leads to a higher ratio of expenditure for energy consumption to wage income. This implies that the ratio of the energy tax base to the labour tax base is also higher with market imperfections than in the competitive scenario. With lower competition, an increase in the energy tax rate is thus associated with a relatively higher amount of revenues. This allows for a relatively larger reduction of the labour tax rate and labour market distortions.[65] After all, numerical simulations with the model calibrated to Italian data confirm that the theoretical results hold even if the initial energy tax is positive.

My survey closes with a brief presentation of the findings of Bovenberg and van der Ploeg (1998b) who employ a search model in which wages are bargained between firms with vacant jobs and individual unemployed workers seeking work. Bargaining is conducted over the rent which originates from (expected) hiring and search costs for the firm and the worker.[66] In addition to imported energy, immobile labour and internationally mobile capital are employed in production. Apart from unemployment benefits the authors consider a second source of utility in unemployment: untaxed

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[64] Marsiliani and Renström (2000:12) show that a payroll tax is equivalent to a labour income tax, provided unemployment benefits are untaxed.

[65] Remember that in Koskela et al. (1998), in which only production externalities are considered, employment effects decline with a lower degree of competition in the labour market.

[66] See also Strand (1999), who employs a search model with bargaining between the firm and the worker.

income from work in the informal sector. While unemployment benefits are indexed to the consumer wage, income in the informal sector is indexed to the producer wage, i.e. to labour productivity in the formal sector.

Bovenberg and van der Ploeg examine the sensitivity of EDD results with respect to different income regimes and indexation rules. They find that an ecological tax reform leaves unemployment unaffected if unemployment benefits are indexed to after-tax wages and if other sources of utility in unemployment are absent. In this case, the unemployed have a share in the costs of a cleaner environment. However, if the unemployed receive untaxed income from the informal sector in addition to unemployment benefits, an EDD may result. This is the case if the initial energy tax rate is small and income from the informal sector is substantial. Since income from the informal sector is indexed to the producer wage, the unemployed bear an additional part of the tax burden as labour productivity in the formal sector declines in response to the energy tax increase. The decay of the outside option of workers induces a fall in wages and thus a lower unemployment rate.

2.4 Conclusion

This chapter outlines the way energy taxes function as tools for climate protection and reviews the theoretical literature on ecological tax reforms. I sum up the main results of this chapter and conclude as follows:

1. From an economic perspective, energy taxes (and tradable permits) are the preferred instruments in climate policy. Theoretically, both instruments minimise overall abatement costs and provide innovative incentives that are higher than in the case of technical standards. Recent literature indicates that energy taxes are superior to tradable permits with respect to innovative incentives, whereas tradable permits have an advantage over taxes that are applied at the international policy level. Generally, one can argue that energy taxes are a suitable instrument for climate protection, in particular for application in national climate policy.
2. Since the early nineties the merits of energy taxes have been mainly discussed from a non-environmental point of view. In this work I concentrate on the employment double dividend hypothesis (EDD) which claims that a shift from labour to environmental taxes simultaneously boosts employment and reduces pollution. The theoretical literature on ecological tax reforms indicates that the EDD is accepted only under certain conditions. Employment rises if, from a public finance point of view, labour is taxed with an excessively high rate

compared to energy in the initial equilibrium and if a tax shifting effect from labour to other private income offsets the negative tax burden effect on labour income.

3. Three ways of tax shifting are considered in the literature: tax shifting between production factors, tax shifting towards the foreign sector through terms-of-trade effects, and tax shifting to non-wage income earners. Accordingly, it depends on several model assumptions – such as the production structure, substitution and supply elasticities of factors, the foreign trade specification (terms-of-trade effects), and the specification of labour markets and the unemployment benefit regime – whether (and how much) employment will increase or not in response to an ecological tax reform.
4. In my literature survey I focus on EDD studies with labour market imperfections and involuntary unemployment. One interesting finding is that in wage-bargaining models the chance for an EDD increases since tax shifting effects from workers to the unemployed become possible which lead to wage moderation and thus to lower producer wages. If long-lasting real wage resistance exists, a labour tax cut causes a long-lasting reduction in labour costs. If, however, real wage resistance is absent or only a short-term phenomenon, long-lasting positive employment effects are reduced and less likely.

The quantitative net effect of all factors mentioned above cannot be determined theoretically. Ultimately, it is impossible to conclude from theoretical models whether the EDD hypothesis is valid or not in real-world economies. In principle, a rich and realistic numerically solvable CGE model structure which incorporates non-clearing labour markets can open all channels (recommended by theory) through which an ecological tax reform affects employment and can produce a definitive net employment effect. The high model complexity of a CGE framework, however, makes it difficult to identify the specific contribution of each key mechanism that leads to an approval or a rejection of the EDD hypothesis. Thus the theoretical findings summarised in this chapter prove to be an indispensable guide for a meaningful interpretation of CGE modelling results.

There is an overall consensus today that there is still a lack of empirical research that quantitatively evaluates the employment effects of ecological tax reforms and analyses the possible trade-off between the first and second dividend (cf. also Bosello et al. 1999). In order to close this gap partially, I use both the single-country and the linked version of the GEM-E3 EU-14 model in the following parts of this work and simulate several ecological tax reform scenarios which apply to both the producer and the consumer side. I will concentrate on the impact that substitution elasticities, foreign trade elasticities, and labour supply elasticities have on the EDD outcome. In order to enhance the validity of model results, I will substantiate some of the non-calibrated functional parameters incorporated in the GEM-E3 model empirically (partially by own econometric estimations) and conduct sensitivity analyses.

3 Employment double dividend and substitution patterns in production

3.1 Introduction

As was already briefly mentioned in Chapter 2, the substitutional relationship between energy and nonenergy inputs is one of the key factors for the labour market effects of an ecological tax reform that raises energy taxes in production and reduces taxes on labour. The more easily labour can be substituted for energy in comparison to other production factors, such as capital, the higher the substitution effect is that works against the negative output effect.

Today, there are only few empirical studies available dealing with detailed substitution relationships in the German economy. Most of them are restricted to manufacturing sectors and consider only a single energy aggregate. The main objective of this chapter is to contribute to an additional empirical clarification of sectoral substitutional opportunities in the German economy and to improve the empirical basis of the GEM-E3 model and its power to simulate ecological tax reform scenarios.

Sectoral substitution elasticities are estimated using a flexible translog functional form for a non-nested and for a three-level nested production function with capital, labour, material, electricity, and fossil fuels. Nearly all producing industries and service sectors in Germany are covered. Compared to the CES, the translog functional form is advantageous as it does not impose a priori restrictions on the underlying technology with respect to substitution patterns, separable structures, and economies of scale.[67]

This chapter is set out as follows: In Section 3.2 I estimate sectoral substitution elasticities with respect to a time-series cross-section data sample for Germany. Section 3.2.1 provides a literature survey, Section 3.2.2 presents the translog cost model, while Section 3.2.3 describes the econometric procedure and the data. Empirical results are discussed in Section 3.2.4. The sensitivity of GEM-E3

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[67] Examples for translog applications are Berndt and Wood (1975), Griffin and Gregory (1976), Halverson (1977), Pindyck (1979), Turnovsky and Donnelly (1984), Chung (1987), Kintis and Panas (1989), Grant (1993), Betts (1997), or Casler (1997). See Section 3.2.1 for a literature review.

simulation results to the choice of substitution elasticity values is analysed in Section 3.3. Finally, Section 3.4 contains the main conclusions.

3.2 Estimation of substitution elasticities in German producing and service sectors

3.2.1 Literature review

When looking into the econometric literature on substitution elasticities between energy and nonenergy inputs, one can find a substantial number of empirical studies which have been published since the energy crisis in the 1970s.[68] Most of them rely on homothetic *KLEM*[69] (or *KLE*) translog cost functions and use highly aggregated data, often for the whole U.S. manufacturing sector. Substitutability relationships are mainly measured by the (constant-output) Allen partial elasticity of substitution (AES). The most cited study in this field was provided by Berndt and Wood (1975) who calculated AES on the basis of a translog cost share system with constant returns to scale and Hicks neutral technical progress, using aggregate U.S. *KLEM* data for the period 1947-71. The main results of this study are that energy demand is responsive to a change of energy prices, that capital and energy are strong complements, and that labour and energy are slightly substitutable.

Whether capital and energy are complements or substitutes in production or, in other words, whether or not an increase of energy prices reduces overall economic investment and economic growth, was the main focus in the 70's and 80's.

Table 1 and Table 2 list the results of a series of papers on the substitutability between capital and energy which have been reviewed by Apostolakis (1990). The author concludes that there is a dichotomy between studies based on time-series data and studies using cross-section or pooled time-series cross-section approaches. While the former tend to support capital-energy complementarity, the latter favour capital-energy substitutability (cf. also Griffin and Gregory 1976).

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[68] See, for example, Hamermesh (1993:88), Kintis and Panas (1989), or Apostolakis (1990) for surveys.

[69] *KLEM* stands for capital (*K*), labour (*L*), energy (*E*), and material (*M*) inputs.

Table 1: *KLEM* studies assessing energy-capital complementarity

*Author(s)**	*Sector(s)*	*Years*	*Remarks*
Berndt/Wood (1975)	US manufacturing	1947-71	CRTS translog cost function with Hicks neutral technological change; σ_{KE} = -3.20
Hudson/Jorgenson (1974)	US manufacturing	1947-71	CRTS translog cost function with no autocorrelation correction; σ_{KE} = -1.39
Fuss (1977)**	5 Canadian regions	1961-71	σ_{KE} = -0.21; translog pooled cross-section time-series with two-stage optimisation
Denny et al. (1978)	Canadian manufacturing	1949-70	Generalized Leontief cost function; σ_{KE} < 0 1952: σ_{KE} = -10.57, 1959: σ_{KE} = -9.86, 1965: σ_{KE} = -11.91, 1970: σ_{KE} = -10.14
Magnus (1979)***	Dutch economy	1950-76	2 models; σ_{KE} = -2.19, σ_{KE} = -2.45; Diewert generalized Cobb-Douglas cost function
Berndt/Khaled (1979)	US manufacturing	1947-71	Test 12 models as derived from a Box-Cox ultra flexible form; Hicks neutral technical change
Anderson (1981)	US manufacturing	1948-71	Mean σ_{KE} = -0.70, 1948: σ_{KE} = -0.65, 1960: σ_{KE} = -0.69, 1971: σ_{KE} = -1.39; CRTS translog cost function
Denny et al. (1981)	USA-Canada 18 industries	1949-71 1961-75	σ_{KE} < 0 in 14 out of 18 US industries (LR); σ_{KE} > 0 in 12 out of 18 Canadian industries (LR); *KLEM*
Norsworthy/Harper (1981)	US manufacturing	1958-77	-0.26 ≤ σ_{KE} ≤ -7.98 in six specifications; translog cost function with CRTS
Morrison/Berndt (1981)	US manufacturing	1952-71	SR:σ_{KE} = 0.000; intermediate-run:σ_{KE} = -0.021; LR: σ_{KE} = -0.075; complementarity increases in the LR
Dargay (1983)	12 Swedish manufacturers	1952-76	In six sectors: σ_{KE} < 0, one sector: σ_{KE} >0, five sectors: σ_{KE} = 0; translog homothetic/nonhomothetic forms
Longva/Olson (1983)	19 Norwegian manufacturers	1962-78	In *E*-intensive sectors: σ_{KE} < 0 (= -0.13); in inclusion of *M* leads to complementarity
Pindyck/Rotemberg (1983)	US manufacturing	1948-71	Translog function using 3SLS; *E-M* are flexible factors; *K-L* are quasi-fixed factors

σ_{ij}: substitution elasticity; CRTS: constant returns to scale; LR: long run; SR: short run.

* See Apostolakis (1990) for detailed references.
** Pooled cross-section data.
*** *KLE* data.

Source: Apostolakis (1990:52).

Apostolakis explains this dichotomy by the fact that annual time series capture only a limited range of input price variations. Thus, a cost function which is estimated from annual time series can be interpreted to reflect short-term relationships. Since the capital stock is fixed in the short run, capital services and energy are likely to be used in fixed proportions. Consequently, an increase of energy prices induces a decrease of capital utilisation. In contrast to this, cross-section and pooled time-series cross-section studies are interpreted to cover long-term relationships. They tend to favour capital-energy substitutability because capital stocks are flexible in the long run and can be adjusted to price changes. An increase in energy prices therefore may stimulate investments in energy-saving technologies which are characterised by higher capital user costs and lower energy consumption (given constant output).

Table 2: *KLEM* studies supporting energy-capital substitutability

*Author(s)**	*Country/sector(s)*	*Method/ years*	*Remarks*
Griffin/Gregory (1976)	9 nations manufacturers	pooled c-s 1955-69	$1.02 \le \sigma_{EK} \le 1.07$; $\sigma_{EK} = 1.02$ (Belgium, Netherlands, Norway); 1.03 (West Germany, Italy); 1.04 (Denmark, UK); 1.05 (France); 1.07 (USA)
Halvorsen/Ford (1979)	8 US 2-digit manufacturers	c-s 1974	$-1.03 \le \sigma_{KE} \le 2.02$; translog function
Ozatalay et al. (1979)	7 nations manufacturers	pooled t-s 1963-74	$\sigma_{KE} = 1.22$; KLEM cost translog function
Pindyck (1979)	10 nations aggregate	pooled c-s t-s 1959-73	$\sigma_{KE} = 1.48$: Canada, 0.56: France, 0.67: Italy, 0.74: Japan, 0.59: Netherlands, 0.54: Norway, 0.63: Sweden, 0.36: UK, 1.77: US, 0.66: West Germany
Uri (1980)	US Manufacturing	c-s 1947-71	*KLEM*; Leontief-type fixed coefficient production function is appropriate; there is directional causality between quantities and prices
Walton (1981)	5 US regions manufacturing	t-s 1950-73	5 inputs: K, L, M, fuels, electricity; all $\sigma_{ij} > 0$; information is lost by regional aggregation
Williams/Laumas (1981)	India manufacturing	c-s 1968	*KLEM* translog function: 96 cross-price elasticities: 88 positive; 8 negative (insignificant)
Turnovsky et al. (1982)		t-s 1946-75	*KLEM* translog function; mean $\sigma_{KE} = 2.26$; $\sigma_{KE} = 2.63$ for 1946-47; 1.91 for 1974-75
Denny et al. (1981)	US-Canada 18 manufacturers	t-s 1949-71 1961-75	$\sigma_{KE} > 0$ in 12 out of 18 Canadian industries; $\sigma_{KE} < 0$ in 14 out of 18 US industries; *KLEM* translog
Apostolakis (1984)	Greece aggregate	t-s 1953-77	$0.92 \le \sigma_{KE} \le 0.94$; two-output three input (*KLE*) translog cost function; separability tests done
Apostolakis (1987)	5 nations aggregate	t-s 1953-84	France: $0.86 \le \sigma_{KE} \le 0.94$; Greece: $0.41 \le \sigma_{KE} \le 0.66$; Italy: $0.83 \le \sigma_{KE} \le 0.95$; Portugal: $0.62 \le \sigma_{KE} \le 0.71$; Spain: $0.74 \le \sigma_{KE} \le 0.82$; translog *KLE* cost function
Iqbal (1986)	Pakistan 16 industries	pooled t-s 5 years	$\sigma_{KE} > 0$ in 9 industries and $\sigma_{KE} < 0$ in 7 industries; total $\sigma_{KE} = 1.641$; *KLE* translog function

σ_{ij}: substitution elasticity, c-s: cross section; t-s: time series.

* See Apostolakis (1990) for detailed references.

Source: Apostolakis (1990:53).

This interpretation of cross-section and time-series studies is questioned by Thompson and Taylor (1995). The authors demonstrate that the dichotomy of both concepts can be partially dissolved if substitutability is no longer measured in terms of the AES, but in terms of the Morishima elasticity of substitution (MES). Based on the latter, positive substitution elasticities are calculated far more frequently between energy and capital. This is due to the fact that the MES per definition tends to favour substitutability relationships (see Section 3.2.2.2).

The question of substitutability between input pairs other than energy and capital is less disputed in the literature. Estimates of substitution between labour and energy and labour and material are summarised in Hamermesh (1993:104). With the exception of only a few studies, labour and energy are found to be substitutes – even if the cross-price elasticity of labour demand with respect to energy prices is quite small and normally below 0.5. According to Hamermesh, labour is also a substitute for material but includes a small cross-price elasticity as well.

Most of the previously cited studies are based on U.S. data. Studies analysing substitution pattern in the German economy were published particularly in the 1980s (e.g. Friede 1980, Nakamura 1984, Unger 1986, Natrop 1986, or Peren 1990). All these studies use time-series *KLEM* data (with the exception of the Natrop study which employs pooled time-series cross-section data) and homothetic translog cost functions. More recent studies are, for example, Falk and Koebel (1999) and Kemfert and Welsch (2000).

Falk and Koebel (1999) estimate cross-price and Morishima substitution elasticities between capital, energy, material, and heterogeneous labour. The factor demand system is derived from a normalised quadratic cost function. The study is based on pooled time-series cross-section data for 27 manufacturing sectors of West Germany over the period 1978-90 and presents estimates for a concavity unrestricted and a concavity restricted model. The authors find very small absolute values of sectorally aggregated price elasticities for aggregated labour. A negative cross-price elasticity is revealed for energy and labour, which suggests a slightly complementary relationship. While the Falk and Koebel study focuses on examining substitution patterns between disaggregated labour and other factor aggregates, my work concentrates on substitutional relationships between disaggregated energy and nonenergy production inputs. As data for disaggregated energy inputs are available only for the same short time period (1978-90), I am also constrained to a time-series cross-section approach, but I still cover a much higher number of sectors (including service sectors).

Based on three alternative nesting structures, Kemfert and Welsch (2000) estimate substitution elasticities directly from a two-level nested CES production function with aggregated energy, capital, and labour input for the entire German industry and seven industrial sectors.[70] The data base consists of time series over the period 1970-88. With regard to the nesting structure the authors find that a nested CES production function with an aggregate of capital and energy is most appropriate for the whole industry, while the ranking varies at the sectoral level. Concerning the magnitude and sign of substitution elasticities, they find that energy, capital, and labour are imperfect substitutes in the production function of the German industry as a whole and of the individual sectors.

From an econometric point of view, the study of Kemfert and Welsch suffers from several shortcomings. Positive substitution elasticities, for example, are an inevitable result because the CES function per definition does not allow for complementarity relationships between input pairs at the same nesting level. In addition, the authors exclude material from production, i.e. they assume that a homothetic *KLE* aggregate exists which is weakly separable from material inputs. The validity of this constraint and other separability restrictions, which are implicitly imposed on the econometric model when a nested CES function is estimated, are, however, not tested.

In order to get around these critical points, I apply a flexible functional form that allows, firstly, to measure for both complementarity and substitutability pattern between input pairs, and, secondly, to test for weak homothetic separability constraints. Compared to previous studies, my work is of higher sectoral coverage; it includes nonenergy materials and introduces a disaggregated energy input.

3.2.2 Theoretical framework

3.2.2.1 Translog cost function

The translog – first introduced by Christensen et al. (1973) – is the most frequently applied flexible functional form in econometrics. In spite of certain limitations, the translog has a number of advantages.[71] In particular it allows testing for approximate separability structures and homotheticity properties of the underlying production structure. In the following sections a flexible translog cost function is employed in order to estimate price and substitution elasticities between five variable production

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[70] The sectors considered are 'chemical industry', 'stone and earth', 'non-ferrous metals', 'iron', 'vehicle', 'paper', and 'food'.

[71] Disadvantages of the translog are the loss of flexibility when global concavity or global weak separability restrictions are imposed (see Section 3.2.2.3 and 3.2.2.4).

factors: capital (*K*), labour (*L*), nonenergy material (*M*), electricity (*EL*), and fossil fuels (*F*). The use of the dual cost function (instead of the production function) with input prices as regressors has proved to be advisable, particularly if empirical data are highly disaggregated and input prices can be assumed to be exogenous for the sectors involved.

The translog cost function can be interpreted as a second-order Taylor series approximation in logarithms to an arbitrary and unknown, twice differentiable cost function. Assume that a twice differentiable non-homothetic cost function exists.[72] Expanding the log of total production costs $\ln C(\mathbf{p},x,t)$ in a second-order Taylor series about the observation point 1990, where $\ln \mathbf{p} = 0$ (**p**=1 in 1990), yields:[73]

$$\begin{aligned}
\ln C(\mathbf{p},x,t) = \alpha_0 &+ \sum_i \beta_i \ln p_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln p_i \ln p_j \\
&+ \beta_x \ln x + \frac{1}{2}\beta_{xx}(\ln x)^2 + \sum_i \beta_{ix} \ln p_i \ln x \qquad (3\text{-}1)\\
&+ \beta_t \cdot t + \beta_{xt} \cdot t \cdot \ln x + \frac{1}{2}\beta_{tt} \cdot t^2 + \sum_i \beta_{it} \cdot t \cdot \ln p_i,\ i,j{=}K,L,M,EL,F,
\end{aligned}$$

where p_i and p_j denote factor prices, x the level of real output and t a time trend reflecting technical progress. Total costs of producing output x are defined by:

$$C = p_K K + p_L L + p_M M + p_{EL} EL + p_F F\ .$$

Slutsky symmetry of cross-price derivatives implies:

(3-2) $\beta_{ij} = \beta_{ji}$.

Theory requires that the cost function be homogeneous of degree one in factor prices, i.e. that, for a fixed level of production, costs increase in the same proportion as prices. Thus the following restrictions are additionally imposed:

(3-3) $\sum_i \beta_i = 1, \quad \sum_i \beta_{ij} = \sum_j \beta_{ij} = \sum_i \beta_{ix} = \sum_i \beta_{it} = 0, \quad i,j = K,L,M,EL,F.$

The translog form is advantageous as it enables statistical testing of the validity of homotheticity and homogeneity restrictions. It is homothetic for $\beta_{ix} = 0, \forall i$,

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[72] The non-homothetic form enables relative input demands to vary with the level of output and places no a priori restrictions on returns to scale.

[73] See Diewert and Wales (1987:46) for a definition of the non-homothetic translog cost function with technical progress.

homogeneous for $\beta_{ix} = \beta_{xt} = \beta_{xx} = 0, \forall i$, and linearly homogeneous for $\beta_{ix} = \beta_{xt} = \beta_{xx} = 0, \forall i$ and $\beta_x = 1$. The translog turns into the Cobb-Douglas form if substitution elasticities are restricted to unity, i.e. if additionally $\beta_{ij} = 0, \forall i, j$.

Assume that firms are price takers and minimise costs. Applying Shephard's lemma leads to the factor share system:

$$\text{(3-4)}\quad s_i := \frac{\partial \ln C}{\partial \ln p_i} = \frac{p_i}{C} \cdot \frac{\partial C}{\partial p_i} = \beta_i + \sum_j \beta_{ij} \ln p_j + \beta_{ix} \ln x + \beta_{it} t, \quad i = K, L, M, EL, F.$$

Due to the restriction of linear homogeneity in prices the adding-up condition is satisfied and cost shares sum up to unity: $\sum_{i=1}^{5} s_i = 1$.

3.2.2.2 Elasticities

Price elasticities

In the empirical part (Section 3.2.4) own- and cross-price elasticities are computed from cost shares and parameter estimates of the translog cost function according to (cf. Berndt 1991):

$$\text{(3-5)}\quad \varepsilon_{ii}(\mathbf{p}, x, t) = \frac{\beta_{ii} + s_i^2 - s_i}{s_i^2}, \quad i = K, L, M, EL, F,$$

$$\varepsilon_{ij}(\mathbf{p}, x, t) = \frac{\beta_{ij} + s_i s_j}{s_i}, \quad i, j = K, L, M, EL, F, \ i \neq j.$$

Substitution elasticities

The computation of Morishima elasticities of substitution (MES) is common in empirical application since the article of Blackorby and Russell in 1989 and their criticism of the Allen partial elasticity of substitution (AES). Blackorby and Russell (1989:883) criticise the AES for being not a quantitative but only a qualitative measure for substitution, which does not provide any new information that is not included in the (constant-output) cross-price elasticity. The AES can be easily expressed as the ratio of the cross-price elasticity of demand for factor *i* with respect to the price of factor *j* to the cost share of input *j* (ε_{ij} / s_j).[74] Assuming non-negative cost shares, the sign of the AES is equivalent to the sign of the cross-price elasticity.

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[74] In terms of the cost function, the AES is defined as: $AES_{ij} = C(\boldsymbol{p},x,t) \cdot C_{ij}(\boldsymbol{p},x,t) / C_i(\boldsymbol{p},x,t) \cdot C_j(\boldsymbol{p},x,t)$.

The MES is defined as:

$$(3\text{-}6)\qquad \sigma_{ij}(\mathbf{p},x,t)=\frac{p_i C_{ij}(\mathbf{p},x,t)}{C_j(\mathbf{p},x,t)}-\frac{p_i C_{ii}(\mathbf{p},x,t)}{C_i(\mathbf{p},x,t)}=\varepsilon_{ji}(\mathbf{p},x,t)-\varepsilon_{ii}(\mathbf{p},x,t).$$

It measures the percentage change in the ratio of input *j* to input *i* when the price of input *i* changes by 1%, keeping output constant. As Burniaux et al. (1992:66) state, the MES is the closest analogue of a CES elasticity in a translog framework.

When interpreting the MES empirically, it is necessary to keep in mind that we are dealing only with a partial elasticity which ignores scale and overall economic effects induced by the change of input prices. It is generally an appropriate measure of the curvature of isoquants and thus a useful concept to calculate substitution elasticities of production functions – which is the main purpose of this chapter.[75]

In contrast to the AES, the MES is generally asymmetric with respect to which price varies ($\sigma_{ij} \neq \sigma_{ji}$), provided that more than two inputs are considered. Input pairs which are Allen substitutes, i.e. which are characterised by positive cross-price elasticities, also have to be Morishima substitutes (assuming positive fitted cost shares and non-positive own-price elasticities), whereas the opposite is not true (cf. Thompson and Taylor 1995:566). Thus, as will be shown in Section 3.2.4.1.2, reporting MES instead of AES (as in the majority of available empirical studies on substitution in the literature) may lead to completely different empirical evidence on substitution pattern.[76]

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[75] Note that if the goal is not only to measure the curvature of isoquants, but to measure changes in relative factor shares, the MES is only useful if technologies are homothetic or if output effects are insignificant. This limitation of the partial MES motivated Davis and Shumway (1996:174) to develop the so-called factor ratio elasticity of substitution. See also Frondel and Schmidt (2000) who propose the concept of generalised cross-price elasticities in order to measure gross substitution effects.

[76] Based on price elasticity estimates of eight major studies of capital-energy substitutability, Thompson and Taylor (1995) demonstrate that substitution elasticities, which are computed according to the MES, are positive in far more cases than when they are calculated according to the AES concept. Additionally, the authors find that the dichotomy between time-series and cross-section studies (see Section 3.2.1) is no longer evident when using the MES instead of the AES.

Economies-of-scale elasticities

In accordance with Berndt (1991), economies of scale, λ, are defined as the inverse of the elasticity of total costs with respect to output, μ_{Cx}. They are computed on the basis of observed output quantities and input prices:[77]

$$\text{(3-7)} \quad \lambda = \frac{1}{\mu_{Cx}},$$

where

$$\mu_{Cx}(\mathbf{p},t,x) := \frac{\partial \ln C(\mathbf{p},t,x)}{\partial \ln x} = \beta_x + \sum_i \beta_{ix} \ln p_i + \beta_{xx} \ln x + \beta_{xt} \cdot t, \quad i = K, L, M, EL, F.$$

$\mu_{Cx}>1$ (or $\lambda<1$ respectively) indicates decreasing and $\mu_{Cx}<1$ (or $\lambda>1$ respectively) increasing returns to scale. Constant returns to scale are characterised by $\mu_{Cx}=\lambda=1$.

3.2.2.3 Monotonicity and concavity

Apart from linear homogeneity in input prices and cross-equation symmetry, monotonicity of the cost function and concavity in factor prices constitute two additional regularity conditions required by microeconomic theory. While it can be easily examined whether the cost function is non-decreasing in input prices by analysing whether fitted cost shares are non-negative, it is more difficult to check concavity conditions and, if they are not satisfied, to impose them. In the literature, a distinction is drawn between the concepts of global concavity and local concavity. Both concepts, applied to the five-input cost function, are discussed in the following.

Global concavity of the translog cost function

As described, for instance, in Lau (1978), Jorgenson and Fraumeni (1981), and Diewert and Wales (1987) a necessary and sufficient condition for global concavity in factor prices is the negative semidefiniteness of the Hessian matrix of second-order partial derivatives of the cost function with respect to input prices: The matrix $\nabla^2_{pp} C(\mathbf{p}, x, t)$ must be negative semidefinite for the observed values of the explanatory variables.

According to Diewert and Wales (1987:47), the logarithmic second-order derivatives of the translog cost function can be expressed by:

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[77] An alternative standardisation can be found in Christensen and Greene (1976). The authors define scale economies as unity minus the elasticity of total cost with respect to output. Increasing returns to scale take positive values, decreasing returns to scale negative values.

$$\frac{\partial^2 \ln C(\mathbf{p},x,t)}{\partial \ln p_i \partial \ln p_j} = \beta_{ij} = \frac{\delta_{ij} p_i C_i}{C} - \frac{p_i p_j C_i C_j}{C^2} + \frac{p_i p_j C_{ij}}{C}$$

where $\delta_{ij} = 1$ if $i = j$ and $\delta_{ij} = 0$ otherwise. These equations can be translated into the matrix form:

$$\text{(3-8)} \qquad \frac{\hat{\mathbf{p}}\left(\nabla^2_{pp} C(\mathbf{p},x,t)\right)\hat{\mathbf{p}}}{C(\mathbf{p},x,t)} = \mathbf{B} - \hat{\mathbf{s}} + \mathbf{s}\mathbf{s}^{\mathbf{T}}$$

where $\mathbf{B} = (\beta_{ij})_{i,j=K,L,M,EL,F}$, $\mathbf{s}$ is a quintuple vector of cost share functions, $\hat{\mathbf{s}}$ is a 5×5 matrix with the share vector on the main diagonal, and $\hat{\mathbf{p}}$ is a 5×5 diagonal matrix, the diagonal elements of which are the elements of price vector $\mathbf{p}$. On the assumption that costs are strictly positive and prices are non-negative the Hessian matrix of the cost function, $\nabla^2_{pp} C(\mathbf{p},x,t)$, is obviously negative semidefinite if and only if the matrix $\mathbf{B} - \hat{\mathbf{s}} + \mathbf{s}\mathbf{s}^{\mathbf{T}}$ is negative semidefinite. Thus, if cost shares s_i are non-negative (which implies monotonicity of the cost function) and since $0 \le s_i \le 1$, the negative semidefiniteness of matrix $\mathbf{B}$ is necessary and sufficient for the negative semidefiniteness of $\nabla^2_{pp} C(\mathbf{p},x,t)$ at each observation point, i.e. for global concavity of the cost function with respect to all input prices generating non-negative cost shares. Consequently, global concavity can be checked ex post by examining whether the signs of the principal minors of the Hessian matrix – or equivalently of the matrix $\mathbf{B}$ – have the correct sign at each observation point.[78] If global concavity properties are violated,[79] global concavity restrictions can be empirically imposed on the translog cost function by means of a Cholesky factorization (see Jorgenson and Fraumeni 1981). This simply requires that the elements of $\mathbf{B}$ in (3-1) be parameterised according to

$$\text{(3-9)} \qquad \mathbf{B} = \mathbf{L}\mathbf{D}\mathbf{L}^{\mathbf{T}}$$

where $\mathbf{D}$ is a diagonal matrix, whose diagonal elements are called Cholesky values (cf. Lau 1978:429). $\mathbf{L}$ is a unit lower triangular matrix, and $\mathbf{L}^{\mathbf{T}}$ is the transposition of $\mathbf{L}$. As $\mathbf{B}$ is negative semidefinite if and only if all Cholesky values are non-positive, i.e. $D_{ii} \le 0, \forall i$, (cf. Lau 1978:429, Theorem 3.2), the cost function can be restricted to global concavity by determining that the D_{ii} are non-positive.

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[78] Neither the monotonicity nor the concavity check represent statistical tests, i.e. they do not examine whether negative fitted cost shares or principal minors with wrong signs are statistically significant.

[79] See Section 3.2.4.1.1 for possible reasons for the non-concavity of the cost function.

However, as indicated by a number of empirical studies, imposing global concavity restrictions on the translog function destroys its flexibility properties.[80] Diewert and Wales (1987:48,62), for example, demonstrate that the Jorgenson and Fraumeni procedure causes distortions with a tendency to bias own-price elasticities upward (in absolute terms). The problem that the translog typically does not have a correct global curvature led to an increased application of other flexible functional forms in recent years, which are based e.g. on the normalised quadratic cost function (see Diewert and Wales 1987, 1995) or linear logit models (see Jones 1996). These forms are actually more appropriate to satisfy the regularity conditions globally prescribed by economic theory.

Local concavity of the translog cost function

Nevertheless, I decided to use the translog because separability constraints can be imposed and tested for this functional form, and functional parameters can be easily interpreted. In order to avoid the inflexibility problem implied by global concavity restrictions, I impose, in line with Lau (1978), less restrictive local concavity conditions on the approximating translog function. In contrast to global concavity, local concavity requires only that the functional form is curvature correct at a single data point, typically the point of approximation.

Lau shows that for local concavity of the cost function it is necessary and sufficient that the matrix $\mathbf{B}-\hat{\mathbf{s}}+\mathbf{s}\mathbf{s}^{\mathbf{T}}$ is negative semidefinite at the approximation point 1990, for which $\ln\mathbf{p}=0$. Its Cholesky factorization yields:

$$\text{(3-10)} \quad \mathbf{B}-\hat{\mathbf{s}}+\mathbf{s}\mathbf{s}^{\mathbf{T}}=\mathbf{L}\mathbf{D}\mathbf{L}^{\mathbf{T}}.$$

Restricting the Cholesky values D_{ii} to non-positiveness is necessary and sufficient to yield a negative semidefinite result for the matrix $\mathbf{B}-\hat{\mathbf{s}}+\mathbf{s}\mathbf{s}^{\mathbf{T}}$ (provided that cost shares for 1990 data are positive), i.e. that the cost function is locally concave in input prices for 1990 data.

3.2.2.4 Weak separability

The GEM-E3 producer model is based on a four-level nested CES production function (see Figure 3 in Section 3.2.3.2). Assuming nested technologies in CGE

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[80] Due to this inflexibility, the translog cannot describe global concavity properties of the true cost function in general, but only for special cases of cost functions, such as the Cobb-Douglas type (see Natrop (1986:57) for a detailed discussion).

modelling is advantageous, as this allows for subsequent optimisation, different elasticities between input pairs, and inter-process substitution, which enables input factors not only to be substitutes, but also to be complements (cf. Anderson and Moroney 1993). In order to estimate substitution elasticities which are consistent with a nested production structure, it is necessary to impose weak separability restrictions a priori.

A definition of weak separability is given in Berndt and Christensen (1973:404) or Chambers (1988:44). The production function $x = f(a,t)$ is weakly separable with respect to a given partition of the set of all inputs into $\{a^1, a^2, ..., a^m\}$, i.e. $x = f\left(f^1(a^1,t), f^2(a^2,t), ..., f^m(a^m,t), t\right)$ if the marginal rate of technical substitution between a_i and a_j, which are elements of the same separable input vector a^r, is independent of the quantities of all factors outside that aggregate, i.e. if $\frac{\partial}{\partial a_k} \frac{\partial f(a,t)/\partial a_i}{\partial f(a,t)/\partial a_j} = 0, \;\; i, j \in a^r, k \notin a^r, \;\; r = 1,...,m$.

While weak separability of the production function is only a necessary condition for the existence of consistent input aggregates, weak homothetic separability in the quantities to be aggregated is a necessary and sufficient condition (cf. Denny and Fuss 1977:408). Weak homothetic separability requires that the macro-production function f be weakly separable and that the micro-production function $f^1, f^2, ..., f^m$ be homothetic. Weak homothetic separability opens up the possibility of a two-stage optimisation procedure which implies that the mix of inputs within each aggregate is optimised in a first step, and then the level of each aggregate in a second step (Fuss 1977:91).[81]

The common empirical procedures for testing for weak separability depend on whether the translog is interpreted as the true production function or just as an approximation of an arbitrary production function. Berndt and Christensen (1974) developed a test procedure under the assumption that the translog exactly represents the unknown production function. However, this exact test was fiercely criticised by Blackorby et al. (1978:297) and Denny and Fuss (1977), who point out that the imposition of weak homothetic separability conditions may cause the micro-production function or the macro function of aggregates – or both – to lose their

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[81] According to duality theory, a homothetically weakly separable production function corresponds to a cost function which is weakly separable in factor prices (with an identical partial aggregation of inputs) and separable in output (cf. Chambers 1988:115).

flexibility, i.e. their capability to provide an arbitrary second-order approximation to the separable technology. Strictly speaking, the restrictions either force the separable form of the translog function to be a Cobb-Douglas function of translog aggregates or to be a translog function of Cobb-Douglas aggregates.[82] Thus a statistical rejection of weak separability, based on this exact test, is not very meaningful.

In order to avoid this inflexibility imposed by the restrictions for weak homothetic separability on the translog production function in the exact case, Denny and Fuss (1977) provide a less restrictive empirical test for (local) weak homothetic separability at the point of approximation. They employ a linear-homogeneous production function and demonstrate that the conditions for weak separability and weak homothetic separability are identical.

Let us assume a five-input production function that is weakly homothetically separable in the partition a^1 and which is expressed by $x = f(f^1(a^1,t), a_5, t)$, where $a^1 = \{a_1, a_2, a_3, a_4\}$ and f^1 is a homothetic micro-production function. According to Chambers (1988:115) and the theorem of duality, this production function corresponds to the cost function $C = c(h(p^1,t), p_5, x, t)$, $p^1 = (p_1, p_2, p_3, p_4)$, which is weakly separable in the 'ext

ended' partition $\{p^1, p_5, x\}$. The parameter restrictions for weak homothetic separability of the underlying production function, which have to be imposed on the translog cost function, are:

$$\beta_i \beta_{j5} = \beta_j \beta_{i5}, \quad \beta_i \beta_{jx} = \beta_j \beta_{ix}, \; i, j = 1, \ldots 4.$$

If the null hypothesis of approximate weak homothetic separability

(3-11) $\beta_i \beta_{j5} - \beta_j \beta_{i5} = 0, \quad \beta_i \beta_{jx} - \beta_j \beta_{ix} = 0, \; i, j = 1, \ldots, 4,$

cannot be rejected, the cost function is thus approximately weakly separable in partition $\{p^1, p_5, x\}$.

For the estimation of a nested cost function, consistent price aggregates of the weakly homothetically separable input factors are required.

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[82] Starting out from the separability and inflexibility criticism of the translog, Diewert and Wales (1995) propose two functional forms, which are based on the normalised quadratic functional form. The authors estimate profit functions and test them for the existence of a homogeneously separable aggregator function. One disadvantage of their separability tests is that both the macro-aggregator function and the micro-aggregator function are assumed to be linearly homogeneous in their arguments.

One option to generate them is to choose a step-by-step translog estimation approach by estimating sub-models of the separable factors. In order to ensure that an aggregate price index is independent of all other prices and quantities and that the product of the aggregate price and quantity indices equals an aggregate's total costs, the condition of weak homogeneous separability on the production function is typically imposed. This means that the micro-production function $f^1(a^1, t)$ is not only required to be homothetic, but additionally linear-homogeneous in its arguments (cf. Diewert and Wales 1995). It is only under this assumption that the aggregate price index is equal to the unit cost of the separable aggregate.

A second option is to employ appropriate index number techniques to compute aggregate prices and quantities from disaggregated data. However, as Natrop (1986:136) critically remarks, the use of index functions may lead to inconsistencies and distortions of estimates and does not give evidence for the relationships among input factors of an aggregate. Due to these disadvantages, I will apply the first method in Section 3.2.3.2.

3.2.3 Estimation procedure and empirical data

3.2.3.1 One-stage estimation

For the purpose of the empirical implementation of the translog cost model I impose the restrictions of symmetry (3-2) and linear homogeneity (3-3) on the parameters of the cost function and the five cost share equations. Stochastic terms are added to each of the equations, which are assumed to be independently and identically multivariate and normally distributed with mean vector zero and a constant non-singular covariance matrix for each equation.[83] Due to the condition of linear homogeneity in prices, the cost shares of the five demand equations sum up to unity; thus the disturbance covariance matrix is singular and non-diagonal. This problem is solved by dropping the share equation for nonenergy materials; the parameters of the omitted equation are then estimated indirectly as linear combinations of the remaining parameter estimates. In order to ensure invariance with respect to the choice of the dropped share equation, I compute maximum-likelihood estimates of the parameters. The econometrics software program used is TSP 4.4.

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[83] The appended error terms incorporate, for example, deviations of the firms from cost-minimising behaviour as well as errors of approximation to the unknown cost function (see Berndt 1991, Greene 1997).

As previously mentioned, I use pooled time-series cross-section data. A total of 49 sectors, for which data are available in the German national account statistics, are pooled into four sector aggregates:[84]

- the energy supply sectors aggregate (7, 8, 11, 15), accounting for 39% of energy consumption,[85]
- the energy-intensive manufacturing sectors aggregate (1, 12, 14, 18-24, 32, 33, 37-39), accounting for 17% of energy consumption,[86]
- the nonenergy-intensive manufacturing sectors aggregate (16, 17, 25-31, 34-36, 40-46), accounting for 11% of energy consumption, and
- the service sectors aggregate (51, 52, 54-57, 60, 61, 64-66), accounting for 33% of energy consumption.

The five-equation system, consisting of the cost function and four factor demand equations, is estimated for each of the four sector aggregates, employing the panel data set described in Section 3.2.3.3.[87] It is assumed that the slopes of the derived demand functions are identical in each sector aggregate, i.e. sectoral dummy variables are added only to first-order coefficients (β_i). This reduces the meaningfulness of sectorally differentiated substitution elasticities, as values differ only according to differences in sectoral cost shares. However, the introduction of sectoral dummy variables in addition to the parameters representing the second derivatives of the cost function failed because the resulting number of free parameters proved to be too high.

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[84] The way of pooling follows the sectoral breakdown of the GEM-E3 model (cf. Table 17 in Appendix I).

[85] Percentage rates refer to an aggregate's share of energy consumption in total energy consumption of all 49 sectors in 1990.

[86] The energy-intensive manufacturing sectors aggregate contains five nonenergy-intensive manufacturing sectors with cost shares of total energy below 5%. These are the sectors 'fabricated metal' (24), 'precision and optical instruments' (32), 'iron, steel, and steel products' (33), 'paper and paper products' (38) and 'printing and publishing' (39). Besides, the aggregate contains the sector 'agriculture' (1), for which a cost share for aggregate energy of 4.9% is calculated in 1990.

[87] Including the cost function is advantageous for two reasons: first, it enhances the efficiency of estimation, and second, it facilitates the estimation of scale elasticities.

3.2.3.2 Three-stage estimation

While the previous section dealt with substitution patterns in the German economy in general, the objective of this section is to estimate substitution elasticities that fit into the nested production structure of the GEM-E3 model.

The GEM-E3 model includes 18 production sectors which are characterised by four-level nested CES production functions with labour, capital, and 18 intermediate inputs.[88] The intermediates consist of electricity, an input aggregate of three fossil fuel components (coal, oil, and gas), and an input aggregate of 14 nonenergy material components. The following figure illustrates the levels of nesting:

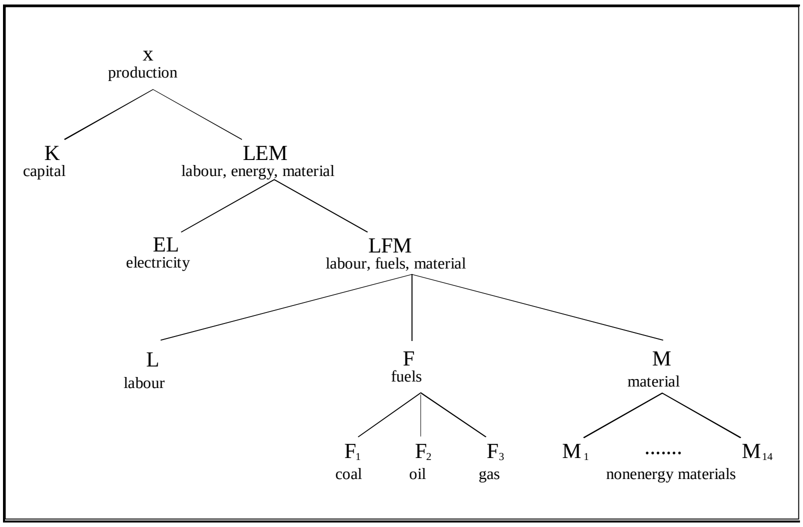

Figure 3: Nested production structure of the GEM-E3 model

This production structure implies that firms at the bottom level minimise costs by choosing optimal quantities of fossil fuels (F_1, F_2, F_3) and material ($M_1,\ldots,M_{14}$) components within the fossil fuel (*F*) and material (*M*) composite. In a second step, firms choose the cost-minimising mix of labour (*L*), the fossil fuel aggregate (*F*), and the material aggregate (*M*), in a third step the cost-minimising mix of the *LFM* bundle and electricity (*EL*) and, finally at the top level, the optimal mix of the *LEM* aggregate and capital (*K*). This four-level nested CES production function implicitly assumes weak homothetic separability, i.e. the cost function is weakly separable in prices and output (cf. Section 3.2.2.4).

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[88] See Appendix IV for a description of the GEM-E3 model.

Assuming weak homothetic separability of the production function opens up the possibility of multi-stage estimation of production decisions using consistent input aggregates. The three-stage estimation procedure, described below, represents an extension of the two-stage estimation procedure applied in Fuss (1977). Due to a lack of disaggregated data, I was not able to examine substitutability relationships between coal, oil, and gas and between the individual nonenergy material components.

First nesting level: *K-LEM* (*third stage of estimation*)

I will now turn to the first stage of the nested GEM-E3 production model. Imposing weak homogeneous separability in the LEM aggregate leads to the production function $x = f(LEM(L,M,EL,F,t),K,t)$, where LEM is a linear-homogeneous aggregator function. The dual cost function is then weakly separable in the same partition: $C = h(p_{LEM}(p_L, p_M, p_{EL}, p_F, t), p_K, x, t)$. p_{LEM} represents an aggregate price index which is equal to the minimum cost per unit of the separable LEM aggregate and which is independent of the level of *LEM*. The non-homothetic translog cost function with exponential technical progress is expressed by:

$$\ln C = \alpha_0 + \sum_i \beta_i \ln p_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln p_i \ln p_j + \beta_x \ln x + \frac{1}{2}\beta_{xx}(\ln x)^2$$

$$+ \sum_i \beta_{ix} \ln p_i \ln x + \beta_t \cdot t + \beta_{xt} \cdot t \cdot \ln x + \frac{1}{2}\beta_{tt} \cdot t^2 + \sum_i \beta_{it} \cdot t \cdot \ln p_i$$

where $i, j \in \{LEM, K\}$. I impose the conditions of symmetry (3-2) and linear homogeneity in prices (3-3) and apply Shephard’s lemma to derive the cost share equations. The factor share system (consisting of only one equation) and the translog cost function is estimated with respect to the prices for capital use (p_K) and the price index for the separable input aggregate (p_{LEM}). p_{LEM} is generated in the second estimation stage.

Second nesting level: *LFM-EL* (*second stage of estimation*)

Due to the assumption that the cost function of the LEM sub-aggregate is linear-homogeneous in LEM, the unit cost function can be approximated by the following translog unit cost function:[89]

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[89] The assumption of linear homogeneity of the sub-aggregate cost function in *LEM* is a necessary assumption in order to ensure that the value of output is equal to the values of inputs. Linear homogeneity implies in addition to homotheticity and homogeneity that β_{LEM}=1. Thus ln(*LEM*) appears on the right hand side of the equation of the log of total costs. Subtracting ln(*LEM*) from

$$\ln p_{LEM} = \alpha_0 + \sum_i \beta_i \ln p_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln p_i \ln p_j + \sum_i \beta_{it} \ln p_i \cdot t$$

where $i, j \in \{LFM, EL\}$. The share equation of electricity is estimated on the basis of exogenous electricity prices (p_{EL}) and estimates of p_{LFM} , which are generated in the first stage of estimation.

Third nesting level: L-F-M (*first stage of estimation*)

The translog unit cost function of the *LFM* aggregate, which is assumed to be linear-homogeneous in the level of *LFM*, is represented by

$$\ln p_{LFM} = \alpha_0 + \sum_i \beta_i \ln p_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln p_i \ln p_j + \sum_i \beta_{it} \ln p_i \cdot t$$

where $i, j \in \{L, F, M\}$. The translog system of the two cost share equations for labour and fossil fuels is estimated on the basis of exogenous prices of labour (p_L), fossil fuels (p_F), and nonenergy materials (p_M).

3.2.3.3 Data

Yearly data on prices and cost shares of capital, labour, nonenergy material, electricity, and fossil fuels are compiled from German national account statistics and input-output tables of 1978-90. Due to the short time period, I use pooled time-series cross-section data. The whole sample contains the agriculture and forestry sector and nearly all producing and service sectors recorded by the German Federal Statistical Office.[90] Input prices and quantities are constructed according to Falk and Koebel (1999).

Electricity and fossil fuels

As sectorally disaggregated data for electricity and fossil fuels are not available from national account statistics, expenditure and quantities (in terajoule) are drawn from (unpublished) input-output tables, which were provided by the Federal Statistical

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the left hand side leads directly to the unit cost function of the *LEM* aggregate, i.e. to the translog price function. Linear homogeneity conditions are also imposed at the third nesting level (see Section 3.2.2.4).

[90] Due to data problems, two sectors – ‘other services’ (67) and ‘house renting’ (62) – were excluded from the data set. The ‘water supply’ sector (9) was separated as well, because its inclusion into the group of energy supply sectors led to implausibly high elasticity values, particularly in cases where fossil fuels were involved.

Office Germany. In order to ensure consistency of input-output energy data with national account data, the following adjustments are required for each sector:[91]

$$(p_i a_i)_{78}^{NA} = (p_i a_i)_{78}^{IO} \cdot \frac{(p_x x)_{78}^{NA}}{(p_x x)_{78}^{IO}},$$

$$(p_i a_i)_t^{NA} = (p_i a_i)_t^{IO} \cdot \frac{(p_i a_i)_{78}^{NA}}{(p_i a_i)_{78}^{IO}}, \qquad i = EL, F, \quad t = 1978, \ldots, 1990$$

where a_i represents demand of input *i*; $(p_i a_i)_t^{NA}$ denotes expenditure in period *t* for input *i*, calculated according to the concept of national account statistics, and $(p_i a_i)_t^{IO}$ stands for expenditure, calculated according to the input-output concept.

This adjustment formula assumes that differences in output x between the national account and the input-output concept do not change over time but can be represented by the discrepancy in 1978.

The prices of electricity and fossil fuels are derived by dividing expenditure by quantities, both are defined in terms of the input-output classification. The energy deflator $p_{i,t}^{IO}$ is then used to approximate the national account energy deflator $p_{i,t}^{NA}$, which is normalised to one in 1990. The quantity indices for electricity and fossil fuels are obtained by dividing expenditure for electricity and fossil fuels by the standardised price deflator:

$$a_{i,t}^{NA} = \frac{(p_i a_i)_t^{NA}}{p_{i,90}^{IO}}, \qquad i = EL, F, \quad t = 1978, \ldots, 1990.$$

Nonenergy materials

Nonenergy material inputs include intermediate inputs other than energy. Expenditure for nonenergy materials are obtained by subtracting energy expenditure $\sum_i (p_i a_i)_t^{NA}$, $i = EL, F$, from material expenditure. Quantities of nonenergy materials in 1990 prices are calculated in a similar way. The deflator for nonenergy materials is computed as the ratio between nonenergy material expenditure and quantities in 1990 prices.

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[91] The concepts of input-output tables (IO) and national account statistics (NA) are not fully compatible. In contrast to input-output tables, which are constructed according to the functional classification scheme (breakdown of sectors by commodities), national account data are classified according to the institutional principle (breakdown of sectors according to institutional units).

Labour

As data on actual working hours in each of the 49 sectors are not available, the quantity of labour is approximated by the total number of employees.[92] For each sector and year, the price for labour is calculated by dividing gross wage income of employed persons by the number of employees. Wages are normalised to unity in 1990. Labour quantities (in prices of 1990) are obtained by dividing gross wage income by normalised wages.

Capital

I assume that capital is variable[93] and calculate sectoral user costs of capital in line with Jorgenson (1974) as follows:[94]

$$p_{K,t} = (1 + r_t) \cdot p_{I\,t} - (1 - \delta_t) \cdot p_{I\,t+1}$$

where r_t denotes the nominal interest rate, $p_{I\,t}$ and $p_{I\,t+1}$ represent the price of gross investment at t and $t+1$ and δ_t the depreciation rate. Nominal interest rates are provided by the Deutsche Bundesbank. δ_t is computed as follows:

$$\delta_t = (NK_t - NK_{t+1} + I_t) / NK_t$$

where NK_t denotes real net capital stock and I_t gross investment in constant prices. The price index for gross investment, $p_{I\,t}$, is derived by dividing gross investment in actual prices by gross investment in constant prices. The quantity of capital is computed by dividing capital costs, $p_{K,t} \cdot NK_t$, by the 1990 normalised user-cost price index of capital.

Figure 4 gives an impression of the development of aggregated prices and quantities over the period 1978-90. In all sector aggregates the development of fossil fuel prices clearly reflects the oil crisis, which led to a sharp price increase from 1978 onward. After a peak in 1985, prices fell again, but then the decline stopped and prices remained at a higher level.

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[92] As Hamermesh (1993:68) emphasises, using employment instead of working hours may result in biases if hours per worker are correlated with factor prices and output.

[93] Alternatively, lagged adjustment mechanisms can be introduced by modelling capital as a quasi-fixed input in the short run (cf. Kintis and Panas 1989).

[94] Sectoral indices are omitted for the sake of simplicity.

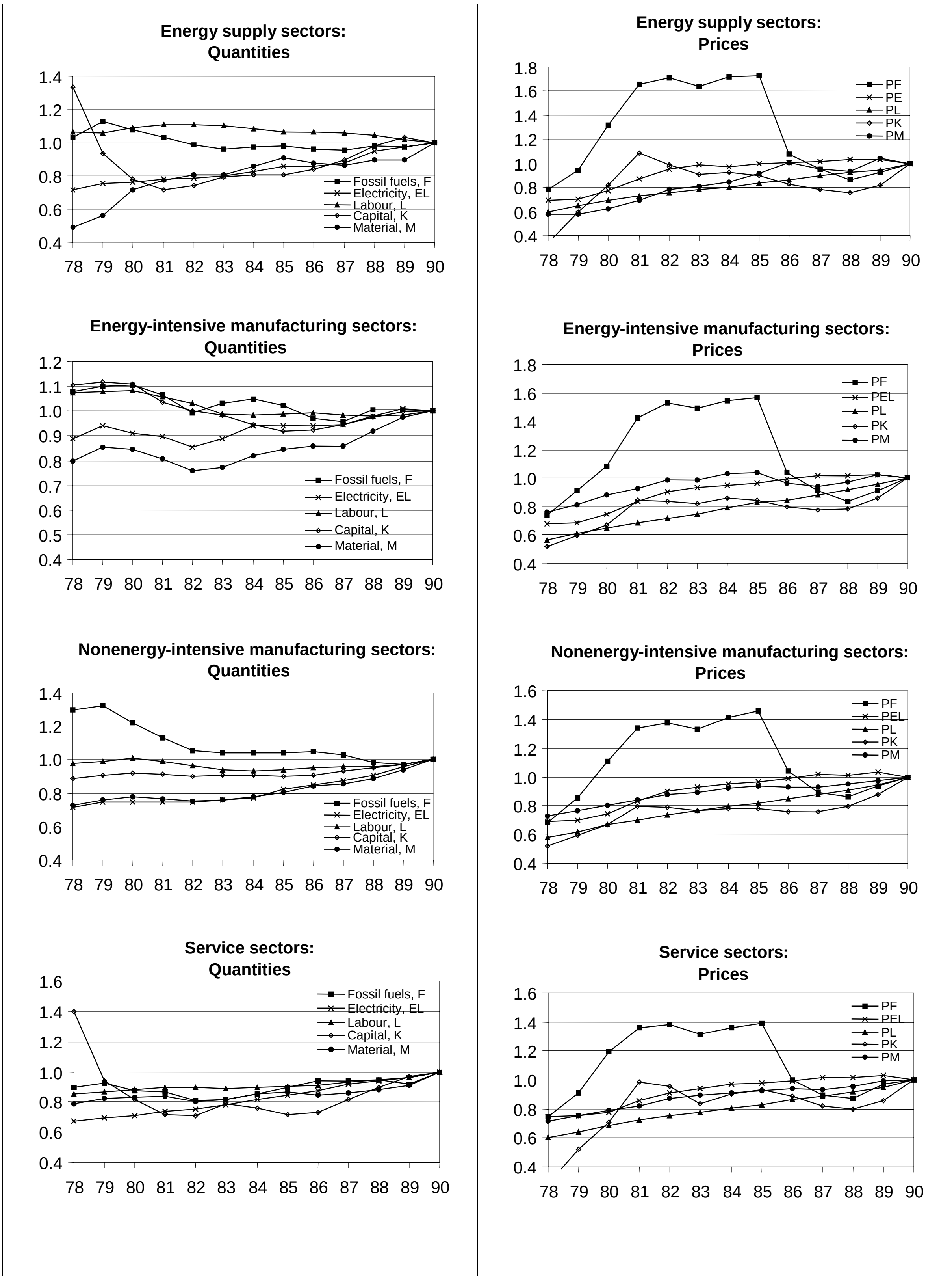

Figure 4: Quantities and prices for sector aggregates (1978-90)

Note: Quantity and price indices for 1978-90 are normalised at unity in 1990.

In contrast, electricity prices were relatively uninfluenced by the oil crisis (prices increased relatively steadily by a total of 40% from 1978 to 1990) as electricity production is mainly based on brown and hard coal, produced in Germany, whereas the share of oil in total fuel inputs is less than 10%.[95]

The development of fossil fuel consumption corresponds to the development of fossil fuel prices. With the exception of the service sectors aggregate, fossil fuel demand declined in all sector groups. In contrast, the trend seems to indicate an increase of electricity use in production. Labour demand remained nearly constant in the nonenergy-intensive manufacturing sectors aggregate and increased in the service sectors aggregate in spite of a significant rise of the wage rate. However, increased labour costs are associated with reduced labour demand in the energy supply and energy-intensive manufacturing sectors.

Cost shares

Cost shares calculated for the entire German economy and for the different sector groups are listed in Table 3. All in all, the figures indicate that cost shares were relatively stable during the examined period. Remarkably, cost shares of fossil fuels are smaller in 1990 than in 1978 in all sector groups, whereas cost shares are slightly higher for electricity. The substantial increase of the cost share of material in the energy supply sectors aggregate is the most striking result which is associated with a significant decrease of the cost share of fossil fuels. This is primarily the consequence of price effects (due to the development of fossil fuel prices between 1978 and 1990) and of the high cost share of fossil fuels in total inputs in this sector group (particularly in the ‘mineral oil’ sector).

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[95] The cost share of oil in total inputs in electricity production was 7.2% in 1980, 3.3% in 1985, and 2.8% in 1990 (BMWi 1993, 1998).

Table 3: Cost shares of sector aggregates [%]

	Year	Fossil fuels (F)	Electricity (EL)	Labour (L)	Capital (K)	Material (M)
All sectors	1978	4.42	1.44	21.70	7.41	65.03
	1984	6.04	1.56	20.25	8.28	63.87
	1990	3.11	1.53	21.30	8.96	65.11
Energy supply sectors	1978	43.04	3.07	15.78	16.73	21.38
	1984	44.84	2.51	10.98	13.90	27.77
	1990	27.03	3.15	12.73	18.79	38.31
Energy-intensive manufacturing sectors	1978	4.45	2.27	25.18	12.38	55.71
	1984	6.48	2.41	23.03	12.54	55.54
	1990	3.41	2.30	25.15	13.14	55.99
Nonenergy-intensive manufacturing sectors	1978	1.10	0.82	29.99	5.97	62.13
	1984	1.34	0.89	28.75	6.78	62.24
	1990	0.66	0.89	28.34	6.97	63.14
Service sectors	1978	2.08	1.39	15.73	5.76	75.04
	1984	2.55	1.55	15.47	7.04	73.39
	1990	1.69	1.51	16.60	7.91	72.29

Table 14 in Appendix I reveals that cost shares vary among the sectors – indicating sectoral differences in factor intensities and production technologies. The share of aggregated energy expenditure in total expenditure is for the most part of sectors far less than 10%. Only the energy supply sectors (7, 8, 11, 15), ‘pulp and paper’ (37), and ‘water transport’ (55) reveal cost shares higher than 10%. The share of electricity in total costs is, for most of the sectors, less than 3%. It exceeds the 3% limit only in nine sectors: ‘electricity’ (7), ‘coal mining’ (11), ‘sand, gravel and stone’ (18), ‘glass’ (20), ‘non-ferrous metals’ (22), ‘foundry’ (23), ‘timber processing’ (35), ‘pulp and paper’ (37), and ‘railways’ (54). The cost share of fossil fuels is above 5% in the transport sectors (55, 57) and the energy supply sectors (7, 8, 11, 15), as well as in several energy-intensive manufacturing sectors, such as the ‘pulp and paper’ industry (37), ‘iron and steel production’ (21), ‘glass’ (20), ‘fine ceramics’ (19), ‘sand, gravel and stone’ (18), and ‘chemical products’ (14).

There is a tendency that (less capital-intensive) sectors with cost shares of capital lower than 10% have cost shares for total energy below 5%. Highly capital-intensive sectors with cost shares exceeding 20% are: ‘agriculture and forestry’ (1), ‘electricity’ (7), ‘railways’ (54), ‘water transport’ (55), ‘postal services’ (56), and ‘education, science, and culture’ (65).

For the majority of sectors cost shares for labour vary between 20 and 30%. Sectors with cost shares below 20% are: ‘agriculture and forestry’ (1), the energy supply sectors (with exception of ‘coal’), ‘non-ferrous metals’ (22), ‘pulp, paper and board’

(37), ‘food’ (43), ‘beverages’ (44) and ‘tobacco’ (45), the trade sectors (51, 52), and ‘water transport’ (55).

3.2.4 Empirical results

3.2.4.1 One-stage estimation

In this section I present estimates of the non-nested and non-homothetic translog cost function with capital, labour, material, electricity, and fossil fuels.

3.2.4.1.1 Curvature conditions

Price elasticities are computed according to definition (3-5) and are evaluated on the basis of 1990 data (the most recent year). The following aggregated elasticities are calculated as the weighted sum of sectoral elasticities, whereas a sector’s share in total input quantity serves as weight.[96] I allow for two ways of aggregation: first, elasticity values which are insignificant at a 5% level enter aggregation with zero (value I). Second, all estimates, whether they differ significantly from zero or not, are used to compute the weighted aggregated elasticity (value II).

Table 4 depicts sectorally aggregated own-price elasticities, calculated from the *concavity unrestricted* translog cost function. In the majority of cases, elasticities show the expected sign; in particular the own-price elasticities of capital, labour, and material are negative for all sectors without exception. However, significantly positive own-price elasticities of electricity demand are computed for the service sectors. Additionally, the own-price elasticity of fossil fuel demand is significantly positive for all sector groups, with the exception of the energy supply sectors, for which I obtain negative values.

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[96] See Falk and Koebel (1999) for a theoretical founding of this aggregation procedure for own- and cross-price elasticities over individual industries. This procedure guarantees that sectorally aggregated own- and cross-price elasticities sum up to zero ($\sum_j \varepsilon_{ij} = 0$) as required by theory.

Table 4: Own-price elasticities for sector aggregates, concavity unrestricted and non-nested translog model (at 1990 data)

	Energy supply sectors			*Energy-intensive manufact. sectors*		
	value I	value II	sig. cas.*	value I	value II	sig. cas.
ε_{KK}	-0.399	-0.399	4	-0.334	-0.334	15
ε_{LL}	-0.000	-0.085	0	-0.133	-0.133	15
ε_{MM}	-0.399	-0.399	4	-0.059	-0.059	15
$\varepsilon_{EL,EL}$	-0.230	-0.230	4	-0.000	-0.012	0
ε_{FF}	-0.281	-0.281	4	0.397	0.397	15
	Nonenergy-intens. manufact. sectors			*Service sectors*		
	value I	value II	sig. cas.	value I	value II	sig. cas.
ε_{KK}	-0.275	-0.275	19	-1.047	-1.047	11
ε_{LL}	-0.155	-0.155	19	-0.760	-0.760	11
ε_{MM}	-0.117	-0.117	19	-0.230	-0.230	11
$\varepsilon_{EL,EL}$	-0.000	0.081	0	0.648	0.648	11
ε_{FF}	0.277	0.277	19	0.406	0.406	11

* t-statistics at a 5% level.

Even if positive own-price elasticities are inconsistent with neo-classical theory, they are a common finding in empirical applications of *KLEM* models to German data and in interfuel substitution studies (cf. Nakamura 1984:201, Jones 1996:815). According to Friede (1980:87), who also computed positive own-price elasticities for West German producing sectors in 1954-1967, positive own-price elasticities can be attributed to: statistical errors (e.g. positive values are statistically not significant), data errors (in particular in cases where the input, e.g. fossil fuels, is unimportant for production), and errors in model assumptions (e.g. with respect to the underlying postulate of cost-minimising behaviour).

In practice, it is quite difficult to identify the source of error. Deviations from cost-minimising behaviour might be, for example, attributed to energy or environmental policy regulations, to information and transaction costs, or to physical constraints which prevent input quantities from adjusting to their optimal levels (cf. Conrad and Unger 1987). Note that for the energy supply sectors own-price elasticities are negative (indicating cost-minimising behaviour) although this sector group (in particular the ‘electricity’ sector) was heavily affected by environmental laws and other energy policy regulations in the 1980s.

Data errors seem to be the most obvious explanation for significantly positive own-price elasticities of fossil fuel demand in the service sectors and in the nonenergy-intensive manufacturing sectors, as these sectors are characterised by cost shares of fossil fuels below 5%.

In order to be able to interpret the estimates in an economically sensible way, I impose *local concavity* restrictions by replacing the substitution parameters β_{ij} in equations (3-1) and (3-4) by a Cholesky factorization according to equation (3-10). For the concavity unrestricted translog, the Cholesky values (D_{ii}, $i=K,L,M,EL,F$) of all five inputs are negative for the energy supply sectors aggregate. However, estimating the translog for the energy-intensive manufacturing sectors, nonenergy-intensive manufacturing sectors, and service sectors aggregates yields non-negative Cholesky values for fossil fuels and/or electricity. Thus the corresponding Cholesky values $D_{EL,EL}$ and D_{FF} are restricted to zero when estimating the translog model for these three sector aggregates.[97]

Table 5 depicts local concavity restricted estimates. All computed own-price elasticities are negative and below unity (in absolute terms), with the exception of capital demand in the service sectors. The monotonicity of the cost function – with the exception of two minor sectors (‘printing and publishing’ and ‘office and data processing’), for which slightly negative fitted cost shares of fossil fuels are computed – is satisfied at 1990 data.

The responsiveness of input demand to a change of own prices is highest for capital and labour in the service sectors. On the whole, the estimates are in accordance with the results in the econometric literature. Hamermesh (1993), for example, derives a range of –0.75 to –0.15 for ε_{LL} in the aggregate. He reports own-price elasticities of capital ε_{KK} and material ε_{MM} which are (in absolute values) below unity and thus also consistent with my estimates. The estimates of Hesse and Tarkka (1986) are in conformity with my results, too. On the basis of pooled individual country time-series data for two periods, 1960-72 and 1973-80, the authors find that capital evokes the highest demand response in Germany’s manufacturing industry. The authors reveal estimates of –0.59 for ε_{KK}, –0.2 for ε_{LL}, –0.36 for $\varepsilon_{EL,EL}$, and –0.09 for ε_{FF} for the second period. However, compared to estimates of own-price elasticities of fossil fuels and electricity demand produced by Halverson (1977) for aggregate U.S. manufacturing or by Jones (1996) for industrial energy consumption of the G7 countries, my estimates of ε_{FF} and $\varepsilon_{EL,EL}$ are relatively small in absolute terms. Both

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[97] If $D_{ii}=0$, the corresponding elements of the triangular matrix **L** which are multiplied by D_{ii} also have to be set equal to zero (cf. Lau 1978:445).

authors yield a higher sensitivity of energy demand to energy prices; they computed elasticities around –1 or even higher negative values.

Table 5: Own-price elasticities for sector aggregates, concavity restricted and non-nested translog model (at 1990 data)

	Energy supply sectors			*Energy-intensive manufact. sectors*		
	value I	value II	sig. cas.*	value I	value II	sig. cas.
ε_{KK}	-0.399	-0.399	4	-0.358	-0.358	15
ε_{LL}	-0.000	-0.085	0	-0.144	-0.144	15
ε_{MM}	-0.399	-0.399	4	-0.065	-0.065	15
$\varepsilon_{EL,EL}$	-0.230	-0.230	4	-0.000	-0.039	0
ε_{FF}	-0.281	-0.281	4	-0.000	-0.023	0
	Nonenergy-intens. manufact. sectors			*Service sectors*		
	value I	value II	sig. cas.	value I	value II	sig. cas.
ε_{KK}	-0.306	-0.306	19	-1.057	-1.057	11
ε_{LL}	-0.249	-0.249	19	-0.821	-0.821	11
ε_{MM}	-0.139	-0.139	19	-0.234	-0.234	11
$\varepsilon_{EL,EL}$	-0.000	-0.040	0	-0.000	-0.042	0
ε_{FF}	-0.000	-0.022	0	-0.000	-0.037	0

* t-statistics at a 5% level.

A comparison of the own-price elasticity estimates of the concavity unrestricted and the concavity restricted models indicates that numerical differences are quite small for ε_{KK}, ε_{LL}, and ε_{MM}.[98] However, imposing local concavity restrictions causes estimates of $\varepsilon_{EL,EL}$ and ε_{FF} to become statistically insignificant. The aggregation of both significant and insignificant sectoral elasticity estimates yields slightly negative values for $\varepsilon_{EL,EL}$ and ε_{FF} in the energy-intensive and nonenergy-intensive manufacturing sectors and the service sectors aggregate. This is in line with Falk and Koebel (1999), who also find that energy demand of German manufacturing sectors is relatively insensitive to own-price changes and that there are small differences between concavity restricted and concavity unrestricted estimates.[99]

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[98] Table 16 in Appendix I sets out cross-price elasticities derived from the unrestricted and the restricted translog models for the energy-intensive manufacturing sectors, the nonenergy-intensive manufacturing sectors, and the service sectors aggregate. For most of the input pairs differences in cross-price elasticities are not substantial either.

[99] In Appendix III in Chapter 5, I derive an expression for the own-price elasticity of labour demand for the nested production function used in the GEM-E3 model and depict sectoral base year values (note that in Chapter 5 ε_{LL} is defined with a minus sign).

3.2.4.1.2 Substitution patterns

Table 6 depicts aggregated cross-price elasticities and Table 7 aggregated MES; for the sake of simplicity both are expressed only in terms of value II. The aggregated MES are directly calculated from sectorally aggregated own- and cross-price elasticities according to (3-6).[100] In this section, both elasticity concepts are quoted to interpret substitution patterns of the five-input production structure – even if they may lead to different evidence. For example, capital and electricity are Allen complements for the energy-intensive manufacturing sectors aggregate with a slightly negative cross-price elasticity of –0.028 when the electricity price changes and with an elasticity of –0.154 when the user-cost price of capital varies. In contrast, the MES of capital and electricity is positive in the case of a capital price change ($\sigma_{K,EL} = 0.204$) as well as in the case of an electricity price adjustment ($\sigma_{EL,K} = 0.011$).

Empirical results indicate that inputs are substitutes in terms of both cross-price elasticity and MES in the majority of cases. Complementary relationships can be observed in exceptional cases only for input pairs with either electricity or fossil fuels involved. Nevertheless, capital and labour, capital and material, and material and labour are always substitutable.[101]

Substitution patterns with respect to magnitude and sign differ widely among the four sector aggregates. The degree of substitutability is particularly striking in the service sectors aggregate. Here, MES above unity indicate strong substitutional relationships between capital and labour, capital and electricity, capital and fossil fuels, capital and material, and labour and electricity.

On the basis of cross-price elasticities, electricity and capital are statistically significant complements for the energy-intensive manufacturing sectors aggregate ($\varepsilon_{K,EL} = -0.028$, $\varepsilon_{EL,K} = -0.154$) and the nonenergy-intensive manufacturing sectors aggregate ($\varepsilon_{K,EL} = -0.028$, $\varepsilon_{EL,K} = -0.220$). For all four sector aggregates,

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[100] Parameter estimates of the concavity restricted models are depicted in Table 15 in Appendix I. Values and t-statistics of sectoral Morishima elasticities of substitution are listed in Table 18 in Appendix I.

[101] Hesse and Tarkka (1986) also discover some complementarity relationships between energy and capital or labour in the whole German manufacturing industry. The authors find that – measured by the AES – capital and electricity are statistically insignificant and that fossil fuels and electricity are significant complements for the period 1960-72 ($\sigma_{K,EL}$ = –0.36, $\sigma_{F,EL}$ = –11.46). For the period 1973-80, only labour and fossil fuels are found to be (statistically insignificant) complements (σ_{LF} = –0.14).

the absolute cross-price elasticity is higher when the capital price changes than when the electricity price fluctuates. Such complementarity patterns between capital and energy inputs can be explained by technical restrictions or long adjustment periods of the capital stock to changed electricity prices (cf. Apostolakis 1990:51). Fossil fuels and capital, however, are characterised by positive cross-price elasticities in all sector aggregates.

Statistically insignificant negative cross-price elasticities between labour and electricity are computed in the energy supply sectors aggregate ($\varepsilon_{L,EL} = -0.012$, $\varepsilon_{EL,L} = -0.050$) and the energy-intensive manufacturing sectors aggregate ($\varepsilon_{L,EL} = -0.005$, $\varepsilon_{EL,L} = -0.054$). The computed cross-price elasticity for labour and fossil fuels is negative in all four sector aggregates as well, but significant values result only for the nonenergy-intensive manufacturing sectors and the service sectors aggregate. The cross-price elasticity is close to zero when the fossil fuel price changes; estimates are around –0.5 when the wage rate varies.

In addition, complementary patterns may exist between electricity and material in the nonenergy-intensive manufacturing sectors aggregate, for which, however, estimated cross-price elasticities are insignificant ($\varepsilon_{M,EL} = -0.003$, $\varepsilon_{EL,M} = -0.189$). The service sectors aggregate, in contrast, is characterised by significantly negative cross-price elasticities ($\varepsilon_{M,EL} = -0.013$, $\varepsilon_{EL,M} = -0.622$).

Insignificant cross-price elasticity estimates for the energy supply sectors aggregate may indicate a complementary interrelation between fossil fuels and electricity ($\varepsilon_{F,EL} = -0.002$, $\varepsilon_{EL,F} = -0.013$). Possible technical reasons for this complementarity are grid losses in the electricity sector: If fossil fuel input decreases due to increased fossil fuel prices, electricity production and grid losses are reduced as well. In the statistics, the latter effect is expressed as a reduction of own consumption of electricity. Higher fuel prices may therefore correspond with lower electricity demand in the electricity sector.

Table 6: Cross-price elasticities for sector aggregates, concavity restricted and non-nested translog model (at 1990 data)

	Energy supply sectors		Energy-intensive manufact. sectors		Nonenergy-intensive manufact. sectors		Service sectors	
	value II	sig. cas.*	value II	sig. cas.	value II	sig. cas.	value II	sig. cas.
ε_{KL}	0.026	0	0.223	15	0.045	0	0.316	11
$\varepsilon_{K,EL}$	0.012	4	-0.028	15	-0.028	19	0.008	0
ε_{KF}	0.023	0	0.040	0	0.001	0	0.023	0
ε_{KM}	0.339	4	0.124	15	0.287	19	0.710	11
ε_{LK}	0.037	0	0.110	15	0.011	0	0.163	11
$\varepsilon_{L,EL}$	-0.012	0	-0.005	0	0.014	19	0.053	11
ε_{LF}	-0.017	0	-0.019	0	-0.011	19	-0.055	11
ε_{LM}	0.077	0	0.058	0	0.235	19	0.660	11
$\varepsilon_{EL,K}$	0.067	4	-0.154	15	-0.220	19	0.045	0
$\varepsilon_{EL,L}$	-0.050	0	-0.054	0	0.431	19	0.579	11
$\varepsilon_{EL,F}$	-0.013	0	0.003	0	0.019	0	0.039	0
$\varepsilon_{EL,M}$	0.225	4	0.244	15	-0.189	0	-0.622	11
ε_{FK}	0.016	0	0.159	0	0.012	0	0.117	0
ε_{FL}	-0.008	0	-0.156	0	-0.477	19	-0.541	11
$\varepsilon_{F,EL}$	-0.002	0	0.002	0	0.025	0	0.034	0
ε_{FM}	0.276	4	0.018	0	0.461	19	0.426	0
ε_{MK}	0.163	4	0.028	15	0.032	19	0.085	11
ε_{ML}	0.026	0	0.026	0	0.105	19	0.152	11
$\varepsilon_{M,EL}$	0.019	4	0.010	15	-0.003	0	-0.013	11
ε_{MF}	0.191	4	0.001	0	0.005	19	0.010	0

* t-statistics at a 5% level.

In contrast to the cross-price elasticity approach, the estimated MES elasticity supports the hypothesis of capital-energy substitutability. It is, however, difficult to draw any policy conclusion from this finding since the (constant-output) MES only reflects (net) substitution effects from price changes, while output (gross) effects are neglected (cf. Davis and Shumway 1996 and Section 3.2.2.2). Capital-energy substitutability, measured by the MES, merely implies that, first, an increase of fossil fuel or electricity prices leads to a reduction of energy consumption and, second, the negative output effect for capital demand (which typically will result from the energy price increase) is weakened by a positive substitution effect for capital.

While all MES are positive for the energy supply sectors, several complementary relationships exist for the other three sector aggregates. The MES – aggregated over all (insignificant) sectoral estimates of σ_{LF} in the energy-intensive manufacturing sectors – is negative when the wage rate changes ($\sigma_{LF} = -0.012$). The aggregated

σ_{LF} is also negative for the nonenergy-intensive manufacturing sectors ($\sigma_{LF} = -0.228$). The aggregated σ_{FL} is slightly negative for the service sectors aggregate ($\sigma_{FL} = -0.019$). Excluding insignificant values from sectoral aggregation in the latter two cases still leads to negative MES.

Table 7: Morishima elasticities of substitution for sector aggregates, concavity restricted and non-nested translog model (at 1990 data)

	Energy supply sectors		*Energy-intensive manufact. sectors*		*Nonenergy-intens. manufact. sectors*		*Service sectors*	
	value II	sig. cas.*	value II	sig. cas.	value II	sig. cas.	value II	sig. cas.
σ_{LK}	0.111	0	0.367	15	0.294	18	1.136	11
σ_{KL}	0.436	4	0.468	15	0.317	19	1.220	11
$\sigma_{EL,K}$	0.242	4	0.011	0	0.012	1	0.050	5
$\sigma_{K,EL}$	0.467	4	0.204	10	0.085	6	1.102	11
σ_{FK}	0.304	3	0.062	0	0.023	0	0.060	0
σ_{KF}	0.415	4	0.517	15	0.318	9	1.174	11
$\sigma_{EL,L}$	0.218	2	0.034	0	0.054	18	0.094	11
$\sigma_{L,EL}$	0.035	0	0.090	2	0.680	19	1.400	11
σ_{FL}	0.264	3	0.004	1	0.010	1	-0.019	4
σ_{LF}	0.076	0	-0.012	0	-0.228	2	0.280	6
$\sigma_{F,EL}$	0.268	3	0.026	0	0.040	0	0.075	0
$\sigma_{EL,F}$	0.228	4	0.042	0	0.066	0	0.076	9
σ_{KM}	0.562	4	0.386	15	0.337	19	1.141	11
σ_{MK}	0.738	4	0.189	15	0.426	19	0.943	11
σ_{LM}	0.111	0	0.170	15	0.354	19	0.973	11
σ_{ML}	0.476	4	0.123	6	0.374	19	0.894	11
$\sigma_{EL,M}$	0.249	4	0.050	0	0.038	0	0.029	1
$\sigma_{M,EL}$	0.624	4	0.309	15	-0.050	0	-0.388	8
σ_{FM}	0.472	4	0.024	0	0.026	0	0.047	0
σ_{MF}	0.674	4	0.083	0	0.600	19	0.660	10

* t-statistics at a 5% level.

Furthermore, electricity and material are complements in the service sectors aggregate ($\sigma_{M,EL} = -0.388$) as well as in the nonenergy-intensive manufacturing sectors aggregate ($\sigma_{M,EL} = -0.050$). For the latter, however, the sectoral elasticities all are insignificant.

According to Chapter 2, a central question in the context of tax shifting effects between production factors is whether labour is a better substitute for the taxed energy input than other input factors, such as capital or nonenergy materials. Table 8 roughly summarises the empirical evidence gained from the estimations of substitutability relationships between energy and nonenergy inputs (assuming a variation of the price of electricity and fossil fuels, respectively). The ranking is independent of whether substitutability is measured in terms of cross-price elasticity, Morishima substitution elasticity, or Allen substitution elasticity.

For the energy supply sectors and the energy-intensive manufacturing sectors aggregate, both electricity and fossil fuels are more substitutable to material and (with exception of electricity in the energy-intensive manufacturing sectors) to capital than to labour. The nonenergy-intensive manufacturing sectors and service sectors are characterised by a higher degree of substitutability between fossil fuels and materials or capital, respectively, than between fossil fuels and labour, whereas labour can be easier substituted for electricity than capital or material.

Table 8: Ranking of substitution elasticities between energy and nonenergy inputs

	Ranking: substitutability between					
	fossil fuels			*electricity*		
	labour	capital	material	labour	capital	material
Energy supply sectors	3	2	1	3	2	1
Energy-intensive manufact. sectors	3	1	2	2	3	1
Nonenergy-intensive manufact. sectors	3	2	1	1	3	2
Service sectors	3	1	2	1	2	3

1: highest degree of substitutability, 3: lowest degree of substitutability.

Thus for the energy supply sectors and the energy-intensive manufacturing sectors, which are responsible for more than 50% of total energy consumption in 1990, a relatively low substitution of labour for energy can be expected from higher energy taxation. For the other sector aggregates at least an electricity price increase would induce substitution processes which primarily favour labour demand.[102]

3.2.4.1.3 Homotheticity and returns to scale

The estimations allow for an additional check as to whether the typical assumption of constant returns to scale in CGE models can be justified empirically. For this purpose

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[102] These empirical results contradict, for example, the theoretical model assumptions in Bovenberg and de Mooij (1994:657). The authors employ a production structure which is intended to account for complementarity between energy and capital and for a higher degree of substitutability between labour and energy than between labour and capital. In a recent paper, however, the authors refer to the study of Hesse and Tarkka (1986) and concede that in European countries labour seems to be a poorer substitute for energy than capital (de Mooij and Bovenberg 1998:30).

I compute sectoral economies-of-scale elasticities, λ, from the estimated parameters according to (3-7) and depict them in Table 9.

Table 9: Sectoral economies-of-scale elasticities, concavity restricted and non-nested translog model (at 1990 data)

	λ	t-stat*		λ	t-stat
Energy supply sectors			*Service sectors*		
No.**			No.		
7	0.73	-6.08	51	1.80	3.75
8	1.52	3.94	52	1.64	4.46
11	2.83	2.68	54	1.06	1.33
15	1.76	4.10	55	0.99	-0.10
			56	1.18	7.97
Nonenergy-intensive manufact. sectors			57	1.31	7.63
			60	1.26	7.34
No.			61	1.14	4.04
16	1.23	6.64	64	1.17	4.71
17	1.14	4.87	65	1.16	3.90
25	1.13	6.07	66	1.45	4.04
26	1.19	3.20	*Energy-intensive manufact. sectors*		
27	1.06	3.51	No.		
28	1.13	2.24	1	1.01	0.40
29	0.95	-1.28	12	1.04	2.32
30	0.95	-2.01	14	0.99	-0.37
31	1.02	0.56	18	1.01	0.95
34	0.89	-3.77	19	1.04	1.90
35	0.87	-4.60	20	1.03	2.36
36	0.89	-10.48	21	1.00	0.38
40	0.83	-5.98	22	1.01	1.10
41	0.85	-12.54	23	1.02	1.43
42	0.82	-11.77	24	1.00	0.11
43	0.85	-6.81	32	1.01	0.51
44	0.79	-14.18	33	1.00	-0.22
45	0.76	-12.72	37	1.01	0.59
46	0.80	-7.95	38	1.01	0.26
			39	1.00	0.02

* t-statistics for the null hypothesis that λ=1, i.e. constant returns to scale.
** Sectors are listed in Table 17 in Appendix I.

The null hypothesis of constant returns to scale (λ=1) is supported only for 17 sectors (mainly energy-intensive manufacturing). For the remaining 32 sectors, λ is significantly different from unity, indicating that increasing or decreasing returns to scale prevail.

The majority of energy supply and service sectors are characterised by increasing returns to scale (λ is significantly greater than 1). Among the group of nonenergy-intensive manufacturing sectors empirical evidence is mixed: increasing returns to scale are computed for six sectors, whereas decreasing returns to scale are obtained for eleven sectors. For two further sectors of this sector group – 'shipbuilding' (29) and 'electrical appliances' (31) – the constant-returns-to-scale hypothesis cannot be rejected.

Results of the Wald test statistics are depicted in Table 10.[103] As I mentioned previously, the null hypothesis (i.e. constant returns to scale) cannot be rejected on empirical grounds for 17 individual sectors, however, the hypothesis that the pooled sectors are jointly homothetic or homogeneous in output is rejected at a 5% level of significance for all four sector groups.[104]

Table 10: Homotheticity and homogeneity: Wald chi-square test statistics

Wald test statistic		*Energy supply sectors*	*Energy-intensive manufact. sectors*	*Nonenergy-intensive manufact. sectors*	*Service sectors*
Homotheticity	Chi-square value*	203.94	77.79	266.22	92.52
Homogeneity	Chi-square value**	208.38	79.33	282.21	102.95

*Critical value at the 5% level is 12.59 (6 degrees of freedom).

** Critical value at the 5% level is 14.07 (7 degrees of freedom).

The estimates suggest that the German economy is characterised by a non-homothetic production function with non-constant returns to scale. Future research should thus concentrate on the application of production functions in CGE models allowing for non-homothetic technologies. In this chapter, however, which focuses on substitutional relationships between inputs, I will not pursue this line further.

3.2.4.2 Three-stage estimation

3.2.4.2.1 Substitution patterns

Table 11 depicts aggregated Morishima elasticities that are derived from aggregated own- and cross-price elasticities for GEM-E3 sectors[105] and contrasts them with the

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[103] The Wald test statistic is distributed asymptotically as a chi-square random variable with degrees of freedom equal to the difference between the number of free parameters estimated in the homotheticity (homogeneity) unconstrained and constrained model (cf. Berndt 1991). The degree of freedom for the Wald test statistic in the case of homotheticity equals six ($\beta_{ix}=0$, $i=K,L,M,EL,F$, $\beta_{xt}=0$), and in the case of homogeneity it equals seven ($\beta_{ix}=0$, $i=K,L,M,EL,F$, $\beta_{xx}=\beta_{xt}=0$).

[104] This outcome principally is in line with the results of Betts (1997) or Denny and May (1978) for Canadian manufacturing.

[105] Parameter estimates of the nested translog models are depicted in Table 19 in Appendix I. For four of 49 sectors, the fitted cost shares of fossil fuels (at 1990 data) are negative, but only slightly below zero. These are the sectors 27, 32, 39, and 60 which are all characterised by very

previously used values in the GEM-E3 model. For every sector, the substitution elasticity between labour, fossil fuels, and nonenergy materials (σ_{LFM}) is calculated as the weighted sum of MES between individual input pairs.

While some sectors reveal considerable differences between the previously used parameter values ('best guess' estimates) and the econometric estimates, both are nearly equivalent for other sectors. The importance of these differences in terms of GEM-E3 model results will be analysed in Section 3.3.

Table 11: Morishima elasticities of substitution for GEM-E3 sectors, three-level nested translog model (at 1990 data)

	Agriculture (1)		*Previously used values in GEM-E3*	*Solid fuels (2)*		*Previously used values in GEM-E3*
	value I	value II		value I	value II	
σ_{LFM}	0.334	0.361	0.5	0.359	0.377	0.5
$\sigma_{EL,LFM}$	0.000	-0.002	0.2	0.121	0.121	0.2
$\sigma_{K,LEM}$	0.164	0.164	0.3	0.553	0.553	0.4
	Liquid fuels (3)		*Previously used values in GEM-E3*	*Natural gas (4)*		*Previously used values in GEM-E3*
	value I	value II		value I	value II	
σ_{LFM}	0.320	0.406	0.5	0.321	0.367	0.5
$\sigma_{EL,LFM}$	0.377	0.377	0.2	3.817	3.817	0.2
$\sigma_{K,LEM}$	1.961	1.961	0.4	0.673	0.673	0.4
	Electricity (5)		*Previously used values in GEM-E3*	*Ferrous/non-ferrous metals (6)*		*Previously used values in GEM-E3*
	value I	value II		value I	value II	
σ_{LFM}	0.347	0.377	0.5	0.266	0.297	0.5
$\sigma_{EL,LFM}$	0.075	0.075	0.2	0.000	-0.002	0.4
$\sigma_{K,LEM}$	0.343	0.343	0.3	0.454	0.454	0.4
	Chemical industry (7)		*Previously used values in GEM-E3*	*Other energy-intens. ind. (8)*		*Previously used values in GEM-E3*
	value I	value II		value I	value II	
σ_{LFM}	0.263	0.280	0.5	0.246	0.291	0.5
$\sigma_{EL,LFM}$	0.000	-0.002	0.4	0.000	-0.002	0.4
$\sigma_{K,LEM}$	0.454	0.454	0.4	0.442	0.442	0.4

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small cost shares of fossil fuels (below 0.5% in 1990, see Table 14 in Appendix I). In all other input components, however, the estimated translog increases monotonously. Table 20 in Appendix I depicts estimates of own- and cross-price elasticities aggregated with respect to the sectoral breakdown of the GEM-E3 model.

continued Table 11

	Electrical goods (9)		Previously used values in GEM-E3	Transport equipment (10)		Previously used values in GEM-E3
	value I	value II		value I	value II	
σ_{LFM}	0.585	0.585	0.5	0.794	0.794	0.5
$\sigma_{EL,LFM}$	0.000	-0.032	0.2	0.000	-0.031	0.2
$\sigma_{K,LEM}$	0.291	0.291	0.4	0.278	0.278	0.4

	Other equipment goods (11)		Previously used values in GEM-E3	Consumer goods (12)		Previously used values in GEM-E3
	value I	value II		value I	value II	
σ_{LFM}	0.600	0.600	0.5	0.723	0.723	0.5
$\sigma_{EL,LFM}$	0.000	-0.032	0.2	0.000	-0.017	0.2
$\sigma_{K,LEM}$	0.314	0.314	0.4	0.283	0.283	0.4

	Building and construction (13)		Previously used values in GEM-E3	Telecomm. services (14)		Previously used values in GEM-E3
	value I	value II		value I	value II	
σ_{LFM}	0.499	0.499	0.5	0.710	0.710	0.5
$\sigma_{EL,LFM}$	0.000	-0.279	0.2	0.495	0.495	0.2
$\sigma_{K,LEM}$	0.450	0.450	0.4	0.471	0.471	0.4

	Transports (15)		Previously used values in GEM-E3	Credit and insurance (16)		Previously used values in GEM-E3
	value I	value II		value I	value II	
σ_{LFM}	0.823	0.867	0.5	0.826	0.826	0.5
$\sigma_{EL,LFM}$	0.373	0.373	0.2	0.808	0.808	0.2
$\sigma_{K,LEM}$	0.736	0.736	0.4	0.970	0.970	0.3

	Other market services (17)		Previously used values in GEM-E3
	value I	value II	
σ_{LFM}	1.545	1.546	0.5
$\sigma_{EL,LFM}$	0.359	0.359	0.2
$\sigma_{K,LEM}$	2.513	2.513	0.3

3.2.4.2.2 Testing for weak homothetic separability

In order to examine whether the multi-stage estimation procedure applied in the previous section can be justified empirically, several restrictions of weak homothetic separability – describing alternative nesting levels of the underlying production function – are tested according to (3-11) and the Wald test statistics.

First, let me turn to the results obtained from testing the *service sectors* aggregate. In contrast to the other aggregates, the service sectors aggregate covers a considerable number of sectors which allow for consistent aggregation of inputs. Table 12 depicts Wald test statistics for the service sectors aggregate which are below the critical value, indicating that weak homothetic separability is accepted at a 5% level.[106]

For example, (*K*,*M*), (*K*,*F*), and (*K*,*L*) form weakly homothetically separable groups for seven service sectors; in six service sectors weak homothetic separability of (*K*,*EL*,*M*), (*EL*,*M*), and (*K*,*EL*) cannot be rejected.

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[106] The chi-square critical value at a 5% level of significance is 12.59 (6 degrees of freedom) and 9.49 (4 degrees of freedom).

Table 12: Weak homothetic separability in the service sectors aggregate: Wald chi-square test statistics

Separability	*Sector No.**										
structure	51	52	54	55	56	57	60	61	64	65	66
Chi-square value											
(L,EL,F,M),K											
(K,EL,F,M),L						8.77	9.30	8.50	5.70		4.80
(K,L,F,M),EL											
(K,L,EL,M),F											
(K,L,EL,F),M											
(EL,F,M),K,L						10.32	6.95				12.55
(L,F,M),K,EL											
(L,EL,M),K,F											
(L,EL,F),K,M											
(K,F,M),L,EL	11.36	11.89					11.33				7.34
(K,EL,M),L,F						8.09	4.98	5.15	6.34	9.88	3.41
(K,EL,F),L,M						6.76	10.93		4.43		
(K,L,M),EL,F											
(K,L,F),EL,M						11.77	7.54	6.62	4.91		4.58
(K,L,EL),F,M								11.25	8.90		8.15
Chi-square value											
(F,M),K,L,EL		9.44					8.13			2.99	4.85
(EL,M),K,L,F					3.82	7.24	0.95	3.60		5.97	3.71
(EL,F),K,L,M				9.35	7.75	1.41	6.83	1.83			
(L,M),K,EL,F											
(L,F),K,EL,M											
(L,EL),K,F,M											
(K,M),L,EL,F	4.76	4.82				4.96	4.77	5.55	5.08		2.56
(K,F),L,EL,M	7.38	7.09				6.50	7.92	5.95	3.66		3.29
(K,EL),L,F,M		6.99				6.06	6.61	7.68	3.67		4.93
(K,L),EL,F,M	4.55	4.30				6.11	4.29	4.43	4.18		4.02

* Sectors are listed in Table 17 in Appendix I.

In the other sector aggregates, separability is statistically rejected for the majority of individual sectors. In the *energy supply sectors* aggregate, it is only for the ‘electricity’ (7) sector that the restriction of weak separability is not rejected for (*K,L,EL*) and (*F,M*). Besides, the ‘mineral oil’ (15) sector allows for consistent aggregation of *K* and *EL*.

With exception of the sectors ‘fine ceramics’ (19) and ‘glass’ (20), the sectors pooled into the *energy-intensive manufacturing sectors* aggregate reveal a production structure that is weakly homothetically separable in energy (fossil fuels and electricity). Testing for (*F,EL*)-separability yields Wald test statistics which are all below the critical value of 9.49. For five further sectors, namely ‘fabricated metals’ (24), ‘precision and optical instruments’ (32), ‘iron and steel’ (33), ‘paper and paper products’ (38), and ‘printing and publishing’ (39), *L* and *F* turn out to be weakly homothetically separable. For two other sectors, ‘non-ferrous metals’ (22) and ‘pulp, paper and board' (37), the aggregation of *K* and *EL* can be justified on empirical grounds as well.

Among the sectors pooled into the *nonenergy-intensive manufacturing sectors* aggregate, it is only for the sectors 'office and data processing' (27), 'automobiles and parts' (28), 'shipbuilding' (29), and 'electrical appliances' (31) that Wald test statistics below 9.49 are calculated for (*F*,*M*)-separability. For the sectors 'airspace equipment manufacturing and repairing' (30), 'musical instruments and toys' (34), 'wooden furniture' (36), and 'leather' (40) a consistent aggregation of *EL* and *M* can be justified.

The empirical results indicate that weak homothetic separability is rejected statistically at a 5% test level for labour, energy, and material in all sector aggregates.[107] Basically, this implies that the multi-stage procedure and the nesting structure used in the GEM-E3 model are not consistent with German data.[108] But, as the results do not suggest any alternative nesting structure, I will proceed with the separability structure given in GEM-E3.

In the next section, the estimates depicted in Table 11 are introduced into the nested-CES specification of the GEM-E3 producer model. They provide the basis for sensitivity analyses with respect to substitution patterns in production.

3.3 Sensitivity of GEM-E3 model results to substitution patterns in production

The sensitivity of GEM-E3 model results to the choice of substitution elasticities in production is tested by applying a simple ecological tax reform scenario to the standard version of the single-country GEM-E3 model of Germany.[109]

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[107] See also Turnovsky and Donnelly (1984:59) who tested for weak separability restrictions using a *KLEM* translog cost function for the Australian iron and steel industry. (*L*,*E*,*M*)-separability is rejected at a 5% level as well, whereas (*K*,*L*,*M*)-separability is accepted.

[108] Actually, (*L*,*E*,*M*)-separability assumes that substitutional possibilities between labour, fossil fuels, and material do not depend on the installation of new capital. This is, of course, a critical assumption.

[109] In this chapter, I apply the single-country version for Germany since my econometric estimations also refer only to Germany. In Chapter 4, however, I will employ the linked GEM-E3 EU-14 model version since terms-of-trade effects are more plausible for large countries, such as the EU-14. A GEM-E3 model description is provided in Appendix IV.

The German model is calibrated against a benchmark data set which includes a number of pre-existing factor and commodity market tax distortions such as labour income taxes, social security contributions, several commodity taxes or taxes on capital income (cf. Schmidt 1999:267-271).

In the standard version, invested physical capital is assumed to be internationally and sectorally immobile. Because sectoral capital stocks are quasi fixed, capital supply is completely inelastic in the short run and capital owners have a share in the overall tax burden. However, capital is supplied with some degree of elasticity in the long run.

The labour market is neo-classical with flexible wages and homogeneous and internationally immobile, sectorally mobile labour.[110] The consumer side is described by a representative household that receives labour and capital income. Note that lower capital income stimulates labour supply through income effects. According to the Armington assumption of product heterogeneity, foreign import demand is imperfectly price elastic thus allowing for tax shifting effects towards the foreign sector.[111]

In the following simulations the balance of payments is assumed to be flexible, implying that the real long-term interest rate and nominal exchange rates are fixed.[112] Admittedly, the assumption of a flexible balance of payments and of an internationally immobile capital stock can be justified in particular for short- or mid-term analyses.[113] The impact of a balance-of-payments restriction on the EDD outcome is analysed in Chapter 4.

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[110] In Chapter 5 I introduce labour market imperfections into the GEM-E3 model.

[111] The Armington concept of national product differentiation is more or less a standard assumption in CGE models. It models domestic demand as a CES aggregate of imports and domestically produced and demanded commodities. The Armington assumption for German import demand implies that the German price level is not completely determined by (exogenous) world market prices; the Armington assumption for foreign import demand leads to a finitely price elastic import demand function of the rest of the world (cf. Chapter 4). Both specifications modify the small-country assumption of exogenous world market prices.

[112] Since a monetary sector is not included in the GEM-E3 standard version, the balance of payments is in fact a current account.

[113] Since the simulations in Chapter 4 are based on a flexible balance of payments, I will not impose a restriction on the current account in this chapter either. As Germany has committed itself to a CO_2 emissions reduction which goes beyond –10%, I will also simulate the impacts of a –20% CO_2 emissions reduction tax policy (in contrast I assume only an EU-wide –10% CO_2 emissions reduction target in Chapter 4). Note at this point that the simulation results should be interpreted with caution since no baseline scenario is applied (see below).

Simulation results, reported in Table 13, are based on an ecological tax reform scenario (*Scenario* D_TAX20) which assumes that Germany unilaterally reduces CO_2 emissions by imposing an endogenous tax on CO_2 emissions of households and firms. A linear reduction path of CO_2 emissions at a total of –20% (compared to the base year) over a 10-year period is assumed (i.e. after 5 years, emissions are reduced by –10%). Revenue neutrality is guaranteed by a fixed ratio of the public deficit to the gross domestic product (GDP). Additional tax revenues are used to equally cut the rate of social security contributions of employees and employers.

Here, and in all other simulations in this thesis, I refrain from applying a baseline scenario, which reproduces the economic development (with respect to growth of GDP, CO_2 emissions, population etc.) in the absence of the CO_2 abatement policy. This reduces the political relevance of simulation results but enables clarification of the effects of changed substitution elasticity values independently of their effects on the baseline scenario.[114] Thus the following simulations primarily serve to test the model's structure for its sensitivity to parameter changes but not to generate figures that are really relevant to policy decision makers.

Table 13 considers several cases of parameter specifications. The first three columns show the results of the standard case (*Case* 0), which are based on the previously used elasticity values in the GEM-E3 model. The next nine columns refer to results which are obtained when the econometrically estimated substitution elasticities generated in the previous sections (see Table 21 in Appendix I) are used (*Case* 2) and halved (*Case* 1) or doubled (*Case* 3), respectively.

Table 13 illustrates that (given the nesting structure in Figure 3) the GEM-E3 single-country version for Germany produces a double dividend in terms of lower CO_2 emissions and higher employment for a wide range of substitution elasticity parameters. Basically, the approval of the EDD is in line with the numerical results of, for example, de Mooij and Bovenberg (1998:30), who also obtain positive employment effects in a model with fixed capital.

In the case of the econometric estimates (*Case* 2), a rise in private income of 0.61% and in employment of 1.33% is realised if CO_2 emissions fall by –20%. Capital income falls by –2.36%. Economic welfare per GDP, however, decreases slightly by –0.04%. Compared to *Case* 0, representing the previously used values in GEM-E3,

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[114] Assuming different substitution elasticities leads not only to differences in policy effects, but also to different growth rates of baseline CO_2 emissions or GDP.

positive employment effects are only slightly stronger, and economic welfare decreases less. In *Case* 0, private income and employment rise by 0.52% and 1.27%, while capital income and economic welfare decrease by –2.29% and –0.06%.

Table 13: *Scenario* D_TAX20: macroeconomic aggregates for Germany, variation of substitution elasticities in production (numbers indicate percent changes from baseline except if defined otherwise)

	Macroeconomic aggregates for Germany											
	Case 0: Standard version of GEM-E3			*Econometric estimates*								
				Case 1: Halved values			*Case 2:* Central values			*Case 3:* Doubled values		
	1. year	5. year	10. year	1. year	5. year	10. year	1. year	5. year	10. year	1. year	5. year	10. year
Gross domestic product	0.04	0.11	0.00	0.07	0.20	0.06	0.03	0.07	-0.10	0.00	-0.02	-0.18
Employment	0.12	0.59	1.27	0.22	1.05	2.31	0.15	0.65	1.33	0.09	0.38	0.73
Production	-0.14	-0.75	-1.76	-0.17	-0.93	-2.40	-0.19	-0.96	-2.24	-0.21	-0.93	-2.01
Domestic demand	-0.13	-0.68	-1.58	-0.14	-0.82	-2.20	-0.16	-0.83	-1.98	-0.17	-0.79	-1.74
Private investment	-0.03	-0.17	-0.52	-0.01	-0.22	-0.96	-0.02	-0.20	-0.73	0.00	-0.09	-0.39
Private consumption	0.09	0.35	0.50	0.15	0.54	0.63	0.12	0.43	0.59	0.09	0.31	0.45
Real net income	0.09	0.36	0.52	0.16	0.56	0.66	0.12	0.45	0.61	0.09	0.33	0.47
- Labour income	0.43	1.96	3.92	0.77	3.42	6.85	0.53	2.23	4.19	0.35	1.38	2.46
- Non-labour income	-0.19	-0.96	-2.29	-0.35	-1.80	-4.48	-0.21	-1.02	-2.36	-0.12	-0.54	-1.18
Real consumer wage	0.31	1.36	2.61	0.54	2.34	4.44	0.38	1.57	2.82	0.26	1.00	1.72
Real producer wage	-0.10	-0.55	-1.37	-0.17	-1.02	-2.80	-0.07	-0.41	-1.12	-0.03	-0.20	-0.54
Exports	-0.22	-1.17	-2.77	-0.32	-1.57	-3.52	-0.37	-1.71	-3.67	-0.39	-1.72	-3.50
Imports	-0.21	-1.05	-2.40	-0.28	-1.45	-3.38	-0.29	-1.37	-3.04	-0.28	-1.25	-2.64
Terms of trade	0.10	0.55	1.32	0.15	0.75	1.66	0.18	0.84	1.81	0.19	0.84	1.74
CO_2 *tax rate (ECU'85)***	4.4	23.8	60.8	8.1	45.0	123.2	4.4	22.6	57.0	2.4	11.4	26.9
CO_2 *tax revenue**	0.38	1.87	4.21	0.70	3.52	8.41	0.38	1.77	3.92	0.21	0.90	1.86
CO_2 *emissions*	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00
*Equivalent variation (economic welfare) ****	0.02	0.03	-0.06	0.03	0.00	-0.23	0.03	0.06	-0.04	0.03	0.07	0.03

* in % of GDP, absolute difference from baseline

** in value figures

*** in % of base year GDP, cumulative from 1st year

The differences between *Case* 0 and *Case* 2 are not very pronounced at the aggregate level. A comparison between *Case* 1 to *Case* 3 is more appropriate to draw some general conclusions. Obviously, higher substitution elasticities generate lower CO_2 tax rates and lower ratios of CO_2 tax revenues to the GDP. The former is the direct result of the higher price sensitivity of input demand functions caused by higher degrees of substitutability in production.[115] Significantly lower tax rates are required to realise a given CO_2 emissions reduction. In actual figures, Table 13 shows that the CO_2 tax rate is 57.0 ECU for the central substitution elasticity values (*Case* 2), while it is more than doubled in the case of halved values (*Case* 1) and more than halved in the case of doubled values (*Case* 3): In *Case* 1 the computed CO_2 tax rate is 123.2 ECU; in *Case* 3 it is 26.9 ECU.

Furthermore, I find that employment effects increase with a declining degree of substitutability between inputs and input aggregates for all four nesting levels. This result (partially) follows from the given nesting structure in the GEM-E3 producer

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[115] Kemfert and Welsch (2000) find a similar result.

model. The more the substitution possibilities are restricted at the first nesting level between capital and the *LEM* aggregate, the lower is the rise in capital demand in response to an increase in the unit costs of the *LEM* aggregate. Hence, given a quasi-fixed capital stock, capital income falls the most in *Case* 1 (–4.48%) and the lowest in *Case* 3 (–1.18%). This corresponds to a further result: The ecological tax reform causes the highest reduction in real labour costs and the highest increase in the real consumer wage in *Case* 1, where substitution possibilities are mostly restricted, while in *Case* 3 the real producer wage and the real consumer wage reaches its highest or lowest level, respectively.

How can the positive employment effects generally computed by the GEM-E3 model be explained? In all four cases of substitution patterns, the real consumer wage rate steadily increases with higher CO_2 emission reduction rates, while real net non-labour income (i.e. capital income) is reduced – indicating tax shifting effects from labour to capital income. Assuming a neo-classical labour market, where labour supply depends positively on the real consumer wage and negatively on the real non-labour income, both effects induce an increase of labour supply. Labour demand increases due to substitution processes in response to the changed ratio of labour to fossil fuel prices. Obviously, substitution effects towards labour input dominate negative output effects (note that domestic production decreases in all cases of parameter choice due to higher energy costs). Moreover, in addition to tax shifting effects towards capital, the GEM-E3 model allows for shifting parts of the tax burden abroad (see below).

The rise in employment in all cases of elasticity values supports the EDD hypothesis. If the second dividend, however, is measured in terms of economic welfare, the ecological tax reform – defined by the *Scenario* D_TAX20 – produces a double dividend only in *Case* 3. This is the only case where economic welfare (measured at the –20% CO_2 reduction goal) increases as the loss of utility through reduced leisure is compensated by the utility gain associated with the higher consumption level.

The development of GDP can be explained by the development of consumption, investment, and net exports. Both real exports and real imports are reduced, the former because of increased production costs, the latter because of the reduction of domestic demand (the positive impact of the higher price ratio on domestic import demand is overcompensated by the negative effect of lower overall domestic demand).[116] The improvement of the German terms of trade reflects tax shifting effects to the foreign sector. Actually, the GEM-E3 single-country version for Germany allows for terms-of-trade effects. Due to the Armington assumption, which underlies the specification of Germany's and the rest of the world's (RoW) import demand, imports are imperfect substitutes for domestically produced goods. Thus, import demand of the RoW for German goods is imperfectly price elastic, and higher prices of German exports can be partially shifted abroad. Some reasons, why empirical models frequently rely on the Armington assumption, are provided in Chapter 4. Actually, in the specific case of Germany and in particular for several export industries (e.g. automobiles or chemical industry), it is appropriate not to assume a infinitely price elastic foreign import demand, but to allow for terms-of-trade effects.

GDP shows positive growth rates, which at the beginning increase due to the strong rise in consumption levels. With increasing CO_2 tax rates, however, exports lose international competitiveness and decline more and more. This effect increasingly slows down GDP growth to even negative growth rates. The German terms of trade as well as the net exports per GDP increase in all cases. This is possible because the balance of payments is flexible, i.e. imbalances have no feedback on the German economy. As will be shown in Chapter 4 in the context of the GEM-E3 EU-14 model, the introduction of a fixed balance of payments and the variation of price elasticities in foreign trade functions may affect results.

3.4 Conclusion

In this chapter the influence of substitution patterns in production on the EDD outcome in the GEM-E3 single-country version for Germany is examined. Considering the lack of empirical studies for Germany, I first estimate substitution elasticities between capital, labour, material, electricity, and fossil fuels for four sector aggregates (including the energy supply sectors, the energy-intensive manufacturing sectors, the nonenergy-intensive manufacturing sectors, and the service sectors) using a non-nested translog cost function. Empirical basis is a pooled

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[116] According to the Armington approach, which assumes that imports and domestically produced goods are imperfect substitutes, domestic demand is a CES aggregate of imports and domestically produced and demanded commodities. Thus German import demand depends positively on the ratio of the CES price aggregate to the import price and on the level of domestic demand.

time-series cross-section data sample for 49 German producing and service sectors over the period 1978-90. In addition, I estimate substitution elasticities for a three-level nested translog cost function that fits into the given nesting structure in the GEM-E3 producer model. The estimates are introduced into the GEM-E3 German single-country version and sensitivity analyses are performed.

The major conclusions from this chapter can be summarised as follows:

1. Estimates of the non-nested translog cost function indicate that differences between unrestricted models and the local concavity restricted models are of minor importance. The constant-output own-price elasticity is (in absolute terms) highest for capital demand, whereas electricity and fossil fuel demand are less price elastic (except for the energy supply sectors aggregate).
2. Positive Morishima elasticities of substitution below unity are obtained for the majority of sectors and input pairs. This indicates an overall dominance of weak substitutability relationships. Due to the high absolute own-price elasticity of capital demand in the service sectors, I find a strong substitutability relationship in particular in the service sectors aggregate for input pairs involving capital. The results support the hypothesis that capital and energy are substitutes.
3. Negative Morishima elasticities of substitution are computed between labour and fossil fuels in the energy-intensive and the nonenergy-intensive manufacturing sectors (when the wage rate changes) and in the service sectors (when the fossil fuel price varies), and between material and electricity in the nonenergy-intensive manufacturing and the service sectors (when the price of material varies). Only for the two latter sector aggregates does labour seem to be a better substitute for electricity than capital or material; in most other cases, labour is more difficult to substitute for energy than capital or material.
4. The estimation of sectoral economy-of-scale elasticities yields the result that it is only for 17 of 49 sectors (mainly energy-intensive manufacturing sectors) that the hypothesis of constant returns to scale cannot be rejected at a 5% level of significance, indicating that the majority of sectors is described by decreasing returns to scale (mainly nonenergy-intensive manufacturing sectors) or increasing returns to scale (mainly energy supply and service sectors). Testing for homotheticity and homogeneity shows that the aggregates are characterised by non-homothetic and non-homogeneous production functions.
5. In order to improve the empirical basis of the computable general equilibrium model GEM-E3, I estimate substitution elasticities for a three-level nested production function. A comparison with the values previously used in GEM-E3

indicates considerable numerical differences for several sectors. Testing for weak homothetic separability restrictions, however, proves that inputs can be aggregated only in exceptional cases. Thus the econometric estimates of the multi-stage estimation are surrounded by some uncertainty, and sensitivity tests are required. Since the econometric tests support no alternative nesting structure, I retain the four-level nesting scheme of the GEM-E3 standard model in the simulations.

6. Simulations are based on the single-country version of the GEM-E3 model for Germany and an ecological tax reform scenario that assumes a unilateral –20% CO_2 emissions reduction in Germany. The model computes a double dividend in terms of lower CO_2 emissions and higher employment for a wide range of substitution elasticity values. Simulation results indicate that – in terms of the sign – the employment effects of an ecological tax reform in Germany are relatively insensitive to a change of substitution elasticities in production. Economic welfare, however, decreases in most cases; it rises only in the case of doubled substitution elasticity values, where the increase in utility due to higher consumption can offset the decrease of utility due to lower leisure.
7. Positive employment effects increase with a declining degree of substitutability between the inputs and input aggregates at all four nesting levels. This result (partially) follows from the given nesting structure of the GEM-E3 producer model. The more restricted substitution possibilities are at the first nesting level, the lower is the rise in capital demand and the higher is the fall in capital income (indicating tax shifting effects towards capital) in response to an increase in the unit costs of the *LEM* aggregate. Moreover, the ecological tax reform causes the highest reduction in real labour costs and the highest increase in the real consumer wage in the case where substitution elasticities are halved.
8. For the neo-classical labour market specification that is assumed in the standard version of the GEM-E3 model labour supply increases in response to the rising real consumer wage and the reduction in real non-labour income. Labour demand increases due to substitution processes in response to the changed ratio of labour to fossil fuel prices. Obviously, substitution effects towards labour input dominate negative output effects.

The discussion of simulation results supports the theoretical finding of Chapter 2 that the specification of the foreign closure (terms-of-trade effects) and the assumptions concerning labour supply and wage formation are further key factors for the employment impacts of an ecological tax reform. The role of both factors will be examined in the following Chapters 4 and 5.

Appendix I

Table 14: Sectoral cost shares [%]

Sectors	*Year*	*Fossil fuels* (*F*)	*Electricity* (*EL*)	*Labour* (*L*)	*Capital* (*K*)	*Material* (*M*)
Agriculture, forestry and fishing (1)	78	4.5	1.4	10.9	31.9	51.4
	84	4.8	1.4	9.9	33.7	50.0
	90	3.4	1.5	10.4	39.5	45.2
Electricity production and distance district heating (7)	78	28.6	4.3	16.1	24.7	26.3
	84	25.4	3.7	12.3	22.5	36.1
	90	18.1	4.1	12.9	25.7	39.3
Gas (8)	78	58.4	0.1	7.1	8.9	25.5
	84	55.9	0.1	3.9	6.0	34.0
	90	41.5	0.1	7.0	12.4	39.0
Coal mining (11)	78	24.5	2.9	40.4	11.5	20.7
	84	23.5	3.4	37.5	13.0	22.6
	90	16.2	3.4	37.8	15.7	27.0
Other mining (12)	78	2.8	2.1	22.6	21.2	51.3
	84	3.5	1.7	21.1	18.8	54.8
	90	1.6	1.5	17.9	19.9	59.2
Chemical products (14)	78	6.3	2.9	23.7	9.0	58.1
	84	10.6	2.8	22.3	8.0	56.4
	90	5.2	2.6	25.4	9.5	57.2
Mineral oil (15)	78	75.1	1.1	4.3	6.3	13.2
	84	75.1	0.8	2.8	3.7	17.6
	90	48.0	1.2	3.4	3.9	43.6
Synthetic resins and plastic (16)	78	0.8	1.7	29.0	7.5	61.0
	84	0.8	1.9	25.9	7.5	64.0
	90	0.4	2.1	27.7	8.3	61.6
Rubber processing (17)	78	1.8	2.0	33.7	8.3	54.2
	84	2.1	2.1	31.1	8.2	56.5
	90	1.0	1.9	30.7	8.6	57.8
Extraction of sand, gravel, stone (18)	78	6.4	3.0	27.1	11.8	51.6
	84	7.7	3.1	25.1	11.5	52.6
	90	4.4	3.2	25.3	11.5	55.6
Fine ceramics (19)	78	6.5	2.2	48.5	9.8	33.0
	84	7.6	2.4	45.4	10.9	33.8
	90	3.9	2.3	43.4	11.5	38.9
Glass (20)	78	7.3	2.8	33.3	10.4	46.2
	84	12.1	3.3	28.7	11.9	44.0
	90	4.5	3.6	28.6	12.8	50.5
Iron and steel (21)	78	5.1	1.4	26.1	11.2	56.1
	84	6.2	1.7	23.8	12.2	56.1
	90	5.0	1.8	25.1	10.9	57.2
Non-ferrous metals (22)	78	1.7	5.7	17.1	7.0	68.6
	84	2.3	5.2	13.8	6.2	72.4
	90	1.2	4.9	16.0	7.0	70.9
Foundry (23)	78	2.5	3.0	41.3	9.0	44.1
	84	2.6	4.9	37.3	9.3	46.0
	90	1.5	3.5	38.0	9.6	47.4
Fabricated metal (24)	78	1.0	1.7	29.4	7.0	60.9
	84	1.3	2.0	28.3	7.9	60.5
	90	0.6	2.0	29.6	7.5	60.3
Steel, light metal, rail machinery (25)	78	0.9	0.5	30.2	3.9	64.4
	84	1.4	0.7	34.8	5.7	57.3
	90	0.7	0.6	33.0	5.1	60.6

continued Table 14

Sectors	*Year*	*Fossil fuels* (*F*)	*Electricity* (*EL*)	*Labour* (*L*)	*Capital* (*K*)	*Material* (*M*)
Machinery (26)	78	0.7	0.7	35.8	5.6	57.2
	84	0.9	0.8	34.6	6.5	57.2
	90	0.4	0.8	34.4	6.5	57.9
Office and data processing (27)	78	0.3	0.8	34.2	15.1	49.6
	84	0.3	0.8	26.4	12.1	60.4
	90	0.1	1.0	27.2	10.6	61.1
Automobiles and parts (28)	78	0.9	0.9	26.5	6.0	65.8
	84	1.0	0.9	25.8	7.9	64.5
	90	0.5	0.8	23.0	7.8	67.9
Shipbuilding (29)	78	0.5	1.1	35.7	6.7	56.0
	84	0.6	1.1	28.9	8.0	61.5
	90	0.3	1.0	27.3	6.7	64.7
Airspace equipment manufacturing and repairing (30)	78	0.6	0.8	43.5	5.0	50.1
	84	0.5	0.8	38.9	6.9	52.9
	90	0.2	0.7	36.3	6.8	56.0
Electrical appliances (31)	78	0.7	0.8	37.7	5.7	55.1
	84	0.9	0.8	35.3	6.6	56.4
	90	0.4	0.8	34.4	7.4	57.1
Precision and optical instruments (32)	78	0.6	0.9	42.8	5.2	50.5
	84	0.8	1.0	39.0	6.6	52.6
	90	0.4	0.9	38.1	7.2	53.4
Iron, steel, and steel products (33)	78	1.1	1.0	33.4	6.7	57.8
	84	1.3	1.2	31.2	7.6	58.7
	90	0.6	1.3	31.4	7.6	59.1
Musical instruments and toys (34)	78	0.6	1.1	31.4	6.1	60.8
	84	0.7	1.2	29.1	8.3	60.7
	90	0.4	1.3	28.5	9.0	60.9
Timber processing and wood products (35)	78	2.2	3.0	21.3	9.2	64.3
	84	2.3	3.2	21.3	10.0	63.2
	90	1.3	3.3	20.6	10.2	64.6
Wooden furniture (36)	78	1.1	0.9	31.2	5.9	61.0
	84	1.3	1.1	31.7	7.0	58.9
	90	0.8	1.1	30.2	6.3	61.7
Pulp, paper and board (37)	78	4.7	6.2	24.1	11.5	53.5
	84	6.4	6.7	18.4	10.2	58.2
	90	4.0	6.8	19.0	13.0	57.2
Paper and paper products (38)	78	1.1	0.8	28.6	7.8	61.7
	84	1.5	1.0	24.3	8.4	64.8
	90	0.6	1.0	23.5	8.3	66.6
Printing and publishing (39)	78	0.4	1.0	40.6	8.7	49.2
	84	0.6	1.3	36.7	10.3	51.1
	90	0.3	1.3	34.7	10.3	53.4
Leather (40)	78	0.8	0.7	28.8	6.9	62.8
	84	0.9	0.8	25.2	7.1	66.1
	90	0.5	0.8	22.6	7.7	68.4
Textiles (41)	78	1.4	1.8	28.1	8.9	59.8
	84	2.0	2.1	25.2	9.2	61.5
	90	1.0	2.4	24.7	9.9	62.1
Clothing (42)	78	0.6	0.5	28.7	3.8	66.5
	84	0.8	0.5	26.3	4.3	68.1
	90	0.4	0.5	23.8	4.1	71.1

continued Table 14

Sectors	*Year*	*Fossil fuels* (*F*)	*Electricity* (*EL*)	*Labour* (*L*)	*Capital* (*K*)	*Material* (*M*)
Food (43)	78	1.2	1.1	13.2	4.5	80.1
	84	1.6	1.2	12.6	4.9	79.7
	90	1.0	1.3	14.5	5.8	77.5
Beverages (44)	78	2.3	1.1	20.3	13.1	63.2
	84	3.2	1.3	18.0	14.5	63.1
	90	1.7	1.2	16.2	15.2	65.6
Tobacco (45)	78	0.6	0.8	21.2	7.5	70.0
	84	0.7	0.7	17.4	8.7	72.5
	90	0.3	0.7	14.3	7.8	76.9
Building and construction (46)	78	1.8	0.1	39.6	5.2	53.4
	84	2.1	0.1	38.6	5.1	54.0
	90	1.1	0.1	36.6	4.6	57.5
Wholesale trade (51)	78	1.8	0.9	6.4	1.5	89.4
	84	2.2	1.0	6.1	1.7	89.0
	90	1.7	1.2	7.4	2.2	87.5
Retail trade (52)	78	2.0	2.5	11.3	3.0	81.1
	84	2.7	3.1	12.0	3.6	78.7
	90	1.8	2.9	11.7	4.1	79.6
Railways (54)	78	2.8	3.8	45.6	34.2	13.5
	84	3.5	4.9	40.5	39.3	11.9
	90	1.7	4.8	35.6	44.5	13.4
Water transport (55)	78	10.0	0.3	19.2	29.1	41.4
	84	16.0	0.2	15.7	29.7	38.5
	90	8.7	0.2	18.7	28.7	43.8
Postal services (56)	78	0.7	0.5	53.0	32.1	13.7
	84	0.7	0.7	45.2	39.3	14.1
	90	0.5	0.7	36.9	43.2	18.6
Other transport (57)	78	7.2	0.6	24.7	11.9	55.6
	84	8.4	0.5	21.7	12.4	56.8
	90	5.3	0.4	23.3	12.0	59.0
Banking and finance (60)	78	0.4	0.6	48.7	11.2	39.1
	84	0.5	0.7	46.6	13.3	38.9
	90	0.3	0.7	48.5	14.1	36.4
Insurance (61)	78	0.4	0.5	39.2	9.4	50.5
	84	0.4	0.6	33.7	12.5	52.8
	90	0.2	0.6	29.2	13.3	56.7
Hotels, catering and public houses (64)	78	1.5	2.7	21.8	8.2	65.8
	84	1.7	3.0	22.8	9.9	62.6
	90	0.9	2.5	23.9	9.8	62.9
Education, science and culture (65)	78	1.0	0.8	29.7	23.3	45.2
	84	1.0	0.9	29.5	29.6	39.0
	90	0.6	0.8	30.3	31.5	36.9
Health and sanitary services (66)	78	1.3	0.4	39.4	8.0	50.8
	84	1.2	0.4	34.8	10.4	53.3
	90	0.5	0.3	29.0	8.5	61.7

Table 15: Parameter estimates, non-nested and concavity restricted translog model

Energy supply sectors			*Energy-intensive manufacturing sectors*					
Parameter	Estimate	t-stat	Parameter	Estimate	t-stat	Parameter	Estimate	t-stat
D_{KK}	-0.0758	-8.1688	D_{KK}	-0.0451	-6.1422	β_{EL}	-0.0315	-3.2148
$L_{K,EL}$	-0.0293	-2.4898	$L_{K,EL}$	0.0794	2.0905	*DEL1*	0.0597	6.6174
L_{KF}	-0.0564	-0.5777	L_{KF}	-0.1105	-2.0615	*DEL12*	0.0494	6.3258
D_{LL}	-0.0109	-1.7127	D_{LL}	-0.0192	-1.8635	*DEL14*	0.0698	8.0350
$L_{L,EL}$	0.1368	0.4779	$L_{L,EL}$	0.1816	1.4470	*DEL18*	0.0627	8.8504
L_{LF}	0.1865	0.5397	L_{LF}	0.0932	0.8498	*DEL19*	0.0410	6.4756
$D_{EL,EL}$	-0.0073	-2.0048	L_{KL}	-0.6220	-4.4916	*DEL20*	0.0503	9.1679
$L_{EL,F}$	0.0029	0.0239	α_0	0.2597	4.4322	*DEL21*	0.0396	7.4559
L_{KL}	-0.0648	-1.1272	β_x	0.9296	23.0032	*DEL22*	0.0716	16.7977
D_{FF}	-0.0763	-6.5243	β_t	-0.0015	-2.1981	*DEL23*	0.0418	11.3130
α_0	1.0146	1.6334	β_K	0.1775	4.4465	*DEL24*	0.0273	8.3310
β_x	0.0465	0.1418	*DK1*	0.2549	6.9964	*DEL32*	0.0118	4.6978
β_t	0.0810	13.0582	*DK12*	0.0700	2.2297	*DEL33*	0.0130	5.5261
β_K	0.3548	3.5579	*DK14*	-0.0365	-1.0224	*DEL37*	0.0606	38.6905
DK7	0.2355	8.2541	*DK18*	-0.0088	-0.3119	*DEL38*	0.0002	0.2064
DK8	-0.0274	-0.8775	*DK19*	-0.0268	-1.0586	β_F	0.1718	7.9495
DK11	0.0161	0.6416	*DK20*	-0.0112	-0.5133	*DF1*	-0.0690	-2.6831
β_L	0.1477	3.7836	*DK21*	-0.0236	-1.0986	*DF12*	-0.1116	-5.8892
DL7	0.0671	5.7575	*DK22*	-0.0587	-3.4258	*DF14*	-0.0156	-0.6094
DL8	-0.0070	-0.5631	*DK23*	-0.0355	-2.4042	*DF18*	-0.0360	-1.8322
DL11	0.3207	32.4794	*DK24*	-0.0326	-2.4384	*DF19*	-0.0611	-4.1758
β_{EL}	0.0284	3.6213	*DK32*	-0.0477	-4.7208	*DF20*	-0.0227	-1.6712
DEL7	0.0435	18.6759	*DK33*	-0.0295	-3.0002	*DF21*	-0.0134	-0.8894
DEL8	-0.0111	-4.4855	*DK37*	0.0017	0.2557	*DF22*	-0.0478	-4.1769
DEL11	0.0152	7.7144	*DK38*	-0.0251	-5.9793	*DF23*	-0.0435	-4.7786
β_F	1.2622	7.9192	β_L	1.2381	21.8359	*DF24*	-0.0327	-3.4849
DF7	-0.8512	-15.7215	*DL1*	-0.7964	-15.0799	*DF32*	-0.0335	-4.9602
DF8	-0.4901	-10.8304	*DL12*	-0.8238	-18.0215	*DF33*	-0.0120	-1.7135
DF11	-0.5505	-14.5604	*DL14*	-0.4904	-9.6402	*DF37*	0.0151	3.9508
β_{xx}	0.3174	3.7696	*DL18*	-0.5421	-13.0892	*DF38*	-0.0081	-3.0153
β_{xt}	-0.0178	-11.9283	*DL19*	-0.4530	-12.3036	β_{xx}	0.0146	1.1526
β_{tt}	-0.0003	-2.5622	*DL20*	-0.5043	-15.7726	β_{xt}	0.0001	0.5656
β_{Kx}	-0.0716	-3.1784	*DL21*	-0.4017	-12.9505	β_{tt}	0.0000	1.4737
β_{Lx}	-0.0150	-1.7153	*DL22*	-0.5091	-20.4367	β_{Kx}	-0.0071	-0.9266
$\beta_{EL,x}$	-0.0079	-4.4727	*DL23*	-0.2715	-12.6406	β_{Lx}	-0.0713	-7.0582
β_{Fx}	-0.0219	-0.5551	*DL24*	-0.2469	-12.8906	$\beta_{EL,x}$	-0.0042	-2.4006
β_{Kt}	0.0001	0.1570	*DL32*	-0.1318	-9.0478	β_{Fx}	-0.0141	-2.9029
β_{Lt}	-0.0008	-2.8266	*DL33*	-0.1232	-8.9842	β_{Kt}	-0.0003	-1.3349
$\beta_{EL,t}$	0.0004	7.3955	*DL37*	-0.2904	-32.2711	β_{Lt}	-0.0032	-11.4140
β_{Ft}	-0.0121	-10.0832	*DL38*	-0.1695	-29.9843	$\beta_{EL,t}$	0.0003	6.1461
						β_{Ft}	-0.0006	-4.8074

continued Table 15

Nonenergy-intensive manufacturing sectors						*Service sectors*					
Parameter	Estimate	t-stat	Parameter	Estimate	t-stat	Parameter	Estimate	t-stat	Parameter	Estimate	t-stat
D_{KK}	-0.0213	-4.5546	*DEL16*	0.0382	8.8264	D_{KK}	-0.0909	-21.3405	*DF57*	0.0262	3.2171
$L_{K,EL}$	0.0919	3.2191	*DEL17*	0.0361	8.6262	$L_{K,EL}$	-0.0075	-1.4368	*DF60*	-0.0236	-3.7285
L_{KF}	-0.0038	-0.1090	*DEL25*	0.0221	5.5988	L_{KF}	-0.0219	-1.5239	*DF61*	-0.0094	-1.4915
D_{LL}	-0.0699	-4.6698	*DEL26*	0.0074	3.9515	D_{LL}	-0.1284	-7.3132	*DF64*	0.0023	0.4790
$L_{L,EL}$	-0.0506	-2.3941	*DEL27*	0.0302	12.7539	$L_{L,EL}$	-0.0697	-3.2633	*DF65*	0.0021	0.3988
L_{LF}	0.0453	2.0683	*DEL28*	-0.0055	-2.4523	L_{LF}	0.0672	2.1216	β_{xx}	-0.1005	-3.8363
L_{KL}	-0.1484	-0.5127	*DEL29*	0.0187	9.2240	L_{KL}	-0.2990	-6.2987	β_{xt}	0.0005	1.5884
α_0	0.3322	2.0522	*DEL30*	0.0151	5.3510	α_0	0.7603	3.7294	β_{tt}	0.0001	5.3144
β_x	0.9349	11.2839	*DEL31*	0.0186	7.9007	β_x	1.2384	10.6963	β_{Kx}	0.0042	0.2872
β_t	-0.0001	-0.1588	*DEL34*	-0.0076	-6.5358	β_t	-0.0190	-7.5395	β_{Lx}	-0.1139	-7.7167
β_K	0.2842	6.4948	*DEL35*	0.0294	28.3237	β_K	0.1339	1.9482	$\beta_{EL,x}$	-0.0067	-4.7676
DK16	-0.0908	-2.3128	*DEL36*	-0.0002	-0.1907	*DK51*	-0.1572	-1.8105	β_{Fx}	0.0055	1.4200
DK17	-0.1058	-2.8222	*DEL40*	0.0094	5.0526	*DK52*	-0.1224	-1.6870	β_{Kt}	-0.0004	-0.7047
DK25	-0.1209	-3.4090	*DEL41*	0.0234	17.2656	*DK54*	0.2198	4.8800	β_{Lt}	0.0010	1.6881
DK26	0.0334	1.7911	*DEL42*	0.0059	4.6562	*DK55*	0.2341	5.5966	$\beta_{EL,t}$	0.0004	6.3884
DK27	0.0251	1.1538	*DEL43*	0.0145	21.4541	*DK56*	0.2270	6.4327	β_{Ft}	-0.0004	-3.0387
DK28	-0.0488	-2.2766	*DEL44*	0.0112	12.7183	*DK57*	-0.0153	-0.4799			
DK29	-0.0862	-4.7335	*DEL45*	0.0017	2.0003	*DK60*	0.0223	0.9028			
DK30	-0.1278	-5.0796	β_F	0.0911	12.3839	*DK61*	-0.0159	-0.7097			
DK31	-0.0334	-1.5287	*DF16*	-0.0832	-12.7273	*DK64*	-0.0301	-1.7674			
DK34	-0.0725	-7.0943	*DF17*	-0.0700	-11.1618	*DK65*	0.1805	10.0996			
DK35	0.0200	2.1459	*DF25*	-0.0707	-11.9205	β_L	0.8444	10.3919			
DK36	-0.0440	-4.0006	*DF26*	-0.0289	-9.4618	*DL51*	-0.0127	-0.1399			
DK40	-0.0867	-5.2948	*DF27*	-0.0461	-12.8747	*DL52*	-0.0388	-0.5035			
DK41	-0.0230	-1.9141	*DF28*	-0.0567	-16.1455	*DL54*	-0.0958	-1.7919			
DK42	-0.0838	-7.5514	*DF29*	-0.0414	-13.6539	*DL55*	-0.4384	-8.9625			
DK43	-0.0152	-2.3793	*DF30*	-0.0568	-13.5023	*DL56*	0.0189	0.4567			
DK44	0.0462	5.7431	*DF31*	-0.0496	-13.7795	*DL57*	-0.1254	-3.5314			
DK45	-0.0391	-4.5633	*DF34*	-0.0243	-14.0055	*DL60*	0.0681	2.4491			
β_L	1.5006	16.5875	*DF35*	-0.0044	-2.8266	*DL61*	-0.1549	-5.9724			
DL16	-0.9625	-12.1782	*DF36*	-0.0188	-10.0271	*DL64*	-0.2312	-12.0076			
DL17	-0.9360	-12.2654	*DF40*	-0.0334	-12.0446	*DL65*	-0.1922	-9.3973			
DL25	-0.8507	-11.8045	*DF41*	-0.0227	-11.3315	β_{EL}	-0.0080	-1.0187			
DL26	0.0474	1.3749	*DF42*	-0.0260	-13.8599	*DEL51*	0.0624	7.4363			
DL27	-0.5895	-13.6130	*DF43*	-0.0154	-14.7421	*DEL52*	0.0701	9.7826			
DL28	-0.3951	-9.6155	*DF44*	-0.0015	-1.1322	*DEL54*	0.0642	12.5571			
DL29	-0.7194	-19.5248	*DF45*	-0.0147	-10.4786	*DEL55*	0.0101	2.1357			
DL30	-0.6203	-12.0698	β_{xx}	-0.0373	-1.6574	*DEL56*	0.0186	4.7319			
DL31	-0.4651	-10.7801	β_{xt}	0.0021	11.7203	*DEL57*	0.0206	6.1754			
DL34	-0.2370	-11.2777	β_{tt}	-0.0001	-13.0178	*DEL60*	0.0151	5.7923			
DL35	-0.2901	-15.4389	β_{Kx}	-0.0290	-7.8728	*DEL61*	0.0053	2.0994			
DL36	-0.0713	-3.1207	β_{Lx}	-0.0596	-9.2288	*DEL64*	0.0238	12.7124			
DL40	-0.5540	-16.5607	$\beta_{EL,x}$	-0.0019	-5.1500	*DEL65*	-0.0033	-1.6247			
DL41	-0.4285	-17.5187	β_{Fx}	-0.0001	-0.2018	β_F	0.0376	2.0060			
DL42	-0.4045	-17.8481	β_{Kt}	-0.0003	-1.7553	*DF51*	-0.0553	-2.5179			
DL43	-0.4023	-32.9899	β_{Lt}	-0.0032	-9.5689	*DF52*	-0.0432	-2.3273			
DL44	-0.3938	-25.3767	$\beta_{EL,t}$	0.0001	5.5821	*DF54*	-0.0123	-1.0104			
DL45	-0.4154	-27.1018	β_{Ft}	-0.0003	-11.1816	*DF55*	0.0457	4.0687			
β_{EL}	-0.0133	-2.6663				*DF56*	-0.0305	-3.2489			

Di1, Di7 etc. , *i=K,L,F,EL* , represent sectoral dummy variables.

Table 16: Cross-price elasticities for sector aggregates, non-nested translog model (at 1990 data)

	Energy-intensive manufact. sectors				*Non energy-intens. manufact. sectors*				*Service sectors*			
	concavity unrestrict.		concavity restrict.		concavity unrestrict.		concavity restrict.		concavity unrestrict.		concavity restrict.	
	value II	sig. cas.*	value II	sig. cas.	value II	sig. cas.	value II	sig. cas.	value II	sig. cas.	value II	sig. cas.
ε_{KL}	0.234	15	0.223	15	-0.009	0	0.045	0	0.323	11	0.316	11
$\varepsilon_{K,EL}$	-0.030	15	-0.028	15	-0.013	0	-0.028	19	0.006	0	0.008	0
ε_{KF}	0.015	0	0.040	0	-0.020	0	0.001	0	-0.016	0	0.023	0
ε_{KM}	0.115	15	0.124	15	0.317	19	0.287	19	0.733	11	0.710	11
ε_{LK}	0.116	15	0.110	15	-0.002	0	0.011	0	0.167	11	0.163	11
$\varepsilon_{L,EL}$	-0.007	0	-0.005	0	0.008	0	0.014	19	-0.006	0	0.053	11
ε_{LF}	-0.042	15	-0.019	0	-0.019	19	-0.011	19	-0.059	11	-0.055	11
ε_{LM}	0.066	0	0.058	0	0.168	19	0.235	19	0.658	11	0.660	11
$\varepsilon_{EL,K}$	-0.164	15	-0.154	15	-0.102	0	-0.220	19	0.036	0	0.045	0
$\varepsilon_{EL,L}$	-0.076	0	-0.054	0	0.264	0	0.431	19	-0.070	0	0.579	11
$\varepsilon_{EL,F}$	0.003	0	0.003	0	-0.068	19	0.019	0	0.054	0	0.039	0
$\varepsilon_{EL,M}$	0.249	15	0.244	15	-0.175	0	-0.189	0	-0.668	11	-0.622	11
ε_{FK}	0.061	0	0.159	0	-0.212	0	0.012	0	-0.080	0	0.117	0
ε_{FL}	-0.339	15	-0.156	0	-0.826	19	-0.477	19	-0.574	11	-0.541	11
$\varepsilon_{F,EL}$	0.003	0	0.002	0	-0.090	19	0.025	0	0.048	0	0.034	0
ε_{FM}	-0.122	0	0.018	0	0.852	19	0.461	19	0.200	0	0.426	0
ε_{MK}	0.026	15	0.028	15	0.035	19	0.032	19	0.087	11	0.085	11
ε_{ML}	0.030	0	0.026	0	0.075	19	0.105	19	0.151	11	0.152	11
$\varepsilon_{M,EL}$	0.010	15	0.010	15	-0.002	0	-0.003	0	-0.014	11	-0.013	11
ε_{MF}	-0.007	0	0.001	0	0.009	19	0.005	19	0.005	0	0.010	0

* t-statistics at a 5% level

Table 17: Sectoral breakdown (national account system and GEM-E3 system)

National account (NA) sectors	*No.*	*GEM-E3 sectors*	*No.*	*Sectoral aggregation for estimation (pooling)*
Agriculture and forestry	1	Agriculture	1	Energy-intens. manufact. sectors
Electricity production	7	Electricity	5	Energy supply sectors
Gas	8	Natural gas	4	Energy supply sectors
Coal mining	11	Solid fuels	2	Energy supply sectors
Other mining	12	Other energy-intensive industries	8	Energy-intens. manufact. sectors
Chemical products	14	Chemical industry	7	Energy-intens. manufact. sectors
Mineral oil	15	Liquid fuels	3	Energy supply sectors
Synthetic resins and plastic	16	Consumer goods	12	Nonenergy-intens. manufact. sectors
Rubber processing	17	Consumer goods	12	Nonenergy-intens. manufact. sectors
Sand, gravel, stone	18	Other energy-intensive industries	8	Energy-intens. manufact. sectors
Fine ceramics	19	Other energy-intensive industries	8	Energy-intens. manufact. sectors
Glass	20	Other energy-intensive industries	8	Energy-intens. manufact. sectors
Iron and steel	21	Ferrous and non-ferrous metals	6	Energy-intens. manufact. sectors
Non-ferrous metals	22	Ferrous and non-ferrous metals	6	Energy-intens. manufact. sectors
Foundry	23	Ferrous and non-ferrous metals	6	Energy-intens. manufact. sectors
Fabricated metal	24	Other energy-intensive industries	8	Energy-intens. manufact. sectors
Steel, light metal	25	Other equipment goods	11	Nonenergy-intens. manufact. sectors
Machinery	26	Other equipment goods	11	Nonenergy-intens. manufact. sectors
Office and data processing	27	Other equipment goods	11	Nonenergy-intens. manufact. sectors
Automobiles and parts	28	Transport equipment	10	Nonenergy-intens. manufact. sectors
Shipbuilding	29	Transport equipment	10	Nonenergy-intens. manufact. sectors
Airspace equipment	30	Transport equipment	10	Nonenergy-intens. manufact. sectors
Electrical appliances	31	Electrical goods	9	Nonenergy-intens. manufact. sectors
Precision and optical instr.	32	Other energy-intensive industries	8	Energy-intens. manufact. sectors
Iron, steel and steel products	33	Other energy-intensive industries	8	Energy-intens. manufact. sectors
Musical instruments and toys	34	Consumer goods	12	Nonenergy-intens. manufact. sectors
Timber processing and wood	35	Consumer goods	12	Nonenergy-intens. manufact. sectors
Wooden furniture	36	Consumer goods	12	Nonenergy-intens. manufact. sectors
Pulp, paper and board	37	Other energy-intensive industries	8	Energy-intens. manufact. sectors
Paper and paper products	38	Other energy-intensive industries	8	Energy-intens. manufact. sectors
Printing and publishing	39	Other energy-intensive industries	8	Energy-intens. manufact. sectors
Leather	40	Consumer goods	12	Nonenergy-intens. manufact. sectors
Textiles	41	Consumer goods	12	Nonenergy-intens. manufact. sectors
Clothing	42	Consumer goods	12	Nonenergy-intens. manufact. sectors
Food	43	Consumer goods	12	Nonenergy-intens. manufact. sectors
Beverages	44	Consumer goods	12	Nonenergy-intens. manufact. sectors
Tobacco	45	Consumer goods	12	Nonenergy-intens. manufact. sectors
Building and construction	46	Building and construction	13	Nonenergy-intens. manufact. sectors
Wholesale trade	51	Other market services	17	Service sectors
Retail trade	52	Other market services	17	Service sectors
Railways	54	Transports	15	Service sectors
Water transport	55	Transports	15	Service sectors
Postal services	56	Telecommunication services	14	Service sectors
Other transports	57	Transports	15	Service sectors
Banking and finance	60	Credit and insurance	16	Service sectors
Insurance	61	Credit and insurance	16	Service sectors
Hotels, catering, publ. houses	64	Other market services	17	Service sectors
Education, science, culture	65	Other market services	17	Service sectors
Health and sanitary services	66	Other market services	17	Service sectors

Table 18: Sectoral Morishima elasticities of substitution, non-nested and concavity restricted translog model (at 1990 data)

Energy supply sectors

	7		8		11		15	
	value	t-stat	value	t-stat	value	t-stat	value	t-stat
σ_{LK}	0.11	1.77	0.20	1.77	0.06	1.59	0.46	1.75
σ_{KL}	0.33	6.59	0.68	6.85	0.50	8.16	2.10	7.58
$\sigma_{EL,K}$	0.19	2.74	7.07	2.62	0.24	2.79	0.68	2.87
$\sigma_{K,EL}$	0.35	8.74	2.68	3.48	0.55	8.83	2.14	8.78
σ_{FK}	0.44	5.86	0.22	3.03	0.50	5.34	0.27	1.33
σ_{KF}	0.32	4.75	0.62	7.32	0.51	5.59	1.96	7.95
$\sigma_{EL,L}$	0.17	1.90	7.03	2.57	0.22	2.38	0.58	1.83
$\sigma_{L,EL}$	0.05	0.49	-1.37	-0.53	-0.02	-0.21	0.20	0.57
σ_{FL}	0.41	5.42	0.15	2.34	0.47	6.38	0.09	0.78
σ_{LF}	0.07	1.40	0.16	1.66	0.02	0.57	0.33	1.69
$\sigma_{F,EL}$	0.42	6.86	-0.21	-0.30	0.46	6.84	0.13	2.04
$\sigma_{EL,F}$	0.18	2.51	7.05	2.61	0.22	2.52	0.63	2.60
σ_{KM}	0.46	8.48	0.78	8.49	0.72	8.50	2.10	8.32
σ_{MK}	0.65	8.69	0.92	8.24	0.99	8.63	2.02	7.36
σ_{LM}	0.11	1.80	0.19	1.77	0.07	1.86	0.36	1.74
σ_{ML}	0.48	6.62	0.55	5.21	0.61	8.47	0.67	3.53
$\sigma_{EL,M}$	0.20	2.86	7.07	2.62	0.25	2.90	0.64	2.68
$\sigma_{M,EL}$	0.58	9.45	7.31	6.92	0.80	9.46	0.98	8.48
σ_{FM}	0.62	6.95	0.38	6.86	0.76	6.94	0.33	6.86
σ_{MF}	0.82	7.61	0.59	8.20	1.05	7.81	0.52	8.22

Service sectors

	51		52		54		55		56		57		60		61		64		65		66	
	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat
σ_{LK}	3.09	8.62	1.83	8.68	0.44	8.28	0.83	8.18	0.43	8.31	0.81	8.66	0.47	8.61	0.67	8.69	0.85	8.69	0.54	8.37	0.79	8.62
σ_{KL}	4.57	19.63	2.45	19.21	0.28	14.32	0.46	13.32	0.28	14.64	0.87	18.11	0.70	19.63	0.77	18.51	1.04	18.81	0.38	15.20	1.16	19.61
$\sigma_{EL,K}$	0.08	2.48	0.04	2.47	0.01	2.08	0.34	1.87	0.09	1.89	0.16	1.93	0.09	1.96	0.12	1.94	0.03	2.31	0.08	1.91	0.24	1.92
$\sigma_{K,EL}$	4.27	21.46	2.24	21.51	0.22	16.47	0.68	2.70	0.31	4.54	0.92	7.87	0.74	10.30	0.81	9.02	0.95	20.57	0.37	6.35	1.32	7.46
σ_{FK}	0.13	1.68	0.08	1.66	0.04	1.26	0.01	1.61	0.13	1.18	0.03	1.66	0.23	1.21	0.31	1.20	0.09	1.38	0.12	1.20	0.15	1.30
σ_{KF}	4.32	20.25	2.33	18.06	0.32	4.20	0.34	15.85	0.62	2.29	0.79	18.18	1.34	2.94	1.62	2.63	1.14	7.75	0.65	2.73	1.47	5.46
$\sigma_{EL,L}$	0.17	2.89	0.10	3.10	0.04	2.81	0.38	1.98	0.11	2.08	0.19	2.07	0.11	2.03	0.14	2.08	0.06	2.68	0.11	2.16	0.26	1.97
$\sigma_{L,EL}$	2.57	9.12	1.47	9.18	0.56	8.96	5.41	4.45	1.62	5.01	2.68	4.95	1.52	4.73	2.04	5.01	0.93	8.49	1.52	5.50	3.66	4.42
σ_{FL}	-0.09	-3.85	-0.04	-7.18	0.01	0.49	-0.04	-2.78	0.10	1.03	-0.03	-3.85	0.20	1.10	0.26	1.09	0.03	0.67	0.08	0.97	0.09	0.98
σ_{LF}	1.29	3.89	0.65	2.42	-0.15	-0.62	0.63	5.91	-1.55	-1.87	0.41	3.90	-2.92	-2.11	-3.85	-2.06	-0.41	-0.95	-1.22	-1.69	-1.39	-1.73
$\sigma_{F,EL}$	0.09	1.58	0.06	1.40	0.05	1.32	0.32	1.93	0.21	1.42	0.15	1.89	0.30	1.34	0.40	1.33	0.09	1.33	0.18	1.42	0.34	1.63
$\sigma_{EL,F}$	0.09	2.22	0.05	2.25	0.05	2.20	0.34	1.87	0.21	2.26	0.16	1.93	0.29	2.22	0.39	2.21	0.09	2.21	0.18	2.26	0.35	2.18
σ_{KM}	4.28	21.42	2.29	21.50	0.66	15.46	0.46	20.46	0.54	16.53	0.86	21.61	0.81	21.29	0.79	21.58	1.02	21.62	0.45	19.80	1.17	21.62
σ_{MK}	3.02	12.69	1.70	13.24	1.40	9.22	0.60	11.79	1.05	9.55	0.79	13.99	0.90	13.04	0.76	13.87	0.89	14.06	0.65	11.18	0.99	14.03
σ_{LM}	1.96	7.51	1.31	7.44	1.21	6.49	0.98	7.19	0.96	6.60	0.77	7.22	0.58	6.76	0.66	7.13	0.75	7.23	0.75	6.96	0.65	7.16
σ_{ML}	1.67	6.22	1.15	6.36	1.57	7.86	0.97	6.83	1.20	7.72	0.76	6.79	0.69	7.51	0.67	6.94	0.73	6.77	0.82	7.22	0.65	6.89
$\sigma_{EL,M}$	0.04	1.60	0.01	1.07	-0.06	-6.47	0.31	1.78	0.04	1.03	0.13	1.73	0.06	1.48	0.10	1.67	0.01	0.99	0.05	1.42	0.21	1.77
$\sigma_{M,EL}$	-0.60	-3.28	-0.11	-1.35	1.07	6.24	-4.63	-4.16	-0.44	-1.25	-1.97	-3.89	-0.87	-2.75	-1.39	-3.63	-0.11	-1.12	-0.69	-2.50	-3.15	-4.15
σ_{FM}	0.04	1.24	0.04	1.25	0.09	1.49	0.02	1.55	0.17	1.27	0.02	1.43	0.24	1.19	0.30	1.17	0.08	1.22	0.13	1.22	0.14	1.19
σ_{MF}	0.62	2.50	0.62	2.60	1.68	5.32	0.47	6.21	2.42	2.72	0.42	4.53	2.98	2.08	3.70	1.92	1.04	2.34	1.77	2.34	1.74	2.08

Energy-intensive manufacturing sectors

	1		12		14		18		19		20		21		22		23		24	
	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat
σ_{LK}	0.42	3.61	0.35	4.12	0.44	4.43	0.39	4.41	0.33	4.43	0.35	4.41	0.40	4.41	0.63	4.41	0.39	4.43	0.49	4.43
σ_{KL}	0.38	5.11	0.38	6.05	0.58	6.35	0.50	6.34	0.46	6.33	0.45	6.34	0.52	6.34	0.82	6.34	0.55	6.33	0.69	6.33
$\sigma_{EL,K}$	0.05	1.16	0.04	1.00	0.00	-0.08	0.00	-0.11	0.01	0.33	0.00	-0.13	0.02	0.52	-0.03	-1.49	-0.01	-0.60	0.00	-0.06
$\sigma_{K,EL}$	-0.13	-1.13	-0.01	-0.12	0.33	3.58	0.28	3.64	0.24	2.63	0.25	3.69	0.21	2.01	0.57	5.44	0.37	4.42	0.42	3.55
σ_{FK}	0.03	1.31	0.07	1.29	0.07	1.67	0.06	1.61	0.06	1.59	0.05	1.59	0.06	1.64	0.13	1.45	0.10	1.43	0.19	1.28
σ_{KF}	0.26	2.91	0.55	2.82	0.57	5.10	0.50	4.69	0.52	4.53	0.46	4.57	0.51	4.90	1.05	3.66	0.80	3.54	1.48	2.78
$\sigma_{EL,L}$	0.05	1.08	0.05	1.19	0.03	1.16	0.02	1.12	0.04	1.24	0.02	1.12	0.05	1.21	0.01	0.70	0.02	1.18	0.04	1.22
$\sigma_{L,EL}$	0.27	1.54	0.12	0.86	0.09	1.10	0.11	1.38	0.03	0.36	0.09	1.38	0.08	0.69	0.20	2.39	0.06	1.00	0.06	0.62
σ_{FL}	-0.03	-2.26	0.02	0.63	-0.01	-1.08	0.00	-0.46	0.01	0.62	0.00	-0.14	-0.01	-0.95	0.03	0.71	0.03	0.91	0.11	0.99
σ_{LF}	0.21	1.90	-0.11	-0.65	0.05	0.90	0.03	0.54	-0.04	-0.62	0.02	0.30	0.05	0.83	-0.17	-0.80	-0.23	-1.29	-0.74	-1.54
$\sigma_{F,EL}$	0.03	0.68	0.05	0.96	0.02	0.73	0.02	0.87	0.02	0.80	0.02	0.91	0.02	0.61	0.06	1.08	0.05	1.08	0.13	1.08
$\sigma_{EL,F}$	0.06	1.25	0.07	1.10	0.04	1.24	0.03	1.17	0.04	1.21	0.03	1.15	0.05	1.27	0.02	0.54	0.03	0.75	0.06	0.59
σ_{KM}	0.15	5.00	0.25	5.76	0.50	5.98	0.42	5.93	0.43	5.82	0.38	5.87	0.44	5.95	0.66	6.06	0.50	5.94	0.62	6.03
σ_{MK}	0.12	2.84	0.14	2.69	0.23	2.50	0.20	2.56	0.23	2.66	0.19	2.62	0.21	2.54	0.27	2.38	0.24	2.55	0.27	2.43
σ_{LM}	0.39	2.99	0.23	2.92	0.17	2.79	0.17	2.78	0.12	2.38	0.16	2.69	0.17	2.79	0.25	2.99	0.13	2.54	0.15	2.75
σ_{ML}	0.22	1.70	0.14	1.77	0.12	1.90	0.12	1.91	0.13	2.21	0.12	1.98	0.12	1.90	0.14	1.69	0.12	2.11	0.11	1.93
$\sigma_{EL,M}$	0.07	1.45	0.07	1.42	0.05	1.49	0.04	1.54	0.05	1.54	0.04	1.58	0.06	1.45	0.03	1.58	0.04	1.59	0.06	1.45
$\sigma_{M,EL}$	0.47	3.19	0.44	3.09	0.29	3.33	0.24	3.44	0.34	3.45	0.23	3.54	0.38	3.18	0.17	3.53	0.24	3.56	0.34	3.20
σ_{FM}	0.02	0.96	0.05	1.03	0.01	0.94	0.02	0.95	0.02	0.92	0.02	0.94	0.02	0.94	0.06	1.04	0.05	1.02	0.13	1.05
σ_{MF}	0.10	0.92	0.10	0.47	0.07	1.04	0.08	0.95	0.11	1.10	0.08	1.02	0.08	1.01	0.10	0.37	0.11	0.52	0.16	0.29

	32		33		37		38		39	
	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat
σ_{LK}	0.48	4.41	0.48	4.43	0.41	4.31	0.49	4.43	0.38	4.43
σ_{KL}	0.70	6.31	0.68	6.33	0.49	6.27	0.66	6.35	0.52	6.34
$\sigma_{EL,K}$	0.05	0.72	0.02	0.49	-0.01	-1.14	0.05	0.80	0.04	0.74
$\sigma_{K,EL}$	0.24	1.26	0.32	2.13	0.29	5.07	0.17	0.90	0.16	1.18
σ_{FK}	0.27	1.22	0.19	1.28	0.06	1.57	0.17	1.29	0.26	1.18
σ_{KF}	1.99	2.51	1.46	2.79	0.47	4.41	1.33	2.80	1.90	2.29
$\sigma_{EL,L}$	0.09	1.28	0.07	1.26	0.01	0.59	0.09	1.26	0.07	1.27
$\sigma_{L,EL}$	-0.04	-0.20	0.02	0.15	0.17	2.51	0.02	0.12	0.01	0.06
σ_{FL}	0.18	1.03	0.11	1.00	-0.01	-1.14	0.09	0.96	0.20	1.03
σ_{LF}	-1.24	-1.65	-0.73	-1.55	0.07	0.93	-0.62	-1.45	-1.32	-1.64
$\sigma_{F,EL}$	0.20	1.08	0.13	1.08	0.02	1.06	0.12	1.05	0.22	1.08
$\sigma_{EL,F}$	0.12	0.71	0.08	0.77	0.02	0.89	0.11	0.94	0.09	0.56
σ_{KM}	0.65	6.02	0.62	6.03	0.37	5.91	0.57	6.03	0.47	5.95
σ_{MK}	0.29	2.45	0.27	2.44	0.18	2.59	0.24	2.43	0.22	2.54
σ_{LM}	0.12	2.59	0.14	2.72	0.22	2.89	0.18	2.87	0.13	2.64
σ_{ML}	0.11	2.06	0.11	1.96	0.14	1.81	0.12	1.82	0.11	2.03
$\sigma_{EL,M}$	0.11	1.39	0.08	1.41	0.02	1.72	0.10	1.37	0.08	1.42
$\sigma_{M,EL}$	0.67	2.99	0.50	3.05	0.15	3.71	0.65	2.94	0.51	3.09
σ_{FM}	0.20	1.05	0.13	1.05	0.02	0.97	0.11	1.05	0.21	1.05
σ_{MF}	0.22	0.26	0.16	0.29	0.08	0.87	0.14	0.29	0.23	0.25

Nonenergy-intensive manufacturing sectors

	16		17		25		26		27		28		29		30		31		34	
	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat
σ_{LK}	0.29	3.05	0.27	2.95	0.28	2.08	0.25	2.34	0.29	3.45	0.35	3.24	0.31	2.74	0.24	2.33	0.25	2.53	0.28	3.13
σ_{KL}	0.27	4.32	0.26	4.35	0.43	4.50	0.34	4.47	0.21	4.17	0.29	4.26	0.33	4.40	0.32	4.47	0.30	4.44	0.25	4.30
$\sigma_{EL,K}$	-0.01	-1.04	0.00	-0.48	0.02	0.88	0.02	0.82	0.02	1.16	0.02	1.02	0.01	0.50	0.02	0.97	0.02	0.99	0.01	0.50
$\sigma_{K,EL}$	0.16	2.81	0.14	2.49	0.09	0.75	0.08	0.89	0.00	-0.04	0.03	0.38	0.12	1.50	0.05	0.53	0.04	0.46	0.09	1.49
σ_{FK}	0.04	1.01	0.01	0.85	0.02	0.84	0.04	0.98	0.12	1.08	0.03	0.99	0.04	1.01	0.07	1.05	0.04	1.00	0.04	1.03
σ_{KF}	0.28	1.38	0.25	2.75	0.43	2.86	0.35	1.73	0.27	0.43	0.29	1.62	0.34	1.46	0.35	0.94	0.31	1.52	0.26	1.22
$\sigma_{EL,L}$	0.03	2.52	0.03	2.44	0.07	2.11	0.06	2.15	0.05	2.26	0.06	2.26	0.05	2.27	0.06	2.13	0.06	2.15	0.04	2.34
$\sigma_{L,EL}$	0.44	6.55	0.44	6.44	0.86	4.89	0.69	5.17	0.66	5.79	0.78	5.78	0.65	5.83	0.71	5.02	0.70	5.16	0.54	6.16
σ_{FL}	0.02	0.89	0.00	0.43	0.01	0.78	0.03	0.93	0.11	1.04	0.02	0.78	0.03	0.92	0.06	1.02	0.03	0.94	0.03	0.91
σ_{LF}	-0.55	-1.51	-0.08	-0.53	-0.27	-1.22	-0.58	-1.64	-2.37	-2.01	-0.39	-1.23	-0.67	-1.60	-1.35	-1.95	-0.60	-1.66	-0.61	-1.58
$\sigma_{F,EL}$	0.04	1.17	0.02	1.23	0.05	1.27	0.06	1.23	0.14	1.15	0.05	1.23	0.06	1.20	0.09	1.19	0.06	1.23	0.05	1.19
$\sigma_{EL,F}$	0.06	1.52	0.04	1.75	0.09	1.87	0.09	1.74	0.18	1.45	0.08	1.75	0.09	1.65	0.13	1.60	0.09	1.73	0.07	1.60
σ_{KM}	0.29	4.51	0.28	4.50	0.45	4.54	0.36	4.52	0.23	4.48	0.30	4.52	0.35	4.53	0.35	4.52	0.32	4.51	0.27	4.50
σ_{MK}	0.38	3.37	0.38	3.43	0.54	3.15	0.46	3.28	0.33	3.51	0.39	3.29	0.43	3.24	0.45	3.32	0.43	3.35	0.37	3.42
σ_{LM}	0.36	4.60	0.34	4.58	0.32	4.58	0.32	4.57	0.37	4.60	0.40	4.62	0.36	4.60	0.31	4.56	0.32	4.57	0.36	4.59
σ_{ML}	0.38	4.35	0.37	4.37	0.35	4.37	0.35	4.38	0.39	4.35	0.42	4.32	0.38	4.35	0.34	4.38	0.35	4.38	0.38	4.36
$\sigma_{EL,M}$	0.01	1.71	0.02	1.72	0.06	1.86	0.04	1.84	0.03	1.83	0.04	1.85	0.03	1.83	0.05	1.85	0.04	1.84	0.02	1.79
$\sigma_{M,EL}$	0.06	1.00	0.06	0.91	-0.14	-0.83	-0.06	-0.48	-0.03	-0.29	-0.08	-0.63	-0.03	-0.32	-0.07	-0.52	-0.06	-0.47	0.02	0.20
σ_{FM}	0.04	1.18	0.02	1.31	0.03	1.23	0.04	1.19	0.12	1.13	0.04	1.19	0.05	1.17	0.08	1.15	0.04	1.19	0.04	1.18
σ_{MF}	0.92	2.53	0.45	3.13	0.61	2.77	0.91	2.57	2.69	2.28	0.80	2.55	1.03	2.47	1.65	2.38	0.93	2.56	0.98	2.51

	35		36		40		41		42		43		44		45		46	
	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat	value	t-stat
σ_{LK}	0.37	3.77	0.28	2.48	0.35	3.25	0.32	3.49	0.37	2.23	0.54	3.49	0.45	4.36	0.53	3.88	0.26	1.82
σ_{KL}	0.22	3.97	0.35	4.45	0.29	4.26	0.23	4.15	0.53	4.49	0.39	4.15	0.16	3.16	0.30	3.88	0.47	4.53
$\sigma_{EL,K}$	-0.01	-2.17	0.00	0.20	0.02	0.96	0.00	-0.85	0.02	0.75	-0.01	-0.58	0.02	1.27	0.03	1.22	0.35	1.78
$\sigma_{K,EL}$	0.15	3.26	0.16	1.89	0.04	0.55	0.13	2.71	0.14	1.04	0.21	2.55	-0.02	-0.46	-0.02	-0.27	-1.69	-3.12
σ_{FK}	0.01	0.84	0.02	0.85	0.03	0.98	0.01	0.89	0.04	0.90	0.02	0.77	0.01	0.87	0.04	1.03	0.01	0.64
σ_{KF}	0.22	2.82	0.35	2.76	0.29	1.78	0.22	2.51	0.53	2.44	0.38	3.24	0.14	2.67	0.30	1.24	0.47	3.78
$\sigma_{EL,L}$	0.03	2.87	0.05	2.26	0.06	2.27	0.03	2.63	0.08	2.14	0.05	2.60	0.05	2.52	0.08	2.34	0.40	1.95
$\sigma_{L,EL}$	0.46	6.19	0.59	5.78	0.77	5.86	0.45	6.55	1.02	5.13	0.78	6.57	0.75	6.55	1.08	6.14	4.40	3.79
σ_{FL}	0.00	-1.12	0.01	0.66	0.01	0.73	0.00	0.14	0.02	0.83	-0.01	-1.44	-0.01	-4.78	0.02	0.72	0.00	0.52
σ_{LF}	0.09	0.73	-0.18	-0.96	-0.32	-1.11	-0.02	-0.15	-0.47	-1.36	0.15	0.85	0.25	2.09	-0.48	-1.08	-0.09	-0.67
$\sigma_{F,EL}$	0.02	1.21	0.03	1.25	0.05	1.24	0.02	1.22	0.07	1.25	0.03	1.25	0.02	1.28	0.07	1.22	0.20	1.28
$\sigma_{EL,F}$	0.02	1.67	0.06	1.80	0.08	1.77	0.03	1.70	0.11	1.82	0.05	1.81	0.04	1.89	0.11	1.73	0.41	1.92
σ_{KM}	0.24	4.49	0.37	4.53	0.31	4.52	0.25	4.49	0.54	4.55	0.39	4.54	0.17	4.43	0.30	4.53	0.50	4.54
σ_{MK}	0.33	3.46	0.46	3.23	0.39	3.28	0.34	3.46	0.61	3.01	0.46	3.10	0.27	3.68	0.37	3.23	0.59	3.13
σ_{LM}	0.45	4.62	0.34	4.59	0.41	4.62	0.39	4.61	0.39	4.62	0.57	4.65	0.53	4.64	0.58	4.65	0.31	4.56
σ_{ML}	0.46	4.32	0.36	4.36	0.42	4.32	0.41	4.34	0.40	4.32	0.57	4.27	0.54	4.30	0.58	4.27	0.33	4.38
$\sigma_{EL,M}$	0.01	1.58	0.03	1.82	0.04	1.85	0.01	1.68	0.07	1.88	0.03	1.82	0.03	1.82	0.05	1.87	0.39	1.91
$\sigma_{M,EL}$	0.09	1.84	-0.02	-0.16	-0.07	-0.60	0.07	1.24	-0.20	-1.07	-0.02	-0.21	-0.01	-0.06	-0.14	-0.96	-1.69	-1.68
σ_{FM}	0.02	1.32	0.02	1.25	0.03	1.19	0.02	1.29	0.04	1.18	0.02	1.25	0.01	1.38	0.05	1.16	0.02	1.32
σ_{MF}	0.38	3.21	0.55	2.85	0.74	2.58	0.44	3.06	0.87	2.50	0.44	2.84	0.31	3.49	1.05	2.41	0.42	3.20

Table 19: Parameter estimates, three-level nested translog model

Energy supply sectors			Energy-intensive manufacturing sectors					
Parameter	Estimate	t-stat	Parameter	Estimate	t-stat	Parameter	Estimate	t-stat
Third nesting level			*Third nesting level*			DEL12	0.0407	5.5927
D_{LL}	-0.0103	-1.0823	D_{LL}	-0.0734	-6.0183	DEL14	0.0456	6.7651
L_{FL}	0.6160	0.7633	L_{FL}	0.0633	1.3143	DEL18	0.0471	7.6358
β_{L}	0.0954	4.5725	β_{L}	1.0348	16.2912	DEL19	0.0350	6.2628
DL7	0.1040	5.9572	DL1	-0.8156	-14.0555	DEL20	0.0441	8.9269
DL8	0.0143	1.2007	DL12	-0.6587	-12.1311	DEL21	0.0244	5.6132
DL11	0.4132	56.3230	DL14	-0.5941	-11.8517	DEL22	0.0651	17.7676
β_{Lt}	-0.0010	-2.3478	DL18	-0.5209	-11.2524	DEL23	0.0378	11.9407
D_{FF}	-0.0919	-4.6277	DL19	-0.2389	-5.6853	DEL24	0.0197	7.7382
β_{F}	1.2633	16.6121	DL20	-0.3579	-9.6273	DEL32	0.0055	2.0614
DF7	-0.8691	-13.9935	DL21	-0.3687	-11.3692	DEL33	0.0065	4.3765
DF8	-0.4596	-10.4185	DL22	-0.4291	-15.5688	DEL37	0.0690	69.6608
DF11	-0.5764	-23.0411	DL23	-0.1056	-4.4518	DEL39	0.0007	0.6713
β_{Ft}	-0.0133	-8.3048	DL24	-0.1655	-8.8505	$\beta_{EL,t}$	0.0002	3.5313
Second nesting level			DL32	-0.1896	-10.3327	*First nesting level*		
$D_{EL,EL}$	-0.0047	-2.2918	DL33	-0.0356	-3.3964	D_{KK}	-0.0391	-5.7433
β_{EL}	-0.0012	-0.2231	DL37	-0.0901	-13.3478	α_{0}	0.2609	4.4215
DEL7	0.0483	10.2598	DL39	0.1798	28.1222	β_{K}	0.1814	6.6530
DEL8	-0.0045	-1.4362	β_{Lt}	-0.0042	-11.8202	DK1	0.2408	6.9598
DEL11	0.0263	12.4235	β_{F}	0.1832	7.4695	DK12	0.0664	2.7858
$\beta_{EL,t}$	0.0003	2.7913	DF1	-0.1112	-4.8419	DK14	-0.0414	-1.1794
First nesting level			DF12	-0.1327	-6.2000	DK18	-0.0102	-0.3936
D_{KK}	-0.0732	-6.3787	DF14	-0.0794	-4.0241	DK19	-0.0211	-1.1892
α_{0}	0.7860	0.9461	DF18	-0.0749	-4.1387	DK20	-0.0048	-0.2830
β_{K}	0.4881	4.2349	DF19	-0.0674	-4.1055	DK21	-0.0153	-0.7555
DK7	0.2933	9.3091	DF20	-0.0319	-2.1936	DK22	-0.0497	-3.3993
DK8	-0.0509	-1.4290	DF21	-0.0430	-3.3805	DK23	-0.0208	-1.9127
DK11	-0.0121	-0.4148	DF22	-0.0683	-6.2550	DK24	-0.0190	-1.5222
β_{t}	0.0829	12.0836	DF23	-0.0519	-5.5640	DK32	-0.0589	-6.3431
β_{tt}	0.0001	0.4965	DF24	-0.0521	-6.9381	DK33	-0.0100	-1.0040
β_{Kt}	0.0011	1.5967	DF32	-0.0505	-6.7983	DK37	0.0242	6.6689
β_{xx}	0.2917	2.6375	DF33	-0.0258	-5.9236	DK39	0.0282	7.4217
β_{x}	0.1688	0.3870	DF37	0.0324	10.7208	β_{t}	-0.0015	-2.1816
β_{xt}	-0.0205	-14.2384	DF39	0.0072	2.4201	β_{tt}	0.0000	1.4040
β_{Kx}	-0.1134	-4.3615	β_{Ft}	-0.0010	-7.1333	β_{Kt}	-0.0004	-2.5155
			Second nesting level			β_{xx}	0.0163	1.2760
			$D_{EL,EL}$	0.0001	0.0191	β_{x}	0.9244	22.6344
			β_{EL}	-0.0199	-2.3866	β_{xt}	0.0001	0.6182
			DEL1	0.0435	5.5131	β_{Kx}	-0.0059	-0.8447

continued Table 19

Nonenergy-intensive manufacturing sectors								
Parameter	Estimate	t-stat	Parameter	Estimate	t-stat	Parameter	Estimate	t-stat
Third nesting level			*Second nesting level*			β_t	-0.0002	-0.3078
D_{FF}	0.0017	4.4795	$D_{EL,EL}$	0.0003	0.2587	β_{tt}	-0.0001	-12.7287
L_{FL}	-4.4597	-3.0860	β_{EL}	-0.0339	-10.0816	β_{Kt}	-0.0003	-2.1365
D_{LL}	-0.1791	-6.9470	*DEL16*	0.0528	16.1352	β_{xx}	-0.0356	-1.5396
β_L	1.2278	10.7994	*DEL17*	0.0524	16.9217	β_x	0.9284	10.9026
DL16	-0.8893	-8.2311	*DEL25*	0.0356	12.2126	β_{xt}	0.0021	11.6412
DL17	-0.7961	-7.7568	*DEL26*	0.0075	5.4081	β_{Kx}	-0.0297	-8.5032
DL25	-0.7549	-7.7234	*DEL27*	0.0394	21.4596			
DL26	-0.0539	-1.1845	*DEL28*	-0.0057	-3.3343			
DL27	-0.5232	-8.8966	*DEL29*	0.0275	18.3658			
DL28	-0.4923	-8.7174	*DEL30*	0.0274	13.5006			
DL29	-0.6316	-13.4102	*DEL31*	0.0258	14.0414			
DL30	-0.4458	-6.8870	*DEL34*	-0.0030	-3.7494			
DL31	-0.4510	-7.5725	*DEL35*	0.0376	48.3046			
DL34	-0.1518	-5.9096	*DEL36*	0.0044	5.2234			
DL35	-0.2104	-8.7452	*DEL40*	0.0186	16.6286			
DL36	0.0311	1.0977	*DEL41*	0.0312	33.1088			
DL40	-0.3869	-10.6241	*DEL42*	0.0117	14.9015			
DL41	-0.3256	-11.0546	*DEL43*	0.0180	29.3743			
DL42	-0.3051	-12.3910	*DEL44*	0.0170	36.2591			
DL43	-0.4061	-24.5116	*DEL45*	0.0084	23.4016			
DL44	-0.2841	-22.6524	$\beta_{EL,t}$	0.0001	10.3095			
DL45	-0.2708	-37.3805	*First nesting level*					
β_{Lt}	-0.0034	-7.2353	D_{KK}	-0.0198	-4.1426			
β_F	0.0714	8.1855	α_0	0.3539	2.1353			
DF16	-0.0647	-7.8001	β_K	0.2831	9.6337			
DF17	-0.0513	-6.5215	*DK16*	-0.0865	-3.0373			
DF25	-0.0540	-7.2125	*DK17*	-0.1027	-3.8864			
DF26	-0.0213	-6.1194	*DK25*	-0.1179	-4.6966			
DF27	-0.0349	-7.7026	*DK26*	0.0369	2.2692			
DF28	-0.0499	-11.5382	*DK27*	0.0273	1.6927			
DF29	-0.0337	-9.2999	*DK28*	-0.0463	-2.6631			
DF30	-0.0465	-9.3433	*DK29*	-0.0855	-6.5588			
DF31	-0.0401	-8.7591	*DK30*	-0.1267	-7.2118			
DF34	-0.0215	-10.9148	*DK31*	-0.0303	-1.8239			
DF35	0.0020	1.1056	*DK34*	-0.0725	-10.2171			
DF36	-0.0141	-6.5359	*DK35*	0.0204	3.0019			
DF40	-0.0269	-9.6289	*DK36*	-0.0448	-6.2677			
DF41	-0.0167	-7.3320	*DK40*	-0.0876	-7.4736			
DF42	-0.0220	-11.5740	*DK41*	-0.0228	-2.6406			
DF43	-0.0128	-9.8117	*DK42*	-0.0842	-10.3905			
DF44	0.0047	4.7661	*DK43*	-0.0139	-2.5544			
DF45	-0.0152	-26.2703	*DK44*	0.0447	6.5938			
β_{Ft}	-0.0002	-6.5654	*DK45*	-0.0415	-5.1350			

continued Table 19

Service sectors					
Parameter	Estimate	t-stat	Parameter	Estimate	t-stat
Third nesting level			*DEL52*	0.0700	9.6113
D_{LL}	-0.2361	-9.4963	*DEL54*	0.1061	16.4384
L_{FL}	0.0492	2.0325	*DEL55*	0.0345	5.9659
β_{L}	0.5489	6.2419	*DEL56*	0.0363	7.4577
DL51	-0.4911	-6.0299	*DEL57*	0.0273	6.5331
DL52	-0.4057	-5.4717	*DEL60*	0.0240	7.3026
DL54	0.2111	3.2366	*DEL61*	0.0178	7.0411
DL55	-0.2383	-4.1845	*DEL64*	0.0341	18.4276
DL56	0.2713	5.4489	*DEL65*	0.0099	8.3468
DL57	-0.1924	-4.6674	$\beta_{EL,t}$	0.0004	6.4438
DL60	0.1125	3.4020	*First nesting level*		
DL61	-0.0387	-1.4752	D_{KK}	-0.1155	-18.9593
DL64	-0.1572	-8.5854	α_{0}	-0.1849	-0.7753
DL65	0.0331	2.1735	β_{K}	0.0951	3.7041
β_{Lt}	-0.0012	-1.9462	*DK51*	0.0487	0.4712
β_{F}	0.0736	3.2456	*DK52*	0.0404	0.4677
DF51	-0.0545	-2.5442	*DK54*	0.2867	7.0429
DF52	-0.0434	-2.2408	*DK55*	0.1816	5.4836
DF54	-0.0155	-0.9053	*DK56*	0.2284	7.0898
DF55	0.0705	4.6494	*DK57*	0.0488	1.4952
DF56	-0.0379	-2.8997	*DK60*	0.0404	1.7097
DF57	0.0257	2.3373	*DK61*	-0.0144	-0.7786
DF60	-0.0316	-3.5559	*DK64*	-0.0295	-1.9286
DF61	-0.0251	-3.5740	*DK65*	0.1293	6.9538
DF64	-0.0075	-1.4888	β_{t}	-0.0230	-8.1021
DF65	-0.0037	-0.8955	β_{tt}	0.0002	7.8339
β_{Ft}	-0.0005	-2.8728	β_{Kt}	0.0007	1.1357
Second nesting level			β_{xx}	-0.2268	-6.9819
$D_{EL,EL}$	-0.0060	-2.7768	β_{x}	1.8146	12.6869
β_{EL}	-0.0248	-5.7949	β_{xt}	-0.0005	-1.6422
DEL51	0.0575	7.0919	β_{Kx}	-0.0360	-2.1505

Di1, Di7 etc., *i= L,F,EL,K* , represent sectoral dummy variables.

Table 20: Own- and cross-price elasticities for GEM-E3 sectors, three-level nested translog model (at 1990 data)

	Agriculture (1)			*Solid fuels (2)*			*Liquid fuels (3)*			*Natural gas (4)*			*Electricity (5)*			*Ferrous/non-ferrous metals (6)*		
	value I	value II	sig. cas.*	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.
									Third nesting level									
ε_{FF}	0.000	-0.005	0	-0.480	-0.480	1	-0.190	-0.190	1	-0.202	-0.202	1	-0.372	-0.372	1	0.000	-0.008	0
ε_{LL}	-0.418	-0.418	1	0.000	-0.022	0	0.000	-0.291	0	0.000	-0.129	0	0.000	-0.052	0	-0.262	-0.262	3
ε_{MM}	-0.108	-0.108	1	-0.356	-0.356	1	-0.259	-0.259	1	-0.267	-0.267	1	-0.206	-0.206	1	-0.120	-0.120	3
ε_{FL}	0.000	-0.080	0	0.000	-0.032	0	0.000	-0.013	0	0.000	-0.013	0	0.000	-0.025	0	0.000	-0.123	0
ε_{LF}	0.000	-0.026	0	0.000	-0.014	0	0.000	-0.179	0	0.000	-0.080	0	0.000	-0.032	0	0.000	-0.017	0
ε_{FM}	0.000	0.085	0	0.512	0.512	1	0.202	0.202	1	0.215	0.215	1	0.397	0.397	1	0.000	0.131	0
ε_{MF}	0.000	0.006	0	0.306	0.306	1	0.223	0.223	1	0.229	0.229	1	0.177	0.177	1	0.000	0.007	0
ε_{LM}	0.444	0.444	1	0.000	0.036	0	0.000	0.471	0	0.000	0.209	0	0.000	0.084	0	0.279	0.279	3
ε_{ML}	0.102	0.102	1	0.000	0.050	0	0.000	0.036	0	0.000	0.038	0	0.000	0.029	0	0.113	0.113	3
									Second nesting level									
$\varepsilon_{EL,EL}$	0.000	0.002	0	-0.117	-0.117	1	-0.373	-0.373	1	-3.812	-3.812	1	-0.070	-0.070	1	0.000	0.002	0
$\varepsilon_{LFM,LFM}$	0.000	0.000	0	-0.005	-0.005	1	-0.005	-0.005	1	-0.005	-0.005	1	-0.005	-0.005	1	0.000	0.000	0
$\varepsilon_{EL,LFM}$	0.000	-0.002	0	0.117	0.117	1	0.373	0.373	1	3.812	3.812	1	0.070	0.070	1	0.000	-0.002	0
$\varepsilon_{LFM,EL}$	0.000	0.000	0	0.005	0.005	1	0.005	0.005	1	0.005	0.005	1	0.005	0.005	1	0.000	0.000	0
									First nesting level									
ε_{KK}	-0.099	-0.099	1	-0.466	-0.466	1	-1.885	-1.885	1	-0.589	-0.589	1	-0.249	-0.249	1	-0.411	-0.411	3
$\varepsilon_{LEM,LEM}$	-0.065	-0.065	1	-0.087	-0.087	1	-0.076	-0.076	1	-0.084	-0.084	1	-0.094	-0.094	1	-0.043	-0.043	3
$\varepsilon_{K,LEM}$	0.099	0.099	1	0.466	0.466	1	1.885	1.885	1	0.589	0.589	1	0.249	0.249	1	0.411	0.411	3
$\varepsilon_{LEM,K}$	0.065	0.065	1	0.087	0.087	1	0.076	0.076	1	0.084	0.084	1	0.094	0.094	1	0.043	0.043	3

	Chemical industry (7)			*Other energy-intensive ind. (8)*			*Electrical goods (9)*			*Transport equip. (10)*			*Other equip. goods (11)*			*Consumer goods (12)*		
	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.
									Third nesting level									
ε_{FF}	0.000	-0.005	0	0.000	-0.016	0	0.394	0.394	1	0.351	0.351	3	0.387	0.387	3	0.175	0.175	11
ε_{LL}	-0.254	-0.254	1	-0.215	-0.215	10	-0.388	-0.388	1	-0.560	-0.560	3	-0.402	-0.402	3	-0.631	-0.631	11
ε_{MM}	-0.128	-0.128	1	-0.125	-0.125	10	-0.256	-0.256	1	-0.216	-0.216	3	-0.251	-0.251	3	-0.209	-0.209	11
ε_{FL}	0.000	-0.078	0	0.000	-0.249	0	-1.758	-1.758	1	-1.564	-1.564	3	-1.728	-1.728	3	-0.782	-0.782	11
ε_{LF}	0.000	-0.016	0	0.000	-0.014	0	-0.020	-0.020	1	-0.029	-0.029	3	-0.021	-0.021	3	-0.033	-0.033	11
ε_{FM}	0.000	0.083	0	0.000	0.265	0	1.364	1.364	1	1.213	1.213	3	1.340	1.340	3	0.607	0.607	11
ε_{MF}	0.000	0.008	0	0.000	0.007	0	0.009	0.009	1	0.008	0.008	3	0.009	0.009	3	0.008	0.008	11
ε_{LM}	0.270	0.270	1	0.228	0.228	10	0.408	0.408	1	0.590	0.590	3	0.423	0.423	3	0.663	0.663	11
ε_{ML}	0.120	0.120	1	0.118	0.118	10	0.246	0.246	1	0.208	0.208	3	0.241	0.241	3	0.201	0.201	11
									Second nesting level									
$\varepsilon_{EL,EL}$	0.000	0.002	0	0.000	0.002	0	0.000	0.032	0	0.000	0.030	0	0.000	0.032	0	0.000	0.017	0
$\varepsilon_{LFM,LFM}$	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0
$\varepsilon_{EL,LFM}$	0.000	-0.002	0	0.000	-0.002	0	0.000	-0.032	0	0.000	-0.030	0	0.000	-0.032	0	0.000	-0.017	0
$\varepsilon_{LFM,EL}$	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0
									First nesting level									
ε_{KK}	-0.411	-0.411	1	-0.400	-0.400	10	-0.270	-0.270	1	-0.256	-0.256	3	-0.292	-0.292	3	-0.262	-0.262	11
$\varepsilon_{LEM,LEM}$	-0.043	-0.043	1	-0.042	-0.042	10	-0.021	-0.021	1	-0.022	-0.022	3	-0.021	-0.021	3	-0.021	-0.021	11
$\varepsilon_{K,LEM}$	0.411	0.411	1	0.400	0.400	10	0.270	0.270	1	0.256	0.256	3	0.292	0.292	3	0.262	0.262	11
$\varepsilon_{LEM,K}$	0.043	0.043	1	0.042	0.042	10	0.021	0.021	1	0.022	0.022	3	0.021	0.021	3	0.021	0.021	11

continued Table 20

	Building/construction (13)			Telecomm. serv. (14)			Transports (15)			Credit and insurance (16)			Other market services (17)		
	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.
Third nesting level															
ε_{FF}	0.142	0.142	1	0.000	-0.067	0	0.000	-0.009	0	0.000	-0.188	0	0.000	-0.036	0
ε_{LL}	-0.378	-0.378	1	-0.358	-0.358	1	-0.731	-0.731	3	-0.490	-0.490	2	-1.707	-1.707	5
ε_{MM}	-0.263	-0.263	1	-0.782	-0.782	1	-0.420	-0.420	3	-0.510	-0.510	2	-0.307	-0.307	5
ε_{FL}	-0.631	-0.631	1	-1.355	-1.355	1	-0.189	-0.189	3	-3.811	-3.811	2	-0.725	-0.725	5
ε_{LF}	-0.020	-0.020	1	-0.018	-0.018	1	-0.036	-0.036	3	-0.024	-0.024	2	-0.084	-0.084	5
ε_{FM}	0.490	0.490	1	1.422	1.422	1	0.199	0.199	3	3.999	3.999	2	0.761	0.761	5
ε_{MF}	0.010	0.010	1	0.037	0.037	1	0.020	0.020	3	0.024	0.024	2	0.014	0.014	5
ε_{LM}	0.398	0.398	1	0.376	0.376	1	0.766	0.766	3	0.514	0.514	2	1.791	1.791	5
ε_{ML}	0.254	0.254	1	0.745	0.745	1	0.400	0.400	3	0.486	0.486	2	0.292	0.292	5
Second nesting level															
$\varepsilon_{EL,EL}$	0.000	0.279	0	-0.489	-0.489	1	-0.367	-0.367	3	-0.802	-0.802	2	-0.353	-0.353	5
$\varepsilon_{LFM,LFM}$	0.000	0.000	0	-0.006	-0.006	1	-0.006	-0.006	3	-0.006	-0.006	2	-0.006	-0.006	5
$\varepsilon_{EL,LFM}$	0.000	-0.279	0	0.489	0.489	1	0.367	0.367	3	0.802	0.802	2	0.353	0.353	5
$\varepsilon_{LFM,EL}$	0.000	0.000	0	0.006	0.006	1	0.006	0.006	3	0.006	0.006	2	0.006	0.006	5
First nesting level															
ε_{KK}	-0.429	-0.429	1	-0.267	-0.267	1	-0.592	-0.592	3	-0.836	-0.836	2	-2.391	-2.391	5
$\varepsilon_{LEM,LEM}$	-0.021	-0.021	1	-0.204	-0.204	1	-0.144	-0.144	3	-0.134	-0.134	2	-0.121	-0.121	5
$\varepsilon_{K,LEM}$	0.429	0.429	1	0.267	0.267	1	0.592	0.592	3	0.836	0.836	2	2.391	2.391	5
$\varepsilon_{LEM,K}$	0.021	0.021	1	0.204	0.204	1	0.144	0.144	3	0.134	0.134	2	0.121	0.121	5

*t-statistics at a 5% level. For a classification of GEM-E3 sectors see Table 17 in this Appendix.

Note: Local concavity restrictions are imposed on the *L-F-M* estimation model when estimating the service sectors and the energy-intensive manufacturing sectors aggregate. No concavity restrictions are imposed on the group of energy supply sectors since – as in the non-nested case – all computed own-price elasticities are negative for them. However, the group of nonenergy-intensive manufacturing sectors as well as the *LFM-EL* and *K-LEM* estimation models of all sectoral aggregates (first and second nesting levels) are not restricted to local concavity, even if significantly positive own-price elasticities are calculated for fossil fuel demand in several GEM-E3 sectors, such as electrical goods (9), transport equipment (10), other equipment goods (11), consumer goods (12), and building and construction (13). While insignificant price elasticities are obtained for nine sectors at the second nesting level (*LFM-EL*), the price elasticities at the first nesting level (*K-LEM*) are statistically significant without exception. Values I refer to elasticity aggregates that are obtained when sectoral elasticity values which are insignificant at a 5% level enter aggregation with zero, whereas values II are calculated as the weighted sum of all significant and insignificant sectoral price elasticity values. For four of 49 sectors the fitted cost shares of fossil fuels (at 1990 data) are negative, but only slightly below zero. These are the sectors (27), (32), (39), and (60) which all are characterised by very small cost shares of fossil fuels (below 0.5% in 1990, see Table 14 in Appendix I). In all other input components, however, the estimated translog cost function increases monotonously.

Table 21: Substitution elasticities in GEM-E3 sectors (Germany)

	Previously used estimates in GEM-E3 (standard version)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
$\sigma_{K,LEM}$	0.30	0.40	0.40	0.40	0.30	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.30	0.30	0.30
$\sigma_{EL,LFM}$	0.20	0.20	0.20	0.20	0.20	0.40	0.40	0.40	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
σ_{LFM}	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
σ_{M}	0.20	0.10	0.10	0.10	0.10	0.50	0.50	0.50	0.30	0.30	0.30	0.30	0.30	0.30	0.10	0.30	0.30	0.30
σ_{F}	0.60	0.10	0.10	0.10	0.90	0.90	0.90	0.90	0.60	0.60	0.60	0.60	0.60	0.60	0.40	0.60	0.60	0.60
	Econometric estimates																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
$\sigma_{K,LEM}$	0.16	0.55	1.96	0.67	0.34	0.45	0.45	0.44	0.29	0.28	0.31	0.28	0.45	0.47	0.74	0.97	2.51	-
$\sigma_{EL,LFM}$	0.10	0.12	0.38	3.82	0.08	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.50	0.37	0.81	0.36	-
σ_{LFM}	0.36	0.38	0.41	0.37	0.38	0.30	0.28	0.29	0.59	0.79	0.60	0.72	0.50	0.71	0.87	0.83	1.55	-
σ_{M}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
σ_{F}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: For a classification of GEM-E3 sectors see Table 17 in Appendix I. Econometric estimates are available only for $\sigma_{K,LEM}$, $\sigma_{EL,LFM}$, and σ_{LFM} in sectors (1)-(17) (see Table 11). In the simulations the previously used GEM-E3 values are retained in all cases where no econometric estimates are available. Estimated elasticity values of zero or negative values have been replaced by 0.1 in order to keep the CGE model solvable.

4 Employment double dividend and foreign trade

4.1 Introduction

The previous chapter emphasised that substitution patterns in production have an influence on the EDD outcome; numerical simulation results indicated that in the GEM-E3 single-country version for Germany the EDD hypothesis is accepted for a wide range of plausible substitution elasticity values.

A second important aspect in numerical open economy models is the specification of foreign trade patterns. In this chapter I study the effects of different foreign trade specifications on the EDD outcome. While substitution elasticities in production influence the size of tax shifting effects between production factors, foreign trade elasticities determine the size of terms-of-trade and tax shifting effects to the foreign sector.

The specification of the foreign trade system depends on whether a multi-country or a single-country model is considered.[117] Both model types differ with respect to the modelling of trade determinants and export and import behaviour. In multi-country models (or world models) production and demand are specified for all countries participating in trade. All regions covered are linked together by bilateral world trade matrices or trade pools. In single-country models the behaviour of the rest of the world (RoW) is modelled rather roughly. Typically, a ‘closure rule’ for trade with the external sector is incorporated that includes a crude specification of the RoW’s import demand and export supply functions and usually a balance-of-payments condition (cf. Shoven and Whalley 1992:81).

In order to scrutinise the role of different foreign trade specifications for the EDD outcome, I use the GEM-E3 EU-14 model version which includes 14 EU countries (EU-15 without Luxembourg) and the RoW (RoW covering all other industrialised regions and all developing countries). Each EU-14 country is modelled explicitly as a national applied general equilibrium model. The country models are linked through bilateral trade relations. GEM-E3 EU-14, however, is not a global model but shows elements of a single-country model with respect to the whole EU since the behaviour of the RoW is exogenous in large parts. World production and export prices are

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[117] Shoven and Whalley (1992) give an overview of various multi-country and single-country models.

fixed, i.e. foreign export supply is assumed to be perfectly price elastic. This assumption reflects price taking behaviour of the EU vis-à-vis RoW. But as price taking behaviour is accompanied by product differentiation on the import side, the EU-wide price level is not completely determined by the world market (and exchange rates). An exogenous rise in foreign export prices would affect the EU-wide price level only partially.

The assumption that the export prices of the RoW remain constant and are independent of the amount of imports demanded by the EU is rather restrictive. It should be taken into consideration that the EU-15's share in the entire world trade volume (measured on merchandise imports and imports of commercial services) is around 40%. Bearing in mind that the share of intra-EU regional trade flows in total EU merchandise imports is around 64%, the share of extra-EU imports in world merchandise imports is still around 19% (1995 figures, WTO 1996). It seems, thus, reasonable to relax the small-country assumption for the EU and to assume that trade activities of the EU affect world market prices.

A further important aspect in the GEM-E3 model is the modelling of interactions between macroeconomic developments in the EU and the foreign sector. Actually, the only feedback between both economies is considered by a price elastic foreign demand for EU exports. Optionally, for the long-term analysis an additional feedback mechanism can be introduced to the GEM-E3 model by a balance-of-payments constraint.

The objective of this chapter is to clarify the relationship between the foreign sector and the EU economy in the GEM-E3 EU-14 model and to test the sensitivity of the EDD outcome with respect to the foreign trade specification. The following Section 4.2 presents some convenient concepts of world closure which are discussed in the literature and are widely applied in numerical modelling. Section 4.3 deals with the specification of the foreign trade system incorporated in GEM-E3 EU-14. Several changes in the foreign trade system are then discussed in Section 4.4 and tested with respect to their influence on EDD outcomes. Sensitivity analyses are based on an ecological tax reform scenario that is slightly different to that used in Chapter 3: First, it assumes that EU-wide CO_2 emissions of households and firms are reduced by -10% by means of an EU-wide, co-ordinated CO_2 tax policy. A moderate CO_2 emissions reduction of –10% (instead of –20% in Chapter 3) is chosen, because this seems to be a more realistic target in the EU context.[118] Second, each EU country uses the revenue from the endogenous CO_2 tax in order to reduce the employers' social security contributions.

4.2 World closure rules and the Armington assumption of product heterogeneity

4.2.1 Approaches of a world closure in empirical models

Whalley and Yeung (1984) find that the closure rule chosen in a general equilibrium model may be of particular importance for simulation results[119] and thus for the EDD outcome of ecological tax reforms. The following survey clarifies that there is not only a single option how to specify the foreign sector in CGE models, but there are several ways of an external closure. The review indicates in particular that the foreign trade specification of the GEM-E3 model incorporates several elements of the different rules discussed below.

In the literature on applied trade models four basic external closure rules for single-country models (including the domestic country and the RoW) were proposed and assessed according to their appropriateness for empirical work. They mix small/big country assumptions for imports/exports with homogeneity/heterogeneity of traded goods and services and typically establish a balance-of-payments constraint.

The first three trade closure rules, which are explained below, are analysed in more detail in Whalley and Yeung (1984); the last one is discussed in de Melo and Robinson (1989) and Bhattarai et al. (1999).

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[118] Note that under the Kyoto Protocol (UNFCCC 1997) the EU has committed itself to a reduction of greenhouse gas emissions of –8% from 1990 until 2008-2012. As CO_2 will have to carry a slightly higher burden compared to the other five greenhouse gas emissions in the Kyoto basket, the assumption of a –10% CO_2 emissions reduction seems to be reasonable.

[119] Whalley and Yeung examine how results from policy simulations depend on the assumptions about international trade using a simple numerical example. The external sector specifications vary according to the elasticity of the foreign offer curve. They include as extremes the assumption of a large country and the assumption of a small, price taking country in which the country has only marginal influence over its terms of trade. By calculating the equilibrium effects of a distorting capital tax, Whalley and Yeung yield a substantial sensitivity of results in terms of welfare gains to the external sector specification. While the terms-of-trade loss offsets the gain from the removing tax in the case of the large country, the domestic gain is assumed to attain its highest value where the small country is concerned.

First external closure rule

The first approach presented in Whalley and Yeung (1984:127-130) is based on a very simple formulation with two homogeneous commodities which are both traded between the home country and the RoW.[120] Foreign import demand and foreign export supply functions are characterised by constant price elasticities:[121]

$$(4\text{-}1) \qquad IM_{row} = IM_{row,0} \cdot \left(\frac{p_{EX}}{e} \right)^{\varepsilon}, \quad -\infty < \varepsilon < 0 \qquad \text{(foreign import demand)}$$

$$(4\text{-}2) \qquad EX_{row} = EX_{row,0} \cdot (p_{EX_{row}})^{\gamma}, \quad 0 < \gamma < \infty \qquad \text{(foreign export supply)}$$

where IM_{row} and EX_{row} are imports demanded and exports supplied by RoW. $IM_{row,0}$ and $EX_{row,0}$ denote base year imports and exports of RoW. The variable p_{EX} represents the price obtained by the domestic country for exports to RoW (given in domestic currency), e denotes the exchange rate from domestic into foreign currency, and $\frac{p_{EX}}{e}$ is the world market price for exports from the domestic country to RoW. $p_{EX_{row}}$ expresses the world market price paid by the home country for foreign exports. ε and γ represent the own-price elasticities of foreign import demand and foreign export supply. The authors introduce a zero trade balance condition in order to close the system:

$$(4\text{-}3) \qquad (e \cdot p_{EX_{row}}) \cdot EX_{row} = p_{EX} \cdot IM_{row} \qquad \text{(balance-of-payments condition).}$$

In equilibrium, the value of RoW’s exports equals the value of its imports. This also implies equalisation of the value of the home country’s exports and imports.

As this closure rule is not very common in CGE modelling, I will not discuss its properties in more detail here. I would just like to mention one interesting feature of the equation system (4-1) to (4-3) which is, however, less relevant to multi-sectoral CGE models than to econometric models: Whalley and Yeung (1984:130) state that the proposed external closure rule “can be misleading both in creating an appearance of monetary non-neutralities, and in potentially leading to misspecification of intended elasticity values”. They demonstrate particularly that the trade balance

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[120] Actually, this closure rule is rather atypical of CGE models which normally have a higher sectoral disaggregation and include traded as well as non-traded goods.

[121] In the following equations, notation has been brought into line with the nomenclature used in the GEM-E3 model. Variables without indices refer to the domestic country.

constraint establishes an analytical interrelation between the trade elasticities ε and γ, which should be considered in econometric estimations of ε and γ.[122]

Second external closure rule

The second closure rule discussed here also relies on a two-goods formulation but is closer to reality and shows a higher field of application. It differs from the first rule primarily in two aspects:

- The assumption of homogeneous goods is given up and, following the Armington assumption, product differentiation on the import side is introduced. The advantages and implications of the Armington concept are explained in Section 4.2.2 in more detail.
- The domestic economy is faced with fixed world market prices for imports (price taking behaviour for imports). This implies that RoW supplies any amount of goods that is demanded by the home country at fixed world market prices.

Whalley and Yeung (1984:131-134) formalised this second external closure rule. Their specification of the domestic import demand function, however, deviates from the Armington concept but is – for reasons of simplicity – characterised by a constant own price elasticity.[123] Like in the first rule, foreign import demand is a downward sloping function with a constant own price elasticity, ε, that is less than infinite. Domestic export prices are not determined by the world market but are given as cost-covering prices from zero profit conditions of the model, i.e. export prices are determined domestically and are converted into foreign currency by using the exchange rate. Again, a zero trade balance equation completes the system. The system is described by the following five equations:

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[122] In CGE modelling the econometric problem of identification and misspecification of foreign trade elasticity parameters is less important since elasticity values are normally not estimated econometrically but are ‘best guess’ estimates (cf. Section 4.4.3). Moreover, the degree of sectoral disaggregation is typically high – the GEM-E3 model for example includes 18 commodities. This implies that any change in one market will be cushioned by reactions in the other markets so as to satisfy the balance-of-payments constraint. In multi-sector models the interdependence of trade elasticities will be less significant than in the two-goods model framework. In addition, the interdependence is relaxed if – like in the GEM-E3 model – the balance-of-payments constraint can be eliminated.

[123] Usually, import demand functions in CGE models do not have a constant price elasticity but are specified, for example, as CES functions. Whalley and Yeung (1984), who choose a constant price elasticity formulation, note that their results remain unchanged, even if an Armington CES specification is used.

(4-4) $IM_{row} = IM_{row,0} \cdot \left(\frac{p_{EX}}{e} \right)^{\varepsilon}, \quad -\infty < \varepsilon < 0$ (foreign import demand)

(4-5) $IM = EX^S_{row} = IM^D$ (equilibrium condition)

(4-6) $IM^D = IM_0 \cdot (e \cdot p_{EX_{row}})^{\eta}, \quad -\infty < \eta < 0$ (domestic import demand)

(4-7) $p_{EX_{row}} = \overline{p_{EX\ row}}$ (foreign export supply)

(4-8) $(e \cdot p_{EX_{row}}) \cdot IM = p_{EX} \cdot IM_{row}$ (balance-of-payments condition).

$IM_{row,0}$ and IM_0 are base year imports of RoW and the home country, IM^D denotes the domestic import demand, while EX^S_{row} represents export supply of RoW. $p_{EX_{row}}$, which is fixed at $\overline{p_{EX\ row}}$, denotes the price of RoW's exports in foreign currency; $(e \cdot p_{EX_{row}})$ is the domestic price for imports from RoW. (p_{EX} / e) is the price of exports of the home country (resulting from zero profit conditions) in foreign currency. The parameters ε and η represent the foreign and the domestic import demand price elasticities. In equilibrium, the balance-of-payments condition is satisfied, and the price vectors p_{EX} and $p_{EX_{row}}$ guarantee that excess demands equal zero.

A comment should be made on this second external closure rule. Similar to the first rule, equation (4-8) establishes an interdependence of both trade elasticities, ε and η, which should be considered in econometric estimations. Whalley and Yeung (1984:132-133) show that the equation system (4-4) to (4-8) does not define a well-behaved foreign offer curve but a locus of external sector equilibria. Consequently, the foreign and domestic offer curves do not intersect but lie one on top of each other – a feature which is contradictory to neo-classical trade theory.

Third external closure rule

The third closure rule proposed by Whalley and Yeung (1984:134-136) is characterised by

- the inclusion of tradable and non-tradable goods,
- price taking behaviour for all tradable goods, and
- the assumption of product homogeneity among countries (no Armington assumption for tradable goods).

Further properties of the third rule are that

- domestic prices for non-tradable goods are determined endogenously in such a way that demand-supply equalities hold for each non-traded good,
- relative domestic prices for tradables are the same as relative world market prices,
- the exchange rate is determined endogenously in such a way that the zero trade balance is satisfied.

According to Whalley and Yeung (1984:135) the foreign offer curve in a two-goods case is a straight line with a slope given by the world market prices of traded goods, whereas the domestic offer curve incorporates some degree of elasticity. Equilibrium quantities of tradables can thus be determined by the point of intersection of both curves. The main disadvantage of this rule refers to the small-country assumption; i.e. this rule is inappropriate for large countries such as the EU-14. In addition, due to missing product heterogeneity, it cannot account for empirically observable intra-industry trade flows. Moreover, de Melo and Robinson (1989:49) argue that the assumption of price taking behaviour and product homogeneity for all tradable goods may cause extreme unrealistic specialisation effects if, for example, a tax policy is simulated.

Fourth external closure rule

The fourth closure rule which is widely used in numerical modelling is discussed in de Melo and Robinson (1989) and Bhattarai et al. (1999). It is characterised by the following features:

- symmetric product differentiation on both the import and export side: a CES function for domestic aggregate import demand (Armington assumption) and a CET (constant elasticity of transformation) function for the domestic export transformation function are introduced,
- the small-country assumption, i.e. the domestic country can sell or purchase any amount of imports and exports at fixed world market prices, and
- the assumption of a zero balance of trade.

De Melo and Robinson demonstrate that this specification is theoretically well-behaved. As was the case in the third rule, the balance-of-trade condition defines the foreign offer curve as a straight 45° line (choosing units so that world market prices for exports and imports equal one), while the domestic offer curve is well-behaved with an elasticity depending on both elasticity of substitution and transformation. Hence the problem of identical offer curves arising from the second rule is avoided.

In contrast to the third rule, the domestic price level is not fully determined by world market prices (despite the small-country assumption) due to the Armington assumption. In a recent study, however, Bhattarai et al. (1999) identify some possible risks of this fourth closure rule. The authors demonstrate that under specific elasticity constellations perverse offer curves may arise even in the case of the two-sided Armington product differentiation structure (exports falling as imports rise with increasing ratio of export prices to import prices).

In summary, all models described above introduce a fixed trade balance for the external sector with a flexible exchange rate variable that clears the foreign exchange market. Alternatively, the exchange rate can be fixed, while the trade balance is allowed to adjust in order to retain equilibrium on the foreign exchange market. As Francois and Shiells (1994:32) note, ideally in general equilibrium models the current and capital accounts and the exchange rate would be determined endogenously. However, this more complex approach is not widely used in CGE models. A third alternative – which is chosen for the (real) standard version of the GEM-E3 model without a money market – is a fixed exchange rate system that is combined with a fixed or a variable current account. In the first case, the long-term real interest rate and national prices adjust to satisfy the trade balance equilibrium (see Section 4.3.4); in the second case, the long-term real interest rate is fixed.

As will be shown in Section 4.3, the trade relations between the EU-14 and the RoW in the GEM-E3 model integrate elements of the last three external closure rules.

4.2.2 The Armington assumption

CGE trade models differ widely in the specification of import demand. While imports and competing domestic goods are treated as perfect substitutes in some models according to the Heckscher-Ohlin model (e.g. in the first and third closure rule discussed in the previous section), the Armington assumption of national or of firm level product differentiation is employed in other models.[124] Models differ also with respect to the functional forms used. Some apply nested or non-nested CES functional forms, while others employ flexible functional forms, such as the almost ideal demand system (AIDS). Armington (1969) and most CGE modellers gave

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[124] In the GREEN model, for example, the Armington specification is implemented for all import goods apart from crude oil for which homogeneity across countries of origin is assumed. This is due to relatively low transportation costs, e.g. compared to natural gas or coal (cf. Burniaux et al. 1992).

preference to CES functions as these require relatively less estimation effort and as regularity conditions (global concavity) are satisfied. On the other hand, the AIDS avoids some of the restrictions imposed by the CES by giving up constancy and pairwise equality of substitution elasticities (see Francois and Shiells 1994, Shiells and Reinert 1993).

However, the majority of empirically based CGE models have introduced the Armington assumption of national product differentiation on the import side, frequently using CES functions with two levels of nesting (cf. Lächler 1985:74, Shiells and Reinert 1993:300).[125] The nested specification includes an upper-level function that specifies a country's demand for the composite of imports (aggregated over all countries) relative to domestic substitutes (see equation (4-10) in Section 4.3.1). The lower-level function defines allocation of imports on competing foreign sources, i.e. countries (see equation (4-12) in Section 4.3.1).

The upper-level Armington elasticity measures the sensitivity of a country's or industry's competitive position in international trade and controls the degree to which the country's price system is ruled by foreign prices. The higher the sectoral upper-level elasticity is, the higher the degree of demand responsiveness to relative prices. Ultimately, the Armington assumption gives small-country models more reality, since it provides a certain degree of autonomy in the domestic price system while preserving all the features of standard neo-classical models (cf. de Melo and Robinson 1989:56).

In practice, the wide use of the Armington assumption is motivated by two further advantages. First, it addresses the phenomenon of intra-industry trade flows which is increasingly observable in the international trade data. Instead of increasing specialisation countries simultaneously increase exports and imports of goods that are classified in the same commodity category, even if an industry is highly disaggregated. This phenomenon of cross-hauling can be explained, for example, by qualitative differences between domestic and foreign goods or transportation costs. A second reason for the popularity of the Armington assumption is that difficulties,

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[125] Some CGE models, for example the Deardorff and Stern model, assume a single level CES function, where domestic production competes with an aggregate of imports (Deardorff and Stern 1981). Other CGE models, for example the models of Cox and Harris (1992), Sobarzo (1992), and Roland-Holst et al. (1992), have adopted the non-nested specification in order to describe national product differentiation. In this case the two-tiered utility function is fitted together into one level by assuming that utility is a function of domestic output and imports from each separate source (Shiells and Reinert 1993:301,303).

such as unrealistically extreme specialisation effects due to homogeneous products and linear production possibility frontiers, can be avoided (see Shoven and Whalley 1992:230, de Melo and Robinson 1989:49).

Among economists and econometricians, however, scepticism of the Armington concept has arisen. Some argue that the empirical relevance of cross-hauling mainly depends on the level of data disaggregation. Thus the main goal is to determine which aggregation level is appropriate for the concept of an industry (cf. Lächler 1985:75). Additionally, some authors describe the Armington approach as a “simple, restricted and ad hoc (but effective) means of capturing the rigidities apparent in observed trade flows patterns” (Abbott 1988:67). Similarly, Norman (1990:726) argues that: “Typically, the Armington approach is used within perfectly competitive models; and must be regarded as a purely ad hoc means of describing intra-industry trade flows and reducing the sensitivity of trade flows to changes in relative prices – essentially, it is an attempt to capture supply-side imperfections through modification of the model demand side“. In their general equilibrium model Trela and Whalley (1994:263) also refrain from using the Armington assumption and treat products as homogeneous referring to the “strong and often artificial terms-of-trade effects“ that the Armington assumption induces in numerical results.

Nevertheless, as long as heterogeneous products are not modelled explicitly, the Armington assumption is a useful approximation to reality. This is why I maintain it in the GEM-E3 model for the import side.

4.3 Specification of foreign trade in GEM-E3 EU-14

Table 22 illustrates the characteristics of the foreign trade system of the GEM-E3 EU-14 model.

International prices that clear domestic and foreign product markets are not completely determined by the model but are partly exogenous. World import demand depends exclusively on international terms of trade and does not include any variable measuring the RoW’s economic performance, e.g. in terms of world income.

Section 4.3.1 and 4.3.2 describe the EU countries’ and the RoW’s export and import supply and demand functions that are incorporated in GEM-E3. Section 4.3.3 deals with the specification of Armington elasticity parameters. The ‘closure’ of the external sector system through the balance-of-payments constraint is explained in Section 4.3.4.

Table 22: Characteristics of the foreign trade specification in GEM-E3 EU-14

	Import demand	*Export supply*
EU-14	- finite price elastic - depends on international price relations and EU economic performance (e.g. income) - Armington assumption	- finite price elastic - export prices given by cost-covering domestic production prices
RoW	- finite price elastic - depends on international price relations - Armington assumption	- perfectly price elastic - exogenous

4.3.1 Foreign trade system: EU countries

Import demand

The specification of the import demand of each EU country for tradable commodities is based on the Armington model of national product differentiation which is combined with the two stage nested CES specification.[126] It is assumed that the allocation of expenditure for tradable goods takes place in two stages. At the upper level of substitution, expenditure is allocated between domestic demand of domestically produced goods and an aggregate of imported goods from all sources. At the lower level, the expenditure for the import composite is allocated by origin, i.e. imports are distinguished by place of production (other EU countries and RoW).[127]

The import function for EU country c is derived at the first level of substitution. The price for domestic supply, p_{Y_c}, in country c is given as a CES aggregate of the import price, p_{IM_c}, and of the price of domestically demanded and produced goods, p_{XD_c}:

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[126] The specification of the import demand for tradable goods takes into account that a fixed share of sectoral imports is non-competitive, i.e. it is not determined by relative prices according to the Armington substitution elasticity. In the actual GEM-E3 model version, this share is uniformly set to 0.5 for all countries and sectors. Non-competitive imports reflect these amounts of goods which cannot be substituted by domestic production. Demand of non-competitive imports is therefore price inelastic and depends on the domestic production level. The import demand for non-tradable goods is specified in close analogy to the demand of non-competitive imports (see Appendix II-A).

[127] In order to keep the notation as simple as possible, the sector specific indices are not explicitly noted in the following equations.

$$(4\text{-}9)\quad p_{Y_c} = (\delta_{IMC\,c} \cdot p_{IM_c}{}^{1-\sigma_{Y\,c}} + \delta_{XD_c} \cdot p_{XD_c}{}^{1-\sigma_{Y\,c}})^{\frac{1}{1-\sigma_{Y\,c}}},\ \forall c,\ c = 1,\ldots,14.$$

Applying Shephard's lemma to the unit cost function yields the demand function for competitive imports of EU country *c*:

$$(4\text{-}10)\quad IMC_c = Y_c \cdot \delta_{IMC\,c} \cdot \left(\frac{p_{Y\,c}}{p_{IM\,c}}\right)^{\sigma_{Y_c}}\ \forall c,\quad c = 1,\ldots,14\,.$$

IMC_c are competitive imports and Y_c is domestic supply in country *c*. The share parameters δ_{IMC_c} and δ_{XD_c} are calibrated to the benchmark data. σ_{Y_c} denotes the elasticity of substitution between domestic and foreign goods (upper-level Armington elasticity) which is assumed to be equal across countries in the GEM-E3 model ($\sigma_{Y_c} = \sigma_Y\ \forall c,\ c = 1,\ldots,14$). Imports and domestic production are complements for $\sigma_Y \to 0$, while they are perfect substitutes for $\sigma_Y \to \infty$. The latter case corresponds to the Heckscher-Ohlin model.

At the second level of substitution, import demand for each good is distinguished by place of production. Hence the aggregate import demand must be allocated to the 14 EU-member countries and to RoW. An import unit cost function in the CES functional form is expressed by

$$(4\text{-}11)\quad p_{IM\,c} = \left[\sum_{k=1}^{14,row} \delta_{IMP\,c,k} \cdot \left(p_{IMP\,c,k}\right)^{1-\sigma_{IM_c}}\right]^{\frac{1}{1-\sigma_{IM_c}}}\ \forall c,\quad c = 1,\ldots,14$$

where $p_{IMP\,c,k}$ represents the price of imports in country *c* for goods produced in country *k*. Since there are import taxes and duties, $t_{c,k}^{dut}$, it follows that $p_{IMP\,c,k} = p_{EX\,k} \cdot e_{c,k} \cdot (1 + t_{c,k}^{dut})$; $p_{EX\,k}$ is the price in currency of country *k* for exports (no price differentiation between destinations), and $e_{c,k}$ denotes the nominal exchange rate in the currency of country *c* per unit of currency of country *k*. The nominal exchange rates $e_{c,k}$ are fixed and are used exclusively to convert currencies. $\delta_{IMP\,c,k}$ represent share parameters which are specified by calibration. σ_{IM_c} denotes the lower-level elasticity of substitution between imports from different EU countries and RoW. Since σ_{IM_c} is assumed to be equal for all EU countries, we have $\sigma_{IM_c} = \sigma_{IM}\ \forall c,\ c = 1,\ldots,14.$

A cost-minimising composition of the import aggregate with respect to countries of origin is given by the following equation:

(4-12) $$IMP_{c,k} = IM_c \cdot \delta_{IMP\,c,k} \cdot \left(\frac{p_{IM\,c}}{p_{IMP\,c,k}} \right)^{\sigma_{IM}} \quad \forall c,k, \quad c = 1,\ldots 14; \quad k = 1,\ldots,14, row,$$

where $IMP_{c,k}$ denotes the imports of country c coming from country k in country c's currency. IM_c comprises competitive and non-competitive imports of country c.

The demand function of the EU as a whole for imported goods from RoW is the aggregate of all imports from non-EU countries demanded by EU countries, i.e.

(4-13) $$IM_{EU,row} = \sum_{c=1}^{14} \frac{IMP_{c,row}}{e_c}.$$

As e_c denotes the price of currency of country c in ECU, $IM_{EU,row}$ is expressed in ECU.

Demand for exports

Each EU country k is faced with a downward sloping export demand curve for all commodities. The demand for the exports of country k is the sum of the corresponding import demands across all other EU countries and RoW. Exports enter the product market equilibrium condition:

(4-14) $$EX_k = \sum_{c=1}^{14,row} IMP_{c,k} \cdot e_{k,c} \;\; \forall k, k = 1,\ldots,14.$$

Export supply

The EU-14 version of the GEM-E3 model is characterised by asymmetric product differentiation: Product differentiation is introduced for the import side by means of the Armington assumption on the first and second level, but not for the export side. Domestically produced goods sold on the domestic market are perfect substitutes for goods that are sold on EU and RoW export markets.[128] Furthermore, no assumption is made about a differentiation of exports by export markets. Exports enter a trade pool and are distributed according to the demands of import countries. A country's sectoral export price is thus not differentiated by importing countries.

Domestic producers of country c supply exports at the price $p_{EX\,c}$:

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[128] This contrasts with other CGE models and earlier versions of GEM-E3 (see Conrad and Schmidt 1999). The latter and, for example, the model of de Melo and Robinson (1989) specify the transformation possibilities between domestic market productions and export market productions by applying a CET (constant elasticity of transformation) function.

(4-15) $p_{EX\,c} = p_{x_c} \cdot (1 + t_{sub,c}) \forall c, \quad c = 1, \ldots, 14$

where p_{x_c} is the price of domestically produced goods, and $t_{sub,c}$ denotes the rate of export subsidies that is calibrated. p_{x_c} is determined for each EU country by the internal costs and the zero profit condition.

4.3.2 Foreign trade system: RoW

As previously mentioned, RoW's production and consumption behaviour is exogenous. Assuming a fixed price of domestically produced goods, i.e. an infinite domestic supply elasticity, RoW supplies exports at fixed export prices. Strictly speaking, with regard to RoW's exports the EU-14 is a price taker on world markets; it does not influence RoW's export prices with its own import demand behaviour.

Import demand

Basically, the RoW's import demand function is modelled in complete analogy to the EU countries' import demand functions. In contrast to this, however, all imports (and not only the competitive part of tradables) are covered by the Armington specification. In addition, it is assumed that sectoral upper-level elasticities are identical to sectoral lower-level elasticities, i.e. $\sigma_{Y_{row}} = \sigma_{IM_{row}} = \sigma_{row}$.

Taking into account that $p_{IMP\,row,k} = p_{EX\,k} \cdot e_{row,k}$ and considering that world market prices $p_{XD\,row}$ and world domestic demand for domestic goods XD_{row} are exogenous, RoW's demand for imports from EU country *k* can be expressed by:

(4-16) $IMP_{row,k} = \alpha_k \cdot \left(\frac{p_{XD\,row}}{p_{EX\,k} \cdot e_{row,k}} \right)^{\sigma_{row}} \quad \forall k, k = 1, \ldots, 14$

where $\alpha_k = \delta_{IMP_{row,k}} \cdot \frac{\delta_{IM\,row}}{\delta_{XD_{row}}} \cdot XD_{row}$ (calibrated) and $p_{XD\,row}$ denotes the price for domestically demanded and produced goods in RoW. Since $p_{XD\,row}$ is exogenous RoW's demand for imports from different EU countries depends only on EU country specific export prices. RoW's demand for imports from the EU-14 as a whole is:

(4-17) $IM_{row} = \sum_{c=1}^{14} IMP_{row,c}$.

Demand for exports

As is the case for every EU country, RoW is faced with a negatively sloped demand function for its exports:

(4-18) $EX_{row} = \sum_{c=1}^{14} IMP_{c,row} \cdot e_{row,c}$.

Since RoW's export prices are fixed, demand of EU countries for RoW's exports exclusively depends on the price of the import aggregate (and on the level of aggregated imports).

Export supply

The export supply of RoW is perfectly price elastic. Any amount of goods will be supplied at export prices which are fixed in foreign exchange terms:

(4-19) $p_{EX\,row} = \overline{p_{EX\,row}}$.

4.3.3 Specification of Armington elasticities

Table 23 contains upper- and lower-level Armington elasticity values that are used in EU and RoW import demand for tradable goods in the GEM-E3 standard version.[129] Elasticities differ among sectors, but values for each sector are identical across EU countries.

The upper-level elasticity values of each EU country are greater than 1 for sectors with a relatively high degree of international competition, such as the energy-intensive or consumer goods industry, while values of service sectors are set below 1.[130] Note that lower-level elasticity values are set higher than upper-level elasticities. As Shiells and Reinert (1993) – with reference to Brown (1987) – note, the two-level nested Armington approach may imply large terms-of-trade effects that rise with increasing upper-level elasticities relative to the lower-level elasticities.

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[129] Non-tradable sectors in EU countries are the sectors (2), (4), (5), (13), and (18).

[130] The sector liquid fuels (3) is characterised by an upper-level elasticity value below unity, even if this sector is characterised by a relatively homogeneous output good and thus by relatively high competitive pressure. This choice can be explained primarily on the basis of modelling techniques.

Thus lower-level elasticities often attain higher values than upper-level elasticities in empirical trade models in order to avoid large terms-of-trade effects.[131]

The last column of Table 23 presents values of substitution elasticities that are used in RoW's import demand. Lower-level elasticity values are set equal to upper-level elasticity values. With regard to relative sectoral degrees of substitutability RoW's elasticities are specified as being nearly comparable to EU elasticities.

Table 23: Armington elasticity values in GEM-E3 EU-14

	EU-14		*RoW*
GEM-E3 Sector	σ_Y	σ_{IM}	σ_{row}
Agriculture (1)	1.2	1.6	1.4
Solid fuels (2)	-	-	0.6
Liquid fuels (3)	0.6	0.8	0.6
Natural gas (4)	-	-	0.6
Electricity (5)	-	-	0.6
Ferrous and non-ferrous metals (6)	1.5	2.4	2.2
Chemical industry (7)	1.5	2.4	2.2
Other energy-intensive ind. (8)	1.5	2.4	2.2
Electrical goods (9)	1.5	2.4	2.2
Transport equipment (10)	1.5	2.4	2.2
Other equipment goods (11)	1.5	2.4	2.2
Consumer goods (12)	1.7	2.8	2.5
Building and construction (13)	-	-	1.4
Telecommunication services (14)	0.6	1.6	1.4
Transports (15)	1.2	2.4	2.2
Credit and insurance (16)	0.6	1.6	1.4
Other market services (17)	0.6	1.6	1.4
Non-market services (18)	-	-	0.6

4.3.4 Balance-of-payments equation

The GEM-E3 EU-14 model can be solved either with a binding or a non-binding balance-of-payments constraint for each of the EU countries or for the EU as a whole. As nominal exchange rates are fixed, the feedback of a surplus or deficit on the performance of the EU economy when the constraint is binding is established through the real long-term interest rate.

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[131] In his seven region model Whalley (1985:109) uses, for example, upper-level elasticity values that are based on literature values of import price elasticities. The lower-level elasticity values are set for all sectors and regions on a common value of 1.5 that roughly approximates literature estimates of export price elasticities.

In the real standard version of the GEM-E3 model, where asset markets and international capital flows are missing, the balance of payments is reduced to the current account. The current account surplus (deficit) of EU country *c* for all traded or non-traded goods *s* is defined as the difference between the value of aggregate exports and the value of aggregate imports. TS_c in (4-20) denotes the trade balance of country *c* for a given level of exchange rates (aggregating TS_c over all EU countries *c*, *c*=1,…,14, leads to the current account of EU-14 vis-à-vis RoW):

$$\text{(4-20)} \quad TS_c = \sum_{s=1}^{18} p_{EX\,s,c} \cdot EX_{s,c} - \sum_{k=1}^{14,row} \sum_{s=1}^{18} p_{IMP\,s,c,k} \cdot IMP_{s,c,k}$$
$$\forall c, s, \quad c = 1,...,14, row; \; s = 1,...,18.$$

In the case of a free variation of the EU current account, the aggregate net EU trade surplus (deficit) is balanced by a corresponding net currency inflow (outflow). However, these currency flows affect neither EU equilibrium prices nor quantities. The market of foreign currency may be unbalanced. Strictly speaking, the model allows long-lasting external deficits for the EU without considering any feedback on the domestic economy.

In the case of a binding balance-of-payments constraint, the EU trade surplus (deficit) in terms of percentage of GDP is fixed at the value of the reference run. In this case, a feedback of a surplus or deficit on the EU economy is considered in GEM-E3. As exchange rates are fixed, adjustment mechanisms run through the real long-term interest rate. An EU current account increase compared to the reference run (which is computed in the case of a flexible current account but not depicted in Table 24) is balanced through a decrease of real long-term interest rates in the EU countries.[132] This drop reduces long-term capital costs and savings and stimulates capital and investment demand as well as private consumption. On the demand side of the economy, the decrease of the real interest rates thus pushes up EU domestic prices. On the supply side, the increase in investment raises the stock of real capital. Short-term interest rates that clear markets for real capital will fall, provided that the demand effect is no longer sufficient to offset the supply effect. Domestic prices rise just enough to maintain product market equilibrium. When holding foreign prices at a constant level, a rise in EU prices increases EU imports and diminishes EU exports

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[132] In all simulations of this chapter the current account per GDP of EU-14 rises in response to the tax reform, but the increase is less than 0.1 percentage points compared to the value in the reference run.

and therefore reduces the surplus; the terms of trade improve. Table 24 shows that employment rises less if a balance-of-payments restriction is imposed.

Note that more or less similar adjustment processes can be observed in a model that includes a monetary sector. A surplus of the balance of payments would also be eliminated by a decrease in the EU interest rate. Effects on the product markets, however, would be smaller as the capital account provides an additional mechanism of adjustment. If EU interest rates decrease, EU citizens will shift their portfolios towards foreign assets. Thus the equilibrium net capital outflow increases, which in turn reduces the balance-of-payments surplus additionally. Since a growing trade surplus would be cushioned by a revaluation of exchange rates, a model with flexible exchange rates would offer a third adjustment process.

Simulations of an ecological tax reform scenario with the GEM-E3 EU-14 model reveal that results differ between both cases, the case of a variable and the case of a fixed current account (see Table 24).

The ecological tax reform scenario applied in the following prescribes an EU-wide reduction of aggregate CO_2 emissions by –10%. In each of the 14 EU-countries I implement an endogenous tax (with a uniform tax rate) that is levied on CO_2 emissions of households and industries. Tax revenue neutrality is guaranteed, since employers' social security contributions are reduced to keep the public deficit constant. This scenario, which is also applied in the following simulations of this chapter, is called *Scenario* EU_TAX10.

Simulation results of the standard version with a non-binding current account will be analysed in detail in the next section. Therefore, at this point I will just mention the main differences between the constrained and unconstrained specification. In the unconstrained version, the ecological tax reform produces both a current account surplus and higher positive employment effects. In the constrained model version, the feedback mechanism described above leads to comparably higher EU prices and these lead, in turn, to a greater fall in exports and a lower drop in imports.

While a long-term analysis should consider the feedback mechanism introduced by the balance-of-payments constraint, a flexible current account seems to be more reasonable in the short or medium term. Nevertheless, it is worthwhile to notice that the assumption about the flexibility in the current account does not alter the results in principle. The ecological tax reform defined by *Scenario* EU_TAX10 generates an EDD in both a flexible case and a fixed current account case.

Table 24: *Scenario* EU_TAX10: macroeconomic aggregates for EU-14, variable current account and fixed current account (numbers indicate percent changes from baseline except if defined otherwise)

Macroeconomic aggregates for EU-14	Variable current account	Fixed current account
Gross domestic product	-0.04	-0.09
Employment	0.58	0.51
Production	-0.57	-0.63
Domestic demand	-0.56	-0.52
Private investment	-0.18	-0.16
Private consumption	0.21	0.40
Exports	-1.02	-1.81
Imports	-1.46	-1.05
EU-intra trade	-1.20	-1.68
Terms of trade	1.03	1.84
Consumers' price index	1.19	1.71
GDP deflator in factor prices	-0.74	-0.16
*CO_2 tax rate (ECU'85)***	22.0	22.3
*CO_2 tax revenue**	1.49	1.50
Energy consumption in volume	-6.21	-6.22
CO_2 emissions	-10.00	-10.00
*Equivalent variation (economic welfare) **	0.23	0.37

* in % of GDP, absolute difference from baseline
** in value figures

4.4 Sensitivity of GEM-E3 model results to foreign trade specifications

In this section sensitivity analyses are performed with respect to alternative foreign trade specifications. Three approaches are tested:

- An additional price equation for exports from RoW to EU is introduced. Instead of fixed world market prices for exports, the EU is now faced with a finite price elastic export supply function (Section 4.4.1).
- The introduction of a link between the activity levels of domestic (EU) and foreign (RoW) economies changes the foreign import demand function (Section 4.4.2).
- Variations in the degree of substitution between goods entering the sectoral aggregate import demand functions of both EU countries and RoW are analysed (Section 4.4.3).

The sensitivity analyses are based on the *Scenario* EU_TAX10 defined in the previous section. As mainly short- and medium-term aspects are considered, the balance of payments is kept variable. Policy induced impacts are calculated for all variations in the foreign trade specification suggested above. The sensitivity of results is analysed by comparing the results with those produced by the (unchanged) standard version of the GEM-E3 EU-14 model. For reasons of clarity, the discussion of results concentrates on selected EU-14 macroeconomic aggregates and sectoral trade flows.

4.4.1 Changes in RoW's export supply

4.4.1.1 Specification of RoW's export supply

In this section the assumption of a perfectly price elastic export supply function of the RoW is given up. A foreign export supply function with a constant own-price elasticity is introduced instead for each sector (sectoral indices are omitted):

$$\text{(4-21)} \quad EX_{row} = EX_{row,0} \cdot \left(p_{EX\,row}\right)^{\gamma},\ 0 < \gamma < \infty$$

where $EX_{row,0}$ denotes exports of the base year. γ is the RoW's export supply elasticity. An increase in the sectoral export price by 1% would increase the supply of exports by γ %. Solving (4-21) for $p_{EX\,row}$ yields:

$$\text{(4-22)} \quad p_{EX\,row} = \left(\frac{EX_{row}}{EX_{row,0}}\right)^{\frac{1}{\gamma}},\ 0 < \gamma < \infty .$$

In the following, (4-22) is introduced as an additional price equation for all sectors in the GEM-E3 EU-14 standard model version. Prices of exports from RoW are no longer fixed; instead they increase with the amount of RoW's exports, or, because of (4-18), with the amount of EU-14 imports, respectively. The new specification may lead to some changes in simulation results, particularly if the policy induced impact on EU imports is substantial.

The new specification is tested for three alternative parameter values of γ (see Table 25). For reasons of simplicity, γ is not differentiated among sectors.

Table 25: Values of parameter γ

GEM-E3 Sector	*Case 0:* Standard version of GEM-E3	*Case 1:* Halved values	*Case 2:* Central values	*Case 3:* Doubled values
1 - 18	∞	0.5	1	2

Econometric estimates indicate that the own-price elasticity of export supply is below unity. Diewert and Morrison (1989:207), for example, find that the own price elasticity of export supply for the U.S. economy is nearly constant between 0.32 and 0.375 over the sample period 1967-1982. Hence *Case* 1 with $\gamma = 0.5$ seems to be the closest to reality and might be interpreted as an upper limit value.

4.4.1.2 Simulation results

The following simulations of an EU-wide ecological tax reform include the cases of a perfectly elastic export supply function (reflecting the standard version of GEM-E3 EU-14) and of an imperfectly elastic export supply function (as specified in the previous section). The results are reported in Table 26 in terms of selected macroeconomic aggregates for EU-14 and in Table 27 in terms of sectoral extra-EU imports and exports.

The results indicate that the EU-14 as a whole would gain from more flexible export prices in terms of economic welfare. The lower the own-price elasticity of foreign export supply, the more the ecological tax reform raises EU-wide economic welfare. While in the GEM-E3 EU-14 standard version with fixed export prices the welfare effect of the ecological tax reform is around 0.23% of GDP, it rises to 0.32% in *Case* 3, to 0.42% in *Case* 2 and, finally, to 0.62% in *Case* 1. The percentage increase in employment is also the highest in *Case* 1, where RoW’s export prices are the most flexible.

Overall, the GDP, production, private investment, private consumption, extra-EU imports, and energy consumption increase with a declining own-price elasticity of export supply. For example, the GDP drops in the standard version ($\gamma \to \infty$) by -0.04% and in *Case* 3 ($\gamma = 2$) by –0.01% but rises in *Case* 2 ($\gamma = 1$) by 0.01% and in *Case* 1 ($\gamma = 0.5$) by 0.05%.

The impacts on exports are opposite to those described above. Exports run parallel to the magnitude of the own-price elasticity of export supply. The reduction rate of exports is the highest (i.e. the export level is the lowest) in *Case* 1 (–2.64%) and the lowest in the standard version (–1.02%). The volume of intra-trade in the EU reacts in the same way. Intra-EU trade, defined as intra-EU exports, decreases the most in *Case* 1 and the least in the standard version.

All in all, the degree of sensitivity of the results to a variation of the RoW's export supply elasticity values is significant, even if an EDD is gained in every case. How can this be explained? To this end I will take a closer look at what happens in the standard version of the GEM-E3 EU-14 model when the ecological tax reform is implemented.

First of all, the EU-wide introduction of a CO_2 tax leads to an increase in production costs, particularly in energy-intensive sectors which produce above-average CO_2 emissions. Secondly, labour costs are reduced due to the cut of the rate of employers' contributions to social security. Hence substitution processes from energy-intensive capital and energy to labour are launched, i.e. demand for labour increases, this, in turn, forces real consumer wages in all EU countries to rise. As Table 29 demonstrates, the country specific rises in the real net wage lie within a range of 0.29% to 1.48%, while real non-labour income (i.e. real capital income) declines in all EU countries. The latter reflects tax shifting effects towards capital. In response to increasing real wage rates and lower non-wage income, households are willing to supply more labour. As a result, EU-wide aggregate employment increases by 0.58%. On the other hand, substitution processes between inputs and losses in production are responsible for a –6.21% drop in energy consumption. The increase in real disposable income stimulates consumption demand, which, in turn, pushes up the consumption price index by 1.19%.

The picture is not as glossy for costs. The EU-wide costs pressure results in a decline of exports by –1.02%. Import demand decreases as well by –1.46%. This is due to the fact that the price induced substitution effect from domestic to foreign products is not high enough to compensate for the negative effect caused by a reduced production. Table 27, however, shows that sectoral patterns differ. In particular positive growth rates are observed for exports of fossil fuels which are exempted from taxation. The decrease in domestic consumption lowers prices and enhances the competitiveness of fossil fuels.

If RoW's export prices are specified according to (4-22), the model's reactions change as follows:

As was the case in the standard version, the ecological tax reform leads to an increase in production costs. Measured in terms of GDP deflator the overall price level is higher than in the standard case in which world export prices are constant. Obviously, European producers are able to evade cost pressures more easily by changing demand patterns and switching to foreign supply in the standard case. Table 28 indicates that RoW's export prices rise for almost all sectors with exception of the energy sectors 2 to 4 in all cases and sectors 5 and 9 in *Case* 3. Particularly, foreign suppliers of carbon-intensive fossil fuels suffer big income losses since both EU import demand and world market prices drop in response to the EU-wide CO_2 tax policy. The size of impact on world market prices increases with the declining own-price elasticity of export supply, γ.

EU-wide imports develop the exact opposite: Extra-EU imports are higher in the case of flexible world market prices than in the standard version and even take positive growth rates in *Case* 1, where sectoral export prices of RoW are the highest. According to the Armington assumption underlying the specification of EU import demand, higher RoW export prices depress import demand, however, on the other hand, higher domestic prices and higher domestic demand stimulate the demand for imported goods from RoW. Obviously, the latter effects dominate. Note that the new specification leads to an increase in the terms of trade, which is the highest in *Case* 2 with 2.46% and the less in *Case* 3 with 1.94%. *Case* 1 lies in the middle with 2.27%.

As already mentioned, the new specification leads to a greater fall in EU-14 exports. This is due to an additional increase in EU production costs which is caused by higher prices for RoW's exports. Producers in the EU now have less possibilities to cushion the tax induced EU-wide price increase.

As Table 26 shows, positive employment effects are stronger in the case of flexible RoW's export prices. This can be easily understood by taking into account that particularly energy-intensive goods, for which domestic prices rise considerably, will be substituted to an increasing extent by imported goods from RoW or by input factors with relatively lower prices, such as labour. As higher world market prices restrict cost-effective possibilities of a switch to foreign products, the switch to labour is reinforced. As labour demand rises sharply, real wage rates are pushed up to a greater extent as well (see Table 29). Thus labour supply and employment increase. Rising income stimulates consumption of private households, which, in turn, reduces the negative impact on production. Note that in all cases the positive effect on consumption outweighs the loss in leisure; hence welfare increases.

Table 26: *Scenario* EU_TAX10: macroeconomic aggregates for EU-14, finite price elastic foreign export supply (numbers indicate percent changes from baseline except if defined otherwise)

Macroeconomic aggregates for EU-14				
	Case 0: Standard version of GEM-E3	*Case 1:* Halved values (γ=0.5)	*Case 2:* Central values (γ=1)	*Case 3:* Doubled values (γ=2)
Gross domestic product	-0.04	0.05	0.01	-0.01
Employment	0.58	0.82	0.70	0.64
Production	-0.57	-0.50	-0.54	-0.56
Domestic demand	-0.56	-0.26	-0.41	-0.49
Private investment	-0.18	-0.01	-0.09	-0.13
Private consumption	0.21	1.03	0.61	0.41
Exports	-1.02	-2.64	-1.81	-1.41
Imports	-1.46	0.04	-0.74	-1.11
EU-intra trade	-1.20	-2.20	-1.71	-1.47
Terms of trade	1.03	2.27	2.46	1.94
Consumers' price index	1.19	6.51	3.02	1.92
GDP deflator in factor prices	-0.74	4.50	1.05	-0.04
*CO_2 tax rate (ECU'85)***	22.0	29.8	26.0	24.10
*CO_2 tax revenue**	1.49	1.91	1.72	1.62
Energy consumption in volume	-6.21	-5.80	-6.01	-6.12
CO_2 emissions	-10.00	-10.00	-10.00	-10.00
*Equivalent variation (economic welfare) **	0.23	0.62	0.42	0.32

* in % of GDP, absolute difference from baseline

** in value figures

Table 27: *Scenario* EU_TAX10: extra-EU imports and extra-EU exports, finite price elastic foreign export supply (numbers indicate percent changes from baseline)

	Extra-EU imports (EU-14)				*Extra-EU exports (EU-14)*			
GEM-E3 Sector	*Case 0:* Standard version of GEM-E3	*Case 1:* Halved values (γ=0.5)	*Case 2:* Central values (γ=1)	*Case 3:* Doubled values (γ=2)	*Case 0:* Standard version of GEM-E3	*Case 1:* Halved values (γ=0.5)	*Case 2:* Central values (γ=1)	*Case 3:* Doubled values (γ=2)
Agriculture (1)	0.60	1.81	1.14	0.85	-1.09	-2.57	-1.76	-1.40
Solid fuels (2)	-25.86	-20.30	-22.63	-24.09	2.97	-21.62	-11.22	-4.78
Liquid fuels (3)	-4.37	-2.69	-3.54	-3.96	1.52	-0.34	0.58	1.04
Natural gas (4)	-4.03	-2.98	-3.58	-3.83	2.45	-2.53	0.06	1.29
Electricity (5)	-0.39	0.83	0.18	-0.11	-2.51	-4.71	-3.55	-3.02
Ferrous and non-ferrous metals (6)	2.53	2.52	2.11	2.12	-6.68	-7.12	-6.34	-6.24
Chemical industry (7)	1.49	2.11	1.55	1.40	-2.72	-3.30	-2.67	-2.53
Other energy-intensive ind. (8)	0.79	2.13	1.39	1.06	-1.48	-2.85	-2.10	-1.76
Electrical goods (9)	-0.72	1.44	0.48	-0.06	0.22	-3.10	-1.71	-0.88
Transport equipment (10)	0.05	2.15	1.26	0.76	-0.32	-1.85	-1.27	-0.91
Other equipment goods (11)	-0.47	1.68	0.77	0.25	-0.01	-2.73	-1.59	-0.94
Consumer goods (12)	0.77	2.09	1.37	1.05	-1.00	-2.51	-1.68	-1.31
Building and construction (13)	-0.08	0.98	0.39	0.14	-0.35	-4.30	-2.09	-1.15
Telecommunication services (14)	0.11	1.84	1.00	0.58	0.11	-1.83	-0.90	-0.43
Transports (15)	1.00	1.97	1.32	1.08	-2.05	-3.11	-2.38	-2.12
Credit and insurance (16)	-0.58	1.82	0.85	0.27	0.29	-1.31	-0.72	-0.34
Other market services (17)	0.53	2.34	1.49	1.06	-0.47	-1.87	-1.23	-0.89
Non-market services (18)	0.24	1.38	0.73	0.46	-0.06	-1.25	-0.56	-0.28
All sectors	-1.46	0.04	-0.74	-1.11	-1.02	-2.64	-1.81	-1.41

Table 28: *Scenario* EU_TAX10: sectoral export prices of RoW, finite price elastic foreign export supply (numbers indicate percent changes from baseline)

Sectoral export prices of RoW				
GEM-E3 Sector	*Case 0:* Standard version of GEM-E3	*Case 1:* Halved values (γ=0.5)	*Case 2:* Central values (γ=1)	*Case 3:* Doubled values (γ=2)
Agriculture (1)	0.00	3.64	1.14	0.43
Solid fuels (2)	0.00	-36.48	-22.63	-12.87
Liquid fuels (3)	0.00	-5.30	-3.54	-2.00
Natural gas (4)	0.00	-5.87	-3.58	-1.93
Electricity (5)	0.00	1.67	0.18	-0.05
Ferrous and non-ferrous metals (6)	0.00	5.10	2.11	1.05
Chemical industry (7)	0.00	4.25	1.55	0.70
Other energy-intensive ind. (8)	0.00	4.31	1.39	0.53
Electrical goods (9)	0.00	2.89	0.48	-0.03
Transport equipment (10)	0.00	4.36	1.26	0.38
Other equipment goods (11)	0.00	3.40	0.77	0.12
Consumer goods (12)	0.00	4.23	1.37	0.53
Building and construction (13)	0.00	1.98	0.39	0.07
Telecommunication services (14)	0.00	3.72	1.00	0.29
Transports (15)	0.00	3.99	1.32	0.54
Credit and insurance (16)	0.00	3.66	0.85	0.14
Other market services (17)	0.00	4.73	1.49	0.53
Non-market services (18)	0.00	2.78	0.73	0.23

Table 29: *Scenario* EU_TAX10: real consumer wage and real non-wage income, finite price elastic foreign export supply (numbers indicate percent changes from baseline)

	Real consumer wage				*Real non-wage income*			
	Case 0: Standard version of GEM-E3	*Case 1:* Halved values (γ=0.5)	*Case 2:* Central values (γ=1)	*Case 3:* Doubled values (γ=2)	*Case 0:* Standard version of GEM-E3	*Case 1:* Halved values (γ=0.5)	*Case 2:* Central values (γ=1)	*Case 3:* Doubled values (γ=2)
Austria	1.05	2.73	1.93	1.51	-0.70	0.49	-0.19	-0.45
Belgium	1.48	3.32	2.43	1.98	-0.30	0.37	0.03	-0.13
Germany	0.99	2.25	1.59	1.28	-0.68	-0.29	-0.51	-0.60
Denmark	1.15	2.96	2.15	1.69	-0.52	0.70	0.01	-0.28
Finland	0.83	1.83	1.30	1.06	-0.78	-0.07	-0.52	-0.67
France	0.67	1.88	1.29	0.99	-0.53	-0.04	-0.29	-0.41
Greece	0.29	0.94	0.67	0.50	-1.20	-1.86	-1.40	-1.27
Ireland	0.71	2.36	1.57	1.15	-0.39	1.33	0.29	-0.09
Italy	0.52	1.88	1.19	0.85	-0.73	-0.18	-0.47	-0.61
Netherlands	0.82	1.94	1.36	1.09	-0.33	0.01	-0.18	-0.25
Portugal	0.51	0.99	0.80	0.67	-0.90	-1.10	-0.96	-0.92
Spain	1.17	2.62	1.91	1.55	-0.99	-0.30	-0.65	-0.81
Sweden	0.99	2.48	1.72	1.35	-0.31	0.58	0.05	-0.15
Un. Kingdom	1.14	1.94	1.53	1.33	-1.45	-1.87	-1.68	-1.57

4.4.2 Changes in RoW's import demand

4.4.2.1 Specification of RoW's import demand

In the standard version of the GEM-E3 EU-14 model neither production and consumption nor domestic supply in RoW is endogenous. The domestic demand for domestically produced goods that enter RoW's import demand function is given as well. Hence no linkage to the economy's activity level (i.e. no income effects) is considered in RoW's import demand specification. In contrast to the EU import demand specification, import demand of RoW exclusively depends on relative prices (terms of trade).

The idea behind the specification presented below is to introduce an additional endogenous variable in the foreign import demand function that measures the economic performance of RoW. Since in the GEM-E3 EU-14 standard version production of RoW is fixed, RoW's exports are used as 'activity variable' entering import demand. However, as RoW's actual exports are completely determined by import demand of EU-14, RoW's import demand is no longer influenced exclusively by EU country specific export prices, but also by the amount of imports demanded by EU-14.

The proposed specification represents a rough attempt to provide RoW's import demand function with more flexibility and empirical evidence by taking into account economic interactions between the EU and RoW. If in reality, for instance, the economy of EU-14 expands and income rises, EU imports will also rise because part of the additional income will be spent for additional imports. This implies a rise in the RoW's exports. Up to this point, the interactions have been covered by the standard model version. In addition to this, however, an actual increase in RoW's exports would result in an increase in RoW's income and therefore in an increase in RoW's import demand as well. This feedback mechanism which is ignored in the standard model version has been included in the new specification presented in the following.

The specification of the RoW's demand for domestically produced and demanded goods, XD_{row}, will be changed by relating RoW's production to RoW's exports. First of all, I will assume that production in RoW, x_{row}, is a function of RoW's exports, EX_{row}:

(4-23) $x_{row} = \beta \cdot (EX_{row})^{\varphi}$.

φ may be interpreted as the elasticity of RoW's production with respect to RoW's exports; it measures the degree of linkage between the EU and foreign economies. It is assumed that the share of RoW's exports in RoW's production, θ, is fixed, as is the share of domestically sold and domestically produced goods in domestic production, $(1-\theta)$. Substituting (4-23) in (4-16) on the basis of this assumption leads to (4-24):

$$\text{(4-24)}\quad IMP_{row,k} = (EX_{row})^{\varphi} \cdot \alpha_k \cdot \left(\frac{p_{XD\,row}}{p_{EX\,k} \cdot e_{row,k}} \right)^{\sigma_{row}} \quad \forall k, k = 1,\ldots,14,$$

where $\alpha_k = (1-\theta) \cdot \beta \cdot \delta_{IMP\,row,k} \cdot \dfrac{\delta_{IM\,row}}{\delta_{XD\,row}}$ is calibrated to the observed benchmark data.

In order to specify φ, (4-23) is used as a regression equation with RoW's exports as the explanatory (exogenous) variable and RoW's production as the dependent (endogenous) variable. The regression coefficients β and φ are estimated by the least-squares method. The empirical data base is constituted by time series of RoW's exports and production indices (see Table 42 in Appendix II-B). There is a lack of data concerning production data of the GEM-E3 sectors agriculture (1), building and construction (13), telecommunication services (14), transports (15), credit and insurance (16), other market services (17), and non-market services (18).

The elasticity φ is estimated for energy-intensive goods industries (sectors 6, 7, 8) ($\hat{\varphi} = 0.47$), equipment goods industries (sectors 9, 10, 11) ($\hat{\varphi} = 0.57$) and consumer goods industries (sector 12) ($\hat{\varphi} = 0.25$). The elasticity values of the remaining sectors are calculated as a linear average of these three estimates ($\overline{\varphi} = 0.43$).

Table 30: Sectoral values of parameter φ

GEM-E3 Sector	*Case 0:* Standard version of GEM-E3	*Case 1:* Halved values	*Case 2:* Central values	*Case 3:* Doubled values
1 - 5, 13 - 18	0	0.22	0.43	0.86
6 - 8	0	0.24	0.47	0.94
9 - 11	0	0.29	0.57	1.14
12	0	0.13	0.25	0.50

The sectoral estimates of φ are used as central values in the sensitivity analyses below; they are halved and doubled (*Case* 1, *Case* 2, and *Case* 3 in Table 30). *Case* 0 represents the standard version of the GEM-E3 EU-14 model, in which φ is set equal to zero for all sectors.

4.4.2.2 Simulation results

Simulation results of the *Scenario* EU-TAX10 are reported in Table 31 for macroeconomic aggregates and in Table 32 for sectoral trade flows. The introduction of a linkage between production and exports has only slight impacts on the model results. The impacts are the greatest in *Case* 3, where the feedback parameter, φ, attains the highest values.

No changes can be observed with respect to the GDP. The percentage reduction rate of –0.04% remains the same in all cases. In *Case* 3, the fall in imports (-1.24%) and the GDP deflator in factor prices (–0.38%) is slightly cushioned. EU-wide economic welfare is not much affected by a variation of φ. However, economic welfare as percentage of the GDP increases in *Case* 3 by 0.25%, compared to the reference scenario. Compared to the standard version, economic welfare rises by 0.02 percentage points, or by 10% respectively.

These differences in results can be explained as follows. In Section 4.4.1.2 I argued that the ecological tax reform brings about a rise in production costs and in consumer prices for domestically produced goods. As a result, domestic demand and exports are reduced. This reduction is responsible for a decrease in the overall production level in EU-14 together with the decline in exports. Thus the quantity of imports demanded, or the quantity of RoW’s exports respectively, are reduced as well, since the substitution effect from domestic to foreign goods is not large enough to compensate the negative income effect in EU-14. According to the new import demand specification, production in RoW decreases if RoW’s exports are reduced, and thus RoW’s imports, or EU-14 exports respectively, go down, too.

Ultimately, aggregate exports of EU-14 are forced back further if RoW’s import demand is modelled in a way that it depends on RoW’s exports. According to Table 31 exports fall by –1.02% only in the standard case, while in *Case* 1 to 3 they are reduced by –1.04%, or –1.05% respectively.

To summarise, in the modified model version a reduction of EU-14 imports has a negative effect on imports of RoW (all other variables being held constant). This negative effect grows with φ, i.e. with the degree of linkage between RoW’s exports and imports.

However, in contrast to its impact on aggregate exports, the new specification softens the fall of aggregate imports. While imports are reduced by –1.46% in the standard case, they show a slightly smaller decrease in *Case* 2 and 3. In particular, imports only fall by –1.24% in *Case* 3. As Table 32 indicates, this pattern is also evident for the development of sectoral imports (apart from a few exceptions, e.g. solid fuels and liquid fuels). The increased import level (with growing values of φ) can be explained with the rise of the terms of trade and higher domestic demand. The consumer price index changes by 1.19% in *Case* 0 and goes up by 1.22% in *Case* 1, to 1.27% in *Case* 2, and to 1.55% in *Case* 3. This increase is explained by declining EU-14 exports due to the setting of φ. As prices of exported goods include (to a certain degree) tax payments which have been paid by European producers, the tax burden share that can be shifted indirectly abroad declines with decreasing exports. Consequently, if exports go down, European consumers themselves must bear a greater part of the CO_2 tax burden.

Employment rises slightly with increasing φ values from 0.58% in *Case* 0 to 0.60% in *Case* 3. As production falls in all cases by nearly the same percentage rate, the increase in employment must be explained mainly by a higher substitution effect from energy and energy-intensive products to labour.

All in all, the impact of the changed import demand specification is very low. Certainly, impacts will be stronger if higher values for φ are chosen. But the strength of the feedback between EU imports and RoW imports should not be overestimated. While the specification must be interpreted with reservations, there is not enough evidence to support it for higher φ values.

Table 31: *Scenario* EU_TAX10: macroeconomic aggregates for EU-14, changed RoW's import demand (numbers indicate percent changes from baseline except if defined otherwise)

Macroeconomic aggregates for EU-14				
	Case 0: Standard version of GEM-E3	*Case 1:* Halved values	*Case 2:* Central values	*Case 3:* Doubled values
Gross domestic product	-0.04	-0.04	-0.04	-0.04
Employment	0.58	0.58	0.58	0.60
Production	-0.57	-0.58	-0.57	-0.58
Domestic demand	-0.56	-0.56	-0.55	-0.54
Private investment	-0.18	-0.17	-0.17	-0.15
Private consumption	0.21	0.21	0.21	0.26
Exports	-1.02	-1.04	-1.05	-1.05
Imports	-1.46	-1.46	-1.44	-1.24
EU-intra trade	-1.20	-1.23	-1.27	-1.36
Terms of trade	1.03	1.05	1.06	1.06
Consumers' price index	1.19	1.22	1.27	1.55
GDP deflator in factor prices	-0.74	-0.71	-0.67	-0.38
*CO_2 tax rate (ECU'85)***	22.0	22.1	22.2	22.6
*CO_2 tax revenue**	1.49	1.50	1.50	1.52
Energy consumption in volume	-6.21	-6.24	-6.27	-6.31
CO_2 emissions	-10.00	-10.00	-10.00	-10.00
*Equivalent variation (economic welfare) **	0.23	0.23	0.23	0.25

* in % of GDP, absolute difference from baseline
** in value figures

Table 32: *Scenario* EU_TAX10: extra-EU imports and extra-EU exports, changed RoW's import demand (numbers indicate percent changes from baseline)

	Extra-EU imports (EU-14)				*Extra-EU exports (EU-14)*			
GEM-E3 Sector	*Case 0:* Standard version of GEM-E3	*Case 1:* Halved values	*Case 2:* Central values	*Case 3:* Doubled values	*Case 0:* Standard version of GEM-E3	*Case 1:* Halved values	*Case 2:* Central values	*Case 3:* Doubled values
Agriculture (1)	0.60	0.62	0.66	0.83	-1.09	-1.00	-0.90	-0.73
Solid fuels (2)	-25.86	-25.95	-26.05	-26.27	2.97	-3.39	-9.42	-20.62
Liquid fuels (3)	-4.37	-4.48	-4.59	-4.79	1.52	0.67	-0.21	-2.10
Natural gas (4)	-4.03	-4.03	-4.03	-4.01	2.45	1.57	0.69	-1.12
Electricity (5)	-0.39	-0.38	-0.36	-0.25	-2.51	-2.61	-2.71	-2.96
Ferrous and non-ferrous metals (6)	2.53	2.65	2.80	3.38	-6.68	-6.21	-5.70	-4.59
Chemical industry (7)	1.49	1.61	1.76	2.40	-2.72	-2.44	-2.13	-1.35
Other energy-intensive ind. (8)	0.79	0.86	0.96	1.53	-1.48	-1.35	-1.21	-0.86
Electrical goods (9)	-0.72	-0.74	-0.74	-0.50	0.22	-0.01	-0.26	-0.84
Transport equipment (10)	0.05	0.11	0.21	0.88	-0.32	-0.34	-0.35	-0.10
Other equipment goods (11)	-0.47	-0.47	-0.43	-0.01	-0.01	-0.18	-0.36	-0.64
Consumer goods (12)	0.77	0.82	0.89	1.28	-1.00	-0.96	-0.94	-1.06
Building and construction (13)	-0.08	-0.07	-0.06	0.04	-0.35	-0.40	-0.47	-0.79
Telecommunication services (14)	0.11	0.13	0.17	0.47	0.11	0.12	0.12	0.07
Transports (15)	1.00	1.09	1.22	1.88	-2.05	-1.90	-1.73	-1.32
Credit and insurance (16)	-0.58	-0.57	-0.53	-0.11	0.29	0.19	0.08	-0.10
Other market services (17)	0.53	0.59	0.67	1.17	-0.47	-0.39	-0.30	-0.06
Non-market services (18)	0.24	0.24	0.26	0.38	-0.06	-0.01	0.04	0.12
All sectors	-1.46	-1.46	-1.44	-1.24	-1.02	-1.04	-1.05	-1.05

4.4.3 Variation of Armington elasticity values

Armington elasticities may represent a key parameter in CGE models as they affect substitution possibilities between imported and domestically produced goods and the own-price elasticity of import demand. One would assume in particular that they influence the strength of terms-of-trade effects and, along with production and consumption effects, the policy induced impact on welfare (see Whalley 1985:110).

The choice of elasticity values is thus a critical issue in CGE modelling. While share parameters are calibrated to the base year’s observed data set in the GEM-E3 model, the values of sector and country specific substitution elasticities need to be specified from the outside of the model. Direct econometric estimates of substitution elasticities in foreign trade, especially at the required sectoral aggregation level, are rarely available in literature. Thus CGE models often rely on ‘best guess’ estimates. Frequently, values are derived indirectly from estimates of import price elasticities for which substantial and disaggregated data exist in the empirical trade literature (see Fehr et al. 1995:157, Shoven and Whalley 1984:1042, Deardorff and Stern 1981, Shiells et al. 1986).[133] Literature, however, offers a wide range of substitution and import price elasticity values. Differences in results can be mainly explained by different import demand specifications and varying estimation methods (cf. Kohli 1982, Thursby and Thursby 1988). Hence sensitivity analysis on the degree of substitution is a common procedure to gain insights into the robustness of results and the model’s reactions to alternative parameter values.

Section 4.4.3.1 provides a short literature survey on econometric estimates of Armington elasticities. In Section 4.4.3.2 and Section 4.4.3.3 I calculate sets of country and sector specific Armington elasticity values. These values are compared with the elasticity values actually used in the standard version of the GEM-E3 EU-14 model. Finally, I test the sensitivity of model results to alternative elasticity values.

4.4.3.1 Literature survey of empirical studies

Despite the popularity of the Armington concept, only few studies on direct econometric estimates of substitution elasticities have been published. Elasticities of upper-level substitution between imported and domestic goods are estimated, for example, by Shiells et al. (1986) and Reinert and Roland-Holst (1992). Further

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[133] The compendium of estimates of trade elasticities provided by Stern et al. (1976) is still widely used.

examples are the studies of Shiells and Reinert (1993), who estimate lower-level elasticities and non-nested elasticities, and of Sobarzo (1994) and Roland-Holst et al. (1994). The estimated values from the literature are difficult to compare since the sectoral aggregation levels differ considerably according to the statistical data base used.

A study for Germany is provided by Lächler (1985). Lächler estimates disaggregated substitution elasticities between demand for imports and domestic substitutes in Germany. He finds that it is precisely the primary goods industry consisting of relatively homogeneous and easily replaceable goods and facing fierce international competition that has the highest elasticity ranking. Apart from two exceptions, elasticity values range from 0.23 to 2.25. In contrast, technological rigidities restrict the substitutability in the case of the investment goods sector and particularly in the case of capital goods in the short run; thus, elasticity values are rather low and range between –2.28 to 1.21. Finally, the sectors that are classified as belonging to the consumption goods industry differ with respect to the degree of international competitive pressure. This is reflected in wide differences in measured substitution elasticities (–0.70 to 1.09).

Likewise, Reinert and Roland-Holst (1992) present substitution elasticities between imported and domestic goods for 163 U.S. mining and manufacturing sectors. Their estimation is based on U.S. trade time series data of both prices of domestic and imported goods, and real values of domestic sales of domestic goods and imports. In about two-thirds of the cases, Reinert and Roland-Holst obtain positive and statistically significant estimates ranging from 0.14 to 3.49. Their results allow the conclusion that (at the particular level of aggregation chosen) imports and U.S. domestic products are far from being perfect substitutes.

Furthermore, Shiells et al. (1986) published estimates of own-price elasticities of import demand for 122 3-digit SIC U.S. industries (covering mainly mining and manufacturing sectors) that serve, in turn, as a basis for inferring upper-level Armington substitution elasticities. The estimations are based on annual data over the period 1962-1978. In 48 cases, positive and statistically significant substitution elasticities are obtained that lie in a range from 0.45 for SIC 208 (‘beverages’) to 32.13 for SIC 373 (‘yachts’).

Shiells and Reinert (1993) estimate both lower-level nested and non-nested substitution elasticities among U.S. imports (from Mexico, Canada, RoW) and competing domestic production for 22 mining and manufacturing sectors.

Estimations are based on quarterly data for 1980-88. In the non-nested specification, U.S. imports from Mexico, Canada, and RoW as well as domestic substitutes enter a single CES function. The estimates of the non-nested substitution elasticities range from 0.10 (sector 'primary lead, zinc, and non-ferrous metals') to 1.49 (sector 'primary aluminium'). The nested specification is composed of an upper-level CES aggregation function for U.S. imports as a whole and a lower-level CES aggregate function for the various import sources, i.e. lower-level substitution elasticities are present in U.S. imports from Mexico, Canada, and RoW. Estimates range from 0.04 (sector 'clay, ceramic, and non-metallic minerals') to 2.97 (sector 'iron, and ferroalloy ores mining').

A comparison of estimates for non-nested, lower-level and upper-level elasticities for selected sectors taken from Shiells and Reinert (1993) and Reinert and Roland-Holst (1992) show that values differ. While the non-nested estimates lie mainly above the upper-level estimates, they are lower than the lower-level estimates in half of the cases and higher than these in the other half of the cases. Lower-level elasticities are not generally higher than upper-level elasticities; only in about two thirds of the sectoral cases do they exceed the upper-level values. However, the range of positive values (0.04-2.97) is larger in the case of lower-level estimates than in the case of the non-nested specification (0.1-1.49) and in the case of upper-level estimates (0.02-1.22).

All in all, the sectoral values used in the GEM-E3 model are close to the typical values found in literature. In most cases, the estimates arise from U.S. data, whereas there are no estimates available for EU countries in literature. In the following two sections, literature based values are thus broken down to the country and sector specific aggregation scheme used in the GEM-E3 model. This breakdown is based on values presented in Shiells et al. (1986).

4.4.3.2 Variation of Armington elasticities: RoW

4.4.3.2.1 Specification of Armington elasticities

There are four variations of upper-level substitution elasticities taken into consideration in Table 33 that are used for subsequent sensitivity analyses. The first column contains the values of the standard version of the GEM-E3 model (*Case* 0) on which sensitivity analyses are performed. In *Case* 1, all sectoral elasticity values are halved from those used in the standard model. In *Case* 2, values are doubled. The fourth and the fifth columns depict 'best guess' estimates (*Case* 3) as well as econometric estimates (*Case* 4), both taken from the Shiells et al. study (1986). As this study is based on the three-digit ISIC classification, the values are aggregated according to the GEM-E3 18-sector scheme using 1988 RoW's import shares as weights. U.S. literature based estimates are taken as crude proxy for the RoW's behaviour. Unfortunately, the data base provided by Shiells et al. is not sufficient to calculate elasticity values for all GEM-E3 sectors. Since no elasticity values are available for sectors 1, 3, 4, and sectors 13 to 18, the corresponding sectoral values from the standard specification (*Case* 0) are used.

Table 33: Sectoral values of upper-level Armington elasticities in RoW's import demand

	Case 0:	*Case 1:*	*Case 2:*	*Case 3:*	*Case 4:*
GEM-E3 Sector	Standard version of GEM-E3	Halved values	Doubled values	U.S. 'best guess' estimates *	U.S. econometric estimates **
Agriculture (1)	1.40	0.70	2.80	1.40	1.40
Solid fuels (2)	0.60	0.30	1.20	2.36	7.12
Liquid fuels (3)	0.60	0.30	1.20	2.36	-0.34
Natural gas (4)	0.60	0.30	1.20	0.60	0.60
Electricity (5)	0.60	0.30	1.20	0.60	0.60
Ferrous and non-ferrous metals (6)	2.20	1.10	4.40	1.44	2.44
Chemical industry (7)	2.20	1.10	4.40	2.61	9.40
Other energy-intensive ind. (8)	2.20	1.10	4.40	2.91	1.78
Electrical goods (9)	2.20	1.10	4.40	2.11	7.46
Transport equipment (10)	2.20	1.10	4.40	3.59	2.01
Other equipment goods (11)	2.20	1.10	4.40	1.07	3.20
Consumer goods (12)	2.50	1.25	5.00	2.07	2.65
Building and construction (13)	1.40	0.70	2.80	1.40	1.40
Telecommunication services (14)	1.40	0.70	2.80	1.40	1.40
Transports (15)	2.20	1.10	4.40	2.20	2.20
Credit and insurance (16)	1.40	0.70	2.80	1.40	1.40
Other market services (17)	1.40	0.70	2.80	1.40	1.40
Non-market services (18)	0.60	0.30	1.20	0.60	0.60

*Based on 'best guess' U.S. estimates constructed by Shiells et al. (1986), weighted by 1988 import shares of RoW. **Based on U.S. econometric estimates of sector specific substitution elasticities provided by Shiells et al. (1986), weighted by 1988 import shares of RoW.

4.4.3.2.2 Simulation results

Table 34 shows the simulation results of the *Scenario* EU-TAX10 in terms of macroeconomic aggregates for the various cases defined in Table 33. Table 35 depicts the results in terms of sectoral imports and exports.

The variations in elasticity values have some impact on the results, but, seen as a whole, the percentage change of quantities, related to the standard case, lies within a range of ±0.5 percentage points. Nor is the sensitivity of economic welfare and employment to alternative parameter values very high. With declining Armington elasticity values in foreign import demand, i.e. lessening foreign sector reactions to increasing production prices in the EU economy, the EU obviously gains more and more from the ecological tax reform policy in terms of economic welfare. In other words, lower Armington elasticities in the RoW import demand function offer greater possibilities of shifting the tax burden abroad.

In the following, I discuss the basic mechanisms that are triggered by a variation of the degree of substitutability in RoW's import demand.

In *Case* 1, where values of the sectoral upper-level Armington elasticities are halved, RoW shows weaker reactions to an increase in EU export prices. Although in the standard case exports fall by –1.02%, they are reduced by only –0.92% in the case of halved elasticity values. This reflects the lower degree of substitutability between domestic and foreign production in RoW's import demand. Exports, however, develop in different ways at a sectoral level (Table 35). While exports are reduced less compared to the standard case for some sectors, they show a higher reduction rate, or diminished growth rates, respectively (fossil fuel sectors), for some other branches (e.g. electrical goods, equipment and consumer goods industries, transports and both service sectors). The increase in world demand for EU exports in *Case* 1 compared to *Case* 0 is the main reason for a comparatively lower drop in the GDP deflator. Prices for domestic production and consumption are higher in *Case* 1 than in the standard case, since both domestic and foreign demand are higher as well. The slowing down of the price decrease in EU-14 in *Case* 1 results in a relatively higher import demand. As exports, investment, and consumption settle down (all at a higher level in *Case* 1 than in *Case* 0), production and GDP both rise (–0.56% reduction of production in *Case* 1 instead of –0.57% in *Case* 0, –0.03% reduction of GDP instead of –0.04%). Thus energy consumption decreases also with a lower rate (–6.18% compared to –6.21%), and employment rises EU-wide by an additional 0.02 percentage point.

Table 34: *Scenario* EU_TAX10: macroeconomic aggregates for EU-14, variation of upper-level Armington elasticities in RoW's import demand (numbers indicate percent changes from baseline except if defined otherwise)

Macroeconomic aggregates for EU-14					
	Case 0: Standard version of GEM-E3	*Case 1:* Halved values	*Case 2:* Doubled values	*Case 3:* U.S. 'best guess' estimates	*Case 4:* U.S. econometric estimates
Gross domestic product	-0.04	-0.03	-0.05	-0.04	-0.04
Employment	0.58	0.60	0.56	0.57	0.59
Production	-0.57	-0.56	-0.59	0.57	0.58
Domestic demand	-0.56	-0.52	-0.58	-0.55	-0.58
Private investment	-0.18	-0.15	-0.20	-0.18	-0.19
Private consumption	0.21	0.29	0.15	0.22	0.16
Exports	-1.02	-0.92	-1.08	-0.98	-1.12
Imports	-1.46	-0.99	-1.73	-1.33	-1.80
EU-intra trade	-1.20	-1.26	-1.17	-1.20	-1.21
Terms of trade	1.03	0.93	1.09	0.99	1.13
Consumers' price index	1.19	1.65	0.93	1.27	0.95
GDP deflator in factor prices	-0.74	-0.27	-0.98	-0.63	-1.01
*CO_2 tax rate (ECU'85)***	22.0	22.5	21.5	21.9	22.00
*CO_2 tax revenue**	1.49	1.52	1.46	1.48	1.49
Energy consumption in volume	-6.21	-6.18	-6.23	-6.21	-6.26
CO_2 emissions	-10.00	-10.00	-10.00	-10.00	-10.00
*Equivalent variation (economic welfare) **	0.23	0.27	0.20	0.24	0.19

* in % of GDP, absolute difference from baseline
** in value figures

Mechanisms change direction if doubled upper-level elasticity values are introduced (*Case* 2). The RoW's reactions to an increase in relative prices are now stronger than in the standard case. Consequently, EU exports go down more sharply (by –1.08%). Due to diminished foreign demand, both EU prices (expressed by the GDP deflator) and imports fall to a greater extent. Overall, the GDP and production drop further.

While the results in *Case* 3 lie, like *Case* 0, somewhere between the two extremes – i.e. the halved and the doubled value cases – *Case* 4 causes greater impacts on exports and imports. *Case* 4 is characterised by very high elasticity values for some sectors, e.g. the coal sector, the chemical goods and the electrical goods industry. Aggregated exports of the EU drop by the highest percentage rate in this case compared to all other cases. The relatively high reduction of aggregate demand, expressed by a smaller increase in consumption and a greater decrease in investment and exports, results in a greater percentage reduction of the GDP deflator. This, in turn, leads to a larger drop in imports.

Table 35: *Scenario* EU_TAX10: extra-EU imports and extra-EU exports, variation of upper-level Armington elasticities in RoW’s import demand (numbers indicate percent changes from baseline)

	Extra-EU imports (EU-14)					*Extra-EU exports (EU-14)*				
	Case 0:	*Case 1:*	*Case 2:*	*Case 3:*	*Case 4:*	*Case 0:*	*Case 1:*	*Case 2:*	*Case 3:*	*Case 4:*
GEM-E3 Sector	Standard version of GEM-E3	Halved values	Doubled values	U.S. ’best guess’ estimates	U.S. econometric estimates	Standard version of GEM-E3	Halved values	Doubled values	U.S. ’best guess’ estimates	U.S. econometric estimates
Agriculture (1)	0.60	0.91	0.41	0.64	0.51	-1.09	-0.77	-1.61	-1.15	-0.92
Solid fuels (2)	-25.86	-25.99	-25.74	-25.68	-25.94	2.97	1.38	6.17	11.17	38.45
Liquid fuels (3)	-4.37	-4.34	-4.33	-4.20	-4.75	1.52	0.81	2.52	3.24	-1.47
Natural gas (4)	-4.03	-3.96	-4.08	-3.99	-4.17	2.45	1.11	5.17	2.33	2.76
Electricity (5)	-0.39	-0.19	-0.55	-0.37	-0.50	-2.51	-1.46	-4.30	-2.52	-2.41
Ferrous and non-ferrous metals (6)	2.53	3.63	1.39	2.93	2.27	-6.68	-3.96	-11.18	-4.60	-6.99
Chemical industry (7)	1.49	2.46	0.70	1.48	0.00	-2.72	-1.86	-3.98	-3.33	-6.35
Other energy-intensive ind. (8)	0.79	1.69	0.24	0.85	0.42	-1.48	-1.23	-1.74	-2.08	-0.87
Electrical goods (9)	-0.72	-0.26	-0.86	-0.64	-0.76	0.22	-0.26	1.13	0.09	1.58
Transport equipment (10)	0.05	1.00	-0.41	0.11	-0.31	-0.32	-0.63	0.36	-0.69	0.08
Other equipment goods (11)	-0.47	0.24	-0.75	-0.34	-0.75	-0.01	-0.43	0.81	-0.08	0.51
Consumer goods (12)	0.77	1.45	0.38	0.89	0.47	-1.00	-0.95	-0.96	-0.94	-0.61
Building and construction (13)	-0.08	0.08	-0.17	-0.04	-0.18	-0.35	-0.49	0.04	-0.47	-0.02
Telecommunication services (14)	0.11	0.62	-0.16	0.24	-0.22	0.11	-0.28	0.95	-0.10	0.60
Transports (15)	1.00	2.06	0.24	1.18	0.56	-2.05	-1.56	-2.72	-2.27	-1.51
Credit and insurance (16)	-0.58	0.13	-0.91	-0.35	-1.14	0.29	-0.17	1.20	-0.06	0.98
Other market services (17)	0.53	1.30	0.11	0.64	0.17	-0.47	-0.60	-0.13	-0.60	-0.08
Non-market services (18)	0.24	0.48	0.11	0.33	0.05	-0.06	-0.17	0.20	-0.21	0.23
All sectors	-1.46	-0.99	-1.73	-1.33	-1.80	-1.02	-0.92	-1.08	-0.98	-1.12

4.4.3.3 Variation of Armington elasticities: EU countries

4.4.3.3.1 Specification of Armington elasticities

To the best of my knowledge, no econometric estimates of sector and country specific substitution elasticities for EU countries are available in the literature. The required set of Armington elasticities for the 14 EU countries is thus generated following a procedure proposed by Harrison et al. (1991:100). The procedure involves three steps:

1. I take the sector specific ‘best guess’ upper-level Armington elasticities for the U.S. presented in Shiells et al. (1986) as a starting point. Using country specific import weights (drawn from 1993 data[134]) country specific average Armington substitution elasticities, $\sigma_{Y_C}^{av}$, are calculated (see Table 37).
2. The country specific average Armington substitution elasticities, $\sigma_{Y_C}^{av}$, are then compared with country specific Armington elasticities, $\sigma_{Y_C}^{\inf}$, that are inferred from country specific import price elasticities, ε_{IM,PIM_C}, and from import shares, ω_c. While the national import price elasticities are taken from the empirical trade literature (Stern et al. 1976), the import shares are calculated from the equilibrium benchmark data set.

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[134] United Nations (1993).

3. Finally, I re-scale the sector specific elasticities for each country so that the aggregated import weighted elasticity, $\sigma_{Y_c}^{av}$, is equal to the country specific elasticity, $\sigma_{Y_c}^{\inf}$, which is derived from the national import price elasticity. The results of the sectorally and nationally disaggregated substitution elasticities are reported in Table 38.

While step 1 and step 3 are more or less self-explanatory, some comments should be made on the derivation of the national Armington elasticities from literature based import price elasticities (step 2).

Obviously, the procedure proposed encounters some problems which arise from the existence of non-tradable sectors and non-competitive imports in the GEM-E3 model. Import demand of both non-traded and non-competitive commodities is excluded from the Armington assumption. It is assumed that it is determined not by price relations, but by the domestic production level and institutional settings, such as supply contracts. As national import price elasticities taken from literature normally refer to the national aggregate of import demand (aggregating all sectors), they may provide a distorted picture of Armington elasticities. This problem, however, is less important here. Fortunately, the national shares of imports of non-tradable goods in total imports are low and in the majority of cases below 5% in the GEM-E3 model (see Table 36). Thus the literature based import price elasticity values are reasonable approximates for the price elasticity of import demand of tradable goods in the GEM-E3 model.

Table 36: Country specific import shares of non-tradable commodities in GEM-E3 EU-14 [%]

Austria	4.14	*Ireland*	2.29
Belgium	4.02	*Italy*	4.87
Germany	5.70	*Netherlands*	1.90
Denmark	3.48	*Portugal*	0.41
Finland	10.34	*Spain*	2.92
France	5.36	*Sweden*	1.00
Greece	0.44	*Un. Kingdom*	3.26

More importance should be attached to the problem that arises from non-competitive imports. Given the same import price elasticity value, the assumed share of non-competitive imports influences the inferred Armington elasticity values, $\sigma_{Y_c}^{\inf}$, decisively. This can be demonstrated by using (4-25) and (4-26) for the derivation of the Armington elasticities. According to the specification in the GEM-E3 EU-14 model the price elasticity of the aggregate import demand, ε_{IM,PIM_c}, in EU country *c* in terms of the country specific upper-level Armington elasticity, σ_{Y_c}, and empirically measurable import shares, ω_c, is given by

(4-25) $\varepsilon_{IM,PIM_c} = \sigma_{Y_c} \cdot (\omega_c - 1)$

if all imports are competitive, and by

(4-26) $\varepsilon^{NC}_{IM,PIM_c} = \sigma_{Y_c} \cdot \left[\frac{IMC_c}{IM_c} \cdot (\omega_c - 1) + \frac{IMNC_c}{IM_c} \cdot \left(\omega_c - \omega_c^{NC}\right) \right]$

if non-competitive imports exist (see Appendix II-A for the derivation of (4-25) and (4-26)). IM_c are total (competitive and non-competitive) imports of tradable goods in country *c*, IMC_c represent the competitive portion and $IMNC$ the non-competitive part. ω_c denotes country *c*'s share of total import expenditure in expenditure on domestically supplied goods, and ω_c^{NC} expresses the ratio of expenditure on only non-competitive imports to expenditure on domestically produced and demanded goods, i.e.

$$\omega_c = \frac{p_{IM_c} \cdot IM_c}{p_{Y_c} \cdot Y_c} \quad \text{and} \quad \omega_c^{NC} = \frac{p_{IM_c} \cdot IMNC_c}{p_{XD_c} \cdot XD_c}.$$

For $IMC_c = IM_c$ and $IMNC_c = 0$, (4-26) is identical with (4-25).

Table 37 shows that a variation of the share of non-competitive imports in total imports of tradable goods leads to different Armington elasticity values. In summary, one can say that the Armington elasticity corresponding to a given import price elasticity will rise with an increasing share of non-competitive imports. In the GEM-E3 EU-14 model the shares of non-competitive imports are set equal to 0.5 for all countries and all sectors. For this reason I will apply the country specific upper-level Armington elasticities, $\sigma_{Y_c}^{\inf}$, depicted in the fourth column of Table 37. Keeping in mind that values of own-price elasticities of import demand vary widely between alternative import demand specifications (see Kohli 1982), the Armington elasticities that are derived from the import price elasticities have to be interpreted as crude approximations. Whalley (1985:103), however, states that import price elasticity values in the neighbourhood of unity still reflect the current consensus on import price elasticities.

Finally, re-scaling the average Armington elasticity values $\sigma_{Y_c}^{av}$ according to step 3 leads to the final values which are reported in Table 38.

Table 37: Country specific price and substitution elasticities of import demand for different shares of non-competitive imports

	$\varepsilon_{IM,PIM\,c}$	$\sigma_{Y\,c}^{av}$ **	$\sigma_{Y\,c}^{inf}$ ***		
			($IMNC_c/IM_c=0$)	($IMNC_c/IM_c=0.5$)	($IMNC_c/IM_c=0.8$)
Austria	-1.32	2.13	1.88	4.57	10.48
Belgium	-0.83	2.13	1.67	5.03	6.53
Germany	-0.88	2.12	1.09	2.90	6.09
Denmark	-1.05	1.99	1.53	2.61	-10.31
Finland	-0.5	2.37	0.62	2.97	3.46
France	-1.08	1.63	1.31	2.36	7.31
Greece	-1.03	2.15	1.04	2.10	5.24
Ireland	-1.37	1.95	1.62	2.65	8.94
Italy	-1.03	2.01	1.77	6.39	8.57
Netherlands	-0.68	2.03	1.20	3.32	5.63
Portugal	-1.03	1.92	1.33	3.05	7.52
Spain	-1.03	2.03	1.21	2.63	6.68
Sweden	-0.79	2.06	0.80	1.38	1.99
Un. Kingdom	-0.65	1.93	0.66	1.17	1.83

* 'Best guess' estimates of uncompensated import price elasticities suggested by Stern et al. (1976:20) and constructed as point estimates for several countries according to the three-digit International Standard Industrial Classification (ISIC). As no data are available for Greece, Spain, and Portugal, I use Italian data. ** Based on Shiells et al. (1986).*** Elasticities are inferred from (4-25) for *IMNC/IM*=0 and from (4-26) for *IMNC/IM*>0. Import shares ω and ω^{NC} are based on observed data of the benchmark equilibrium.

Table 38: Sector and country specific upper-level Armington elasticities of substitution in EU-14 import demand

GEM-E3 Sector	*Austria*	*Belgium*	*Germany*	*Denmark*	*Finland*	*France*	*Greece*	*Ireland*	*Italy*	*Netherlands*	*Portugal*	*Spain*	*Sweden*	*Un. Kingdom*
Liquid fuels (3)	5.1	5.6	3.2	3.1	3.0	3.4	2.3	3.2	7.5	3.9	3.8	3.1	1.6	1.4
Ferrous and non-ferrous metal (6)	3.1	3.4	2.0	1.9	1.8	2.1	1.4	2.0	4.6	2.4	2.3	1.9	1.0	0.9
Chemical industry (7)	5.6	6.2	3.6	3.4	3.3	3.8	2.5	3.5	8.3	4.3	4.2	3.4	1.7	1.6
Other energy-intens. ind. (8)	6.2	6.5	3.7	3.3	3.5	3.8	2.4	3.5	8.3	4.2	3.8	3.4	1.9	1.5
Electrical goods (9)	4.5	5.0	2.9	2.8	2.6	3.1	2.1	2.9	6.7	3.5	3.4	2.7	1.4	1.3
Transport equipment (10)	7.7	8.5	4.9	4.7	4.5	5.2	3.5	4.9	11.4	5.9	5.7	4.6	2.4	2.2
Other equipment goods (11)	2.3	2.5	1.4	1.4	1.6	1.5	1.0	1.4	3.4	1.7	1.7	1.4	0.7	0.6
Consumer goods (12)	5.2	4.9	3.2	2.6	2.7	2.0	1.9	2.8	5.9	3.4	2.5	2.5	1.5	1.2

Table 39 reports the values of the upper-level Armington elasticity for which sensitivity analyses are performed. As in the previous section, the case of doubled and halved elasticity values are tested. Additionally, the calculated sector and country specific values (depicted in Table 38) are applied. The policy underlying the simulations is again the *Scenario* EU-TAX10.

Table 39: Sectoral values of upper-level Armington elasticities of substitution in EU-14 import demand

GEM-E3 Sector	*Case 0:* Standard version of GEM-E3	*Case 1:* Halved values	*Case 2:* Doubled values	*Case 3:* U.S. 'best guess' estimates
Agriculture (1)	1.2	0.60	2.40	Country and sector specific values (for sectors 3, 6- 12: values as shown in Table 38; for sectors 1, 14-17: values as in standard version)
Liquid fuels (3)	0.6	0.30	1.20	
Ferrous and non-ferrous metals (6)	1.5	0.75	3.00	
Chemical industry (7)	1.5	0.75	3.00	
Other energy-intensive ind. (8)	1.5	0.75	3.00	
Electrical goods (9)	1.5	0.75	3.00	
Transport equipment (10)	1.5	0.75	3.00	
Other equipment goods (11)	1.5	0.75	3.00	
Consumer goods (12)	1.7	0.85	3.40	
Telecommunication services (14)	0.6	0.30	1.20	
Transports (15)	1.2	0.60	2.40	
Credit and insurance (16)	0.6	0.30	1.20	
Other market services (17)	0.6	0.30	1.20	

4.4.3.3.2 Simulation results

As Table 40 indicates, the four cases of parameter choice differ only slightly with respect to macroeconomic impacts. Differences arise mainly in trade flows and price indices. All other macroeconomic variables reveal only marginal changes. As consumption and employment remain nearly constant, economic welfare scarcely varies. One can conclude, however, that the EU-wide ecological tax reform generates positive employment effects, no matter what parameter is selected. Sectoral trade flows between EU-14 and RoW are given in Table 41.

Table 40: *Scenario* EU_TAX10: macroeconomic aggregates, variation of upper-level Armington elasticities in import demand of EU countries (numbers indicate percent changes from baseline except if defined otherwise)

Macroeconomic aggregates for EU-14				
	Case 0: Standard version of GEM-E3	*Case 1:* Halved values	*Case 2:* Doubled values	*Case 3:* U.S. 'best guess' estimates
Gross domestic product	-0.04	-0.04	-0.04	-0.04
Employment	0.58	0.58	0.57	0.57
Production	-0.57	-0.57	-0.58	-0.58
Domestic demand	-0.56	-0.55	-0.56	-0.56
Private investment	-0.18	-0.17	-0.18	-0.18
Private consumption	0.21	0.21	0.20	0.20
Exports	-1.02	-1.05	-0.97	-1.02
Imports	-1.46	-1.48	-1.42	-1.45
EU-intra trade	-1.20	-1.25	-1.11	-1.14
Terms of trade	1.03	1.06	0.98	1.03
Consumers' price index	1.19	1.21	1.16	1.18
GDP deflator in factor prices	-0.74	-0.72	-0.77	-0.73
*CO_2 tax rate (ECU'85)***	22.0	22.1	21.9	21.9
*CO_2 tax revenue**	1.49	1.50	1.49	1.49
Energy consumption in volume	-6.21	-6.21	-6.22	-6.25
CO_2 emissions	-10.00	-10.00	-10.00	-10.00
*Equivalent variation (economic welfare) **	0.23	0.23	0.22	0.23

* in % of GDP, absolute difference from baseline
** in value figures

The interpretation of results starts with the examination of the pure effects of a variation of Armington elasticities.

In *Case* 1, Armington elasticity values in the aggregate import demand of all EU countries are halved, i.e. substitution possibilities between domestic production and imports are more restricted for all EU countries. In *Case* 1, for instance, a policy induced price increase in European domestic supply will induce a lower substitution effect than in the standard version, i.e. import demand for tradable goods will expand, however, not as much as in the standard case. This implies that (relatively expensive) domestic production has a relatively larger share in overall EU domestic supply in *Case* 1. The pure substitution effect leads to relatively higher prices in *Case* 1. The latter is expressed by a decrease in the GDP deflator by –0.72% (compared to –0.74% in *Case* 0).

In *Case* 2, I argue the other way round. Doubling the Armington elasticities increases the substitution effect, i.e. a shift in the price relation of domestic supply and imports results in a comparatively higher demand for imports. Domestic production constitutes a lower share in domestic supply compared with both *Case* 0 and *Case* 1. This, in turn, results in a decrease in domestic prices. To conclude, the price level is at its highest in *Case* 1 and at its lowest in *Case* 2. *Case* 0 lies in between.

Let me reiterate the main mechanisms running in the standard version that already have been described in Section 4.4.1.2. In the standard model, the ecological tax reform policy results in a decrease in exports and imports and in a drop in the GDP deflator (resulting from a decrease in aggregate demand).

As was just mentioned, in the case of halved Armington elasticity values (*Case* 1) the drop in the GDP deflator is less significant, i.e. prices are higher. This accurately reflects the cost effects of a lower degree of substitution for European producers and consumers. Due to comparably higher prices, EU exports go down. Whereas exports fall by –1.02% in the standard version, they fall by –1.05% in *Case* 1. The greater percentage reduction of imports can be explained by reduced substitution possibilities in *Case* 1, i.e. import demand increases more slowly in response to an increase in domestic production prices.

In the case of doubled Armington elasticities (*Case* 2) domestic prices are lower. Thus, exports decline but not as fast (by –0.97% compared to –1.02% in *Case* 0). Imports also decrease more slowly (by –1.42% compared to –1.46% in *Case* 0) due to the higher substitution possibilities given by doubled elasticity values.

The variation of Armington elasticities according to the calculated set of country and sector specific parameter values given in Table 38 (*Case* 3) indicates that impacts lie between those of *Case* 1 and *Case* 2.

Table 43 and Table 44 in Appendix II-B illustrate the impacts of the ecological tax reform at a national level for the standard case and for *Case* 3. While economic welfare goes down in Greece, Italy, and Portugal, all EU countries without exception gain in terms of employment.

Table 41: *Scenario* EU_TAX10: extra-EU imports and extra-EU exports, variation of upper-level Armington elasticities in import demand of EU countries (numbers indicate percent changes from baseline)

	Extra-EU imports (EU-14)				*Extra-EU exports (EU-14)*			
	Case 0:	*Case 1:*	*Case 2:*	*Case 3:*	*Case 0:*	*Case 1:*	*Case 2:*	*Case 3:*
GEM-E3 Sector	Standard version of GEM-E3	Halved values	Doubled values	U.S. 'best guess' estimates	Standard version of GEM-E3	Halved values	Doubled values	U.S. 'best guess' estimates
Agriculture (1)	0.60	0.50	0.76	0.58	-1.09	-1.13	-1.01	-1.07
Solid fuels (2)	-25.86	-25.89	-25.81	-25.83	2.97	2.96	3.00	2.97
Liquid fuels (3)	-4.37	-4.33	-4.45	-4.43	1.52	1.59	1.39	1.31
Natural gas (4)	-4.03	-4.03	-4.03	-4.04	2.45	2.44	2.46	2.47
Electricity (5)	-0.39	-0.38	-0.41	-0.41	-2.51	-2.52	-2.48	-2.48
Ferrous and non-ferrous metals (6)	2.53	2.30	2.99	2.84	-6.68	-6.75	-6.57	-6.64
Chemical industry (7)	1.49	1.43	1.61	1.67	-2.72	-2.76	-2.65	-2.69
Other energy-intensive ind. (8)	0.79	0.77	0.82	0.82	-1.48	-1.52	-1.40	-1.45
Electrical goods (9)	-0.72	-0.70	-0.77	-0.77	0.22	0.19	0.28	0.23
Transport equipment (10)	0.05	0.08	0.01	-0.02	-0.32	-0.36	-0.24	-0.29
Other equipment goods (11)	-0.47	-0.44	-0.53	-0.51	-0.01	-0.06	0.06	0.01
Consumer goods (12)	0.77	0.72	0.85	0.78	-1.00	-1.04	-0.92	-0.97
Building and construction (13)	-0.08	-0.08	-0.09	-0.08	-0.35	-0.39	-0.29	-0.33
Telecommunication services (14)	0.11	0.13	0.08	0.12	0.11	0.07	0.18	0.08
Transports (15)	1.00	0.88	1.23	1.02	-2.05	-2.07	-2.01	-2.07
Credit and insurance (16)	-0.58	-0.58	-0.58	-0.54	0.29	0.25	0.36	0.19
Other market services (17)	0.53	0.55	0.50	0.51	-0.47	-0.49	-0.42	-0.46
Non-market services (18)	0.24	0.26	0.22	0.26	-0.06	-0.08	-0.03	-0.10
All sectors	-1.46	-1.48	-1.42	-1.45	-1.02	-1.05	-0.97	-1.02

4.5 Conclusion

This chapter deals with the influence of different foreign trade specifications on the macroeconomic effects of ecological tax reforms. As previously mentioned in Chapter 2, the impact of terms-of-trade effects has been widely neglected in the theoretical double dividend literature; the majority of analytical models relies on the small-country assumption and assumes that exogenous world market prices completely determine the domestic price level. Terms-of-trade effects can be observed in the case of a large country that exerts market power on world markets. Hence, in order to investigate terms-of-trade effects, I apply the GEM-E3 EU-14 model version and an EU-wide ecological tax reform scenario. The focus of this chapter, however, is not only on terms-of-trade effects, but also on the effects of varying foreign closure specifications on the EDD outcome. Even if GEM-E3 EU-14 is a multi-country model, a closure rule is necessary because the behaviour of the rest of the world is exogenous in large parts.

In this chapter, I suggest three changes in the foreign trade specification and test them with respect to the employment effects of an EU-wide ecological tax reform. The first replaces the assumption of fixed world market prices by a finite price elastic foreign export supply function. The second concerns the modelling of foreign import demand and introduces an additional variable which accounts for income effects. The third change refers to the empirical specification of Armington elasticities in the import demand function of both the EU-14 and the rest of the world and, thus, to import price elasticities. The main findings of this chapter can be summarised as follows:

1. The closure rule incorporated in the GEM-E3 EU-14 model is advantageous in empirical applications as it avoids complete specialisation in production, allows for modelling of intra-industrial trade flows, and includes non-traded and traded goods. In particular intra-EU trade activities, which account for around 60% of the whole EU trade, are modelled realistically as they depend on an endogenous EU-price system.
2. In the standard version of GEM-E3 EU-14, the EU-wide ecological tax reform (*Scenario* EU_TAX10) leads to an employment double dividend, i.e. to a reduction in EU-wide CO_2 emissions by –10% and simultaneously to an increase in employment by 0.58%. Real net consumer wages go up, while capital income falls in all EU countries. The EU-wide terms of trade rise (by 1.03%), implying income redistribution between the EU-14 and the rest of the world. Tax shifting effects arise not only from labour to the foreign consumers of exported (intermediate and final) goods from the EU-14, but also from labour to capital income.
3. Relaxing the assumption of fixed prices facing the EU as a whole for exports from RoW leads to considerable effects for the EDD outcome. The simulation results suggest that the EU-14 as a whole gains from more flexible export prices. Sensitivity analyses with respect to the export price elasticity indicate that a lower own-price elasticity of foreign export supply leads to a stronger rise in EU-wide economic welfare and employment. For an export price elasticity of 0.5 for all sectors, employment increases by 0.82%. World market prices increase (except for energy products) with the declining own-price elasticity of export supply. Positive employment effects are stronger in the case of a finite price elastic foreign export supply function, since cost-effective substitution possibilities to foreign imports are restricted; this reinforces the switch to labour. Increased labour demand leads to higher real wage rates and to higher labour supply.
4. The introduction of RoW's exports as 'activity variable' into foreign import demand shows only slight impacts on simulation results. Sensitivity analyses with respect to the estimated degree of linkage show that employment nearly remains unaffected compared to the standard version (for the highest degree of linkage considered, employment rises by 0.60%). As expected, aggregate exports of EU-14 are forced back further, while the fall of aggregate imports is diminished.

5. Both changes, the introduction of finite elastic foreign export supply and of income effects into foreign import demand through an ‘activity’ variable, have some shortcomings which can only be overcome by extending the regional scope of the GEM-E3 EU-14 model towards a global model with an endogenous representation of the behaviour of agents in RoW. Recent developments of a world model version (GEM-E3 World) are geared toward this issue.
6. Additionally, the sensitivity of the GEM-E3 EU-14 model to variations in the upper-level Armington elasticities is analysed. Obviously, the EU increasingly benefits from the ecological tax reform policy in terms of economic welfare and employment with declining Armington elasticity values in foreign import demand. In other words, lower Armington elasticities in foreign import demand offer the EU-14 countries greater possibilities of shifting the tax burden abroad. Sensitivity analyses based on an EU-wide ecological tax reform scenario (*Scenario* EU_TAX10) indicate that employment increases by 0.56% for doubled upper-level Armington substitution elasticity values (recall that employment rises in the standard version by 0.58%). This increase is associated with a stronger rise in the EU-wide terms of trade. However, the sensitivity of economic welfare and employment to variations in upper-level Armington elasticities is not very high; the GEM-E3 EU-14 model proves to be rather robust.

Appendix II

II-A Derivation of the own-price elasticity of import demand in EU country *c*

Competitive imports only

If all tradable imports are competitive, it is $IM = IMC$ (IMC denotes competitive imports). The own-price elasticity of the EU country's demand for aggregate imports, $\varepsilon_{IM,p_{IM}}$, is derived from (4-9) and (4-10) in Section 4.3.1. The price elasticity of import demand with respect to the price of aggregate imports is defined by:[135]

$$\text{(4-27)} \quad \varepsilon_{IM,p_{IM}} = \frac{\partial IM}{\partial PIM} \frac{PIM}{IM}.$$

Assume that the level of domestic supply, Y, is fixed. From (4-10) we obtain:

$$\text{(4-28)} \quad \varepsilon_{IM,p_{IM}} = \left[Y \cdot \delta_{IM} \cdot \sigma_Y \cdot \left(\frac{p_Y}{p_{IM}} \right)^{\sigma_Y - 1} \cdot \left(\frac{\partial p_Y}{\partial p_{IM}} \cdot \frac{1}{p_{IM}} - \frac{p_Y}{p_{IM}^2} \right) \right] \cdot \frac{p_{IM}}{IM}.$$

The first derivative of (4-9) with respect to p_{IM} is:

$$\text{(4-29)} \quad \frac{\partial p_Y}{\partial p_{IM}} = \frac{1}{\sigma_Y - 1} \left(\delta_{IM} \cdot p_{IM}{}^{1-\sigma_Y} + \delta_{XD} \cdot p_{XD}{}^{1-\sigma_Y} \right)^{\frac{\sigma_Y}{1-\sigma_Y}} \cdot \delta_{IM} \cdot (1 - \sigma_Y) \cdot p_{IM}{}^{-\sigma_Y}$$

$$= \left(\frac{p_Y}{p_{IM}} \right)^{\sigma_Y} \cdot \delta_{IM} = \frac{IM}{Y}.$$

Inserting (4-29) into (4-28) and considering equation (4-10) yields:

$$\text{(4-30)} \quad \varepsilon_{IM,p_{IM}} = \left[IM \cdot \sigma_Y \cdot \left(\frac{p_{IM}}{p_Y} \right) \cdot \left(\frac{IM}{Y} \cdot \frac{1}{p_{IM}} - \frac{p_Y}{p_{IM}^2} \right) \right] \cdot \frac{p_{IM}}{IM} = \sigma_Y (\omega - 1)$$

where ω, $\omega = \frac{p_{IM} \cdot IM}{p_Y \cdot Y}$, defines the share of expenditure on imports in expenditure on domestically supplied commodities. (4-30) is equivalent to (4-25) in Section 4.4.3.3.1.

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[135] I omit sector and country specific indices in the following equations.

Competitive and non-competitive imports

If the share of non-competitive imports in aggregate tradable imports is positive, total tradable imports IM are given by $IM = IMC + IMNC$, where IMC denotes competitive imports and $IMPNC$ stands for non-competitive imports.

In the case of non-competitive imports the price for domestically produced and demanded goods, p_{XD}, is no longer independent of the price for the import aggregate, p_{IM}, in the GEM-E3 model (p_x is the price of domestically produced good x):

$$\text{(4-31)} \quad p_{XD} = p_x + RTNC \cdot p_{IM} \,.$$

Non-competitive imports are modelled as a fixed share, $RTNC$, in domestically produced and demanded goods:

$$\text{(4-32)} \quad IMNC = RTNC \cdot XD$$

where $RTNC$ is calibrated. Applying Shephard's lemma to (4-9) in Section 4.3.1 yields the demand for domestically produced and demanded goods XD:

$$\text{(4-33)} \quad XD = Y \cdot \delta_{XD} \cdot \left(\frac{p_Y}{p_{XD}} \right)^{\sigma_Y} \,.$$

The demand for competitive imports is determined by (4-10):

$$\text{(4-34)} \quad IMC = Y \cdot \delta_{IMC} \cdot \left(\frac{p_Y}{p_{IM}} \right)^{\sigma_Y} \,.$$

The own-price elasticity of aggregate demand for competitive and non-competitive imports is defined by:

$$\text{(4-35)} \quad \varepsilon^{NC}_{IM,p_{IM}} = \frac{\partial IMC}{\partial p_{IM}} \cdot \frac{p_{IM}}{IM} + \frac{\partial IMNC}{\partial p_{IM}} \cdot \frac{p_{IM}}{IM} \,.$$

Assume again that the level of domestic supply, Y, is fixed. Then the first term of the right hand side of (4-35) is:

$$\text{(4-36)} \quad \frac{\partial IMC}{\partial p_{IM}} \cdot \frac{p_{IM}}{IM} = \left[Y \cdot \delta_{IMC} \cdot \sigma_Y \cdot \left(\frac{p_Y}{p_{IM}} \right)^{\sigma_Y - 1} \cdot \left(\frac{\partial p_Y}{\partial p_{IM}} \cdot \frac{1}{p_{IM}} - \frac{p_Y}{p_{IM}^2} \right) \right] \cdot \frac{p_{IM}}{IM} \,.$$

The price for domestically produced and demanded goods, p_{XD}, depends on the import price, p_{IM}, according to (4-31). Hence $\frac{\partial p_Y}{\partial p_{IM}}$ is calculated as follows:

$$(4\text{-}37)\quad \frac{\partial p_Y}{\partial p_{IM}} = p_Y^{\sigma_Y} \cdot \left(\delta_{IMC} \cdot p_{IM}^{-\sigma_Y} + \delta_{XD} \cdot p_{XD}^{-\sigma_Y} \cdot RTNC\right)$$

$$= \left(\frac{p_Y}{p_{IM}}\right)^{\sigma_Y} \cdot \delta_{IMC} + \left(\frac{p_Y}{p_{XD}}\right)^{\sigma_Y} \cdot \delta_{XD} \cdot RTNC = \frac{IMC}{Y} + \frac{XD \cdot RTNC}{Y} = \frac{IM}{Y}.$$

Inserting (4-37) into (4-36) yields

$$(4\text{-}38)\quad \frac{\partial IMC}{\partial p_{IM}} \cdot \frac{p_{IM}}{IM} = \sigma_Y \cdot IMC \cdot \frac{p_{IM}}{p_Y} \cdot \left(\frac{IM}{p_{IM} \cdot Y} - \frac{p_Y}{(p_{IM})^2}\right) \cdot \frac{p_{IM}}{IM} = \sigma_Y \cdot \frac{IMC}{IM} \cdot (\omega - 1)$$

where $\omega = \dfrac{p_{IM} \cdot IM}{p_Y \cdot Y}$.

The second term of the right hand side of (4-35) is:

$$(4\text{-}39)\quad \frac{\partial IMNC}{\partial p_{IM}} \cdot \frac{p_{IM}}{IM} = RTNC \cdot \frac{\partial XD}{\partial p_{IM}} \cdot \frac{p_{IM}}{IM}$$

$$= RTNC \cdot \sigma_Y \left[Y \cdot \delta_{XD} \cdot \left(\frac{p_Y}{p_{XD}}\right)^{\sigma_Y} \cdot \frac{p_{XD}}{p_Y} \cdot \left(\frac{IM}{Y} \cdot \frac{1}{p_{XD}} - \frac{p_Y}{p_{XD}} \cdot RTNC\right)\right] \frac{p_{IM}}{IM}$$

$$= \sigma_Y \cdot \frac{RTNC \cdot XD}{IM} \cdot \left(\frac{p_{IM} IM}{p_Y Y} - \frac{p_{IM} \cdot XD \cdot RTNC}{p_{XD} \cdot XD}\right)$$

$$= \sigma_Y \cdot \frac{IMNC}{IM} \cdot \left(\omega - \omega^{NC}\right)$$

where $\omega^{NC} = \dfrac{p_{IM} \cdot IMNC}{p_{XD} \cdot XD}$.

Finally, inserting (4-38) and (4-39) into (4-35) leads to equation (4-26) in Section 4.4.3.3.1:

$$(4\text{-}26)\quad \varepsilon_{IM,p_{IM}}^{NC} = \sigma_Y \cdot \left[\frac{IMC}{IM} \cdot (\omega - 1) + \frac{IMNC}{IM} \cdot \left(\omega - \omega^{NC}\right)\right].$$

II-B Tables

Table 42: Time series of RoW’s exports (in Million ECU) and RoW’s production indices

GEM-E3 Sector	*RoW*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*
2	Exports *	3868.08	4495.84	3780.43	5026.61	6832.42	4966.65	3488.00	3583.98
	Production index **	102.23	104.32	105.03	115.41	121.44	123.55	125.87	124.65
3	Exports	93306.74	98029.52	92467.82	100092.51	113494.63	52879.79	48242.00	37288.92
	Production index	93.76	82.27	78.53	81.13	78.50	79.03	80.31	86.13
4	Exports	3803.35	5628.27	6182.69	8946.74	10366.69	5284.65	3822.00	3418.23
	Production index	102.25	103.88	109.60	116.53	120.40	121.03	126.45	134.88
5	Exports	560.01	676.99	766.47	735.16	690.89	689.72	622.00	576.81
	Production index	102.25	103.88	109.60	116.53	120.40	121.03	126.45	134.88
6, 7, 8	Exports	44220.12	49732.27	55368.53	68174.47	71924.02	67330.66	62690.00	72657.05
	Production index	101.08	95.57	101.45	110.72	113.05	115.86	123.30	132.54
9, 10, 11	Exports	46253.22	52220.73	61945.58	76218.53	83647.36	84721.98	85592.00	100963.29
	Production index	104.43	101.45	107.21	125.61	131.89	135.51	142.86	159.18
12	Exports	78223.76	87558.70	96681.84	113522.75	120066.87	111887.58	108606.00	114056.56
	Production index	102.18	100.52	106.23	110.17	97.40	115.48	120.61	123.74

* Disaggregated extra-EU imports for the period 1981 to 1988 are taken from the OECD Statistic ‘External Trade’. These values are set equal to exports of RoW to the EU. RoW’s exports are deflated to the base year 1987. The values of RoW’s exports are deflated using a merchandise export price index (1987=100) that is created from World Bank data (World Data 1995, World Bank Indicators on CD-ROM). ** Production indices (1980=100). Unfortunately, data of RoW’s production in absolute terms are not available for the necessary disaggregation level. I thus calculate the weighted sum of the index numbers of industrial production for three main RoW regions, EFTA, ASIA, and North America, with the share of these regions in total industrial production (taken from Industrial Statistics Yearbook 1991). The shares of the three RoW regions in total production are calculated on the basis of World Bank data.

Table 43: *Scenario* EU_TAX10: macroeconomic aggregates, GEM-E3 standard version (numbers indicate percent changes from baseline except if defined otherwise)

Macroeconomic aggregates for EU-14

	Austria	Belgium	Germany	Denmark	Finland	France	Greece
Gross domestic product	-0.23	-0.25	-0.07	-0.09	-0.01	-0.01	-0.28
Employment	0.38	0.69	0.51	0.39	0.26	0.43	0.51
Domestic demand	-0.53	-0.80	-0.60	-0.43	-0.41	-0.44	-0.93
Private investment	-0.15	-0.14	-0.14	-0.17	-0.13	-0.17	-0.47
Private consumption	0.46	0.63	0.29	0.45	0.33	0.13	-0.27
Exports	-1.35	-1.57	-1.14	-1.56	-1.27	-0.96	-1.36
Imports	-1.08	-1.41	-1.09	-1.34	-0.86	-1.27	-1.84
Consumers' price index	1.12	1.30	1.19	2.11	1.41	0.99	0.94
GDP deflator in factor prices	-0.18	-0.39	-0.71	-0.06	-0.03	-0.60	-0.85
Energy consumption in volume	-5.73	-6.69	-6.55	-7.35	-6.19	-5.26	-7.37
CO_2 emissions	-10.39	-13.80	-8.78	-10.93	-11.69	-8.76	-13.26
*Equivalent variation (economic welfare) **	0.35	0.41	0.34	0.46	0.23	0.26	-0.22

	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	Un. Kingdom
Gross domestic product	-0.40	0.03	0.08	0.08	0.01	-0.13	-0.02
Employment	0.51	0.26	0.74	0.61	0.76	0.94	0.21
Domestic demand	-0.53	-0.55	-0.19	-0.52	-0.65	-0.29	-0.71
Private investment	-0.36	-0.16	-0.09	-0.44	-0.29	-0.14	-0.22
Private consumption	0.36	-0.10	0.24	-0.14	0.25	0.57	0.27
Exports	-1.44	-0.56	-0.39	0.09	-1.29	-1.48	-0.94
Imports	-1.13	-1.72	-0.62	-0.85	-1.78	-1.08	-0.89
Consumers' price index	1.52	0.74	0.51	0.49	1.27	1.96	1.73
GDP deflator in factor prices	-0.10	-0.91	-0.89	-1.13	-0.82	0.35	-1.11
Energy consumption in volume	-6.49	-5.92	-3.55	-5.39	-6.00	-5.21	-7.49
CO_2 emissions	-12.67	-9.94	-7.41	-8.70	-10.50	-8.91	-11.36
*Equivalent variation (economic welfare) **	0.35	-0.08	0.13	-0.18	0.17	0.47	0.27

* in % of GDP, absolute difference from baseline

Table 44: *Scenario* EU_TAX10: macroeconomic aggregates, respecified Armington elasticity values in import demand of EU countries – *Case* 3 (numbers indicate percent changes from baseline except if defined otherwise)

Macroeconomic aggregates for EU-14

	Austria	Belgium	Germany	Denmark	Finland	France	Greece
Gross domestic product	-0.22	-0.29	-0.07	-0.09	-0.01	-0.03	-0.28
Employment	0.37	0.68	0.51	0.38	0.29	0.43	0.51
Domestic demand	-0.55	-0.86	-0.61	-0.43	-0.42	-0.45	-0.92
Private investment	-0.16	-0.16	-0.14	-0.17	-0.13	-0.17	-0.47
Private consumption	0.41	0.57	0.28	0.43	0.32	0.11	-0.27
Exports	-1.15	-1.46	-1.06	-1.54	-1.20	-0.90	-1.30
Imports	-0.98	-1.34	-1.03	-1.34	-0.82	-1.22	-1.79
Consumers' price index	1.04	1.24	1.15	2.10	1.38	0.96	0.92
GDP deflator in factor prices	-0.31	-0.45	-0.75	-0.09	-0.06	-0.62	-0.86
Energy consumption in volume	-5.67	-6.93	-6.62	-7.15	-6.17	-5.47	-7.36
CO_2 emissions	-10.46	-13.90	-8.77	-10.95	-11.65	-8.76	-13.23
*Equivalent variation (economic welfare) **	0.33	0.38	0.33	0.45	0.23	0.25	-0.22

continued Table 44

	Ireland	**Italy**	**Netherlands**	**Portugal**	**Spain**	**Sweden**	**Un. Kingdom**
Gross domestic product	-0.47	0.04	0.07	0.09	0.01	-0.13	-0.02
Employment	0.25	0.74	0.62	0.76	0.96	0.20	0.56
Domestic demand	-0.60	-0.55	-0.19	-0.50	-0.65	-0.29	-0.69
Private investment	-0.40	-0.17	-0.08	-0.41	-0.29	-0.14	-0.21
Private consumption	0.22	-0.10	0.25	-0.12	0.24	0.55	0.32
Exports	-1.34	-0.51	-0.41	-0.03	-1.23	-1.48	-1.14
Imports	-1.13	-1.69	-0.62	-0.91	-1.73	-1.10	-0.98
Consumers' price index	1.44	0.72	0.53	0.55	1.24	1.95	1.84
GDP deflator in factor prices	-0.22	-0.93	-0.84	-1.05	-0.84	0.34	-0.93
Energy consumption in volume	-6.74	-5.83	-3.66	-5.28	-6.00	-5.25	-7.44
CO_2 emissions	-12.81	-9.96	-7.41	-8.65	-10.47	-8.93	-11.35
*Equivalent variation (economic welfare) **	0.28	-0.08	0.14	-0.16	0.17	0.46	0.31

* in % of GDP, absolute difference from baseline

5 Employment double dividend and labour market imperfections

5.1 Introduction

Chapter 2 stressed that only a few attempts have been made as yet to analyse the impacts of ecological tax reforms in the presence of wage setting institutions and involuntary unemployment; in particular applications in large-scale models are hardly available.[136] Typically, labour market imperfections are introduced by an upward sloping wage setting curve which replaces the labour supply curve used in the competitive model. The equilibrium wage and employment level are now determined by the intersection of the wage setting and the labour demand curve. I also pointed out in Chapter 2 that the theory of equilibrium unemployment offers three microeconomic models, which all capture specific institutional factors of actually existing labour markets – namely trade union models, efficiency wage models, and mismatch models. Each model is appropriate to describe a specific part of the multi-facetted phenomenon of involuntary unemployment. Like the recent double dividend literature, however, I will concentrate exclusively on trade union behaviour in this chapter in order to address involuntary unemployment on the German labour market.

As will be substantiated empirically in the next section, the trade union model is best suited to describe the unemployment situation in Germany. Nickell and Layard (1999), for example, find that strong trade unions – in addition to generous and long-lasting unemployment benefit payments – are the key institutional factor of involuntary unemployment. In a cross-sectional study covering 20 OECD countries, the authors find that trade unions increase wage pressure and raise unemployment. Actually, among labour market economists there is little dispute that trade unions have a strong influence on wage formation in continental Europe, whereas they are of less importance in the USA. Consequently, in the majority of studies referring to European countries wages are supposed to be the outcome of a collective bargaining process.

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[136] Exceptions, for example, are the MIMIC model (an applied general equilibrium model for the Netherlands, cf. Graafland/de Mooij 1998) and the WARM model (an econometric general equilibrium model for the EU and the member states, including Germany, cf. Carraro et al. 1996).

In the following Section 5.2, I empirically motivate the wage setting equation applied at a later stage and summarise the evidence on collective wage bargaining and its institutional structure in Germany. I present a simple macroeconomic model of the labour market in Section 5.3 and introduce it into the single-country version of the GEM-E3 model for Germany. Sensitivity analyses are conducted with respect to the labour market specification. Alternatively to the trade union model, I assume exogenous real wage rigidities and test model results with respect to different rules of wage fixing.

5.2 Wage bargaining in Germany: empirical facts and theoretical background

5.2.1 Institutional structure of wage bargaining

According to the literature, important institutional features of a wage bargaining system are the bargaining coverage (measured by union density figures and the degree of contract coverage) and the degree of trade union centralisation and co-ordination (cf. Layard et al. 1991: Chapter 2).

Over the period 1988-94 around 30-40% of wage and salary earners belonged to a trade union in (West-)Germany (cf. Nickell and Layard 1999:3041). But since union wage agreements are frequently extended by law to non-union firms, *union coverage* is much higher: Effectively around 90% of all German employees are directly or indirectly covered by wage settlements (cf. Carruth and Schnabel 1993:298, Franz 1999:235). Hence, even if the German economy is only partly unionised, wages in nearly all sectors are influenced by trade union behaviour.

A further important institutional aspect is the *degree of centralisation* of wage setting. In this context, the literature distinguishes between three levels (cf. Booth 1995:244): First, wage setting can be decentralised to the level of the individual firm (i.e. one union per firm); second, it can take place at the industry level (intermediate bargaining); or, third, it can be centralised on the economy level. In the latter case, a centralised union confederation bargains with an employers' association that represents all firms in the economy. According to Calmfors and Driffill (1988:18) wage setting among 17 OECD countries has the highest degree of centralisation in Austria and the Nordic countries and the highest degree of decentralisation in the United States, Canada, Japan, and Switzerland; Germany ranks among the first six countries. In actual figures, 49,540 collective agreements were valid in Germany at the end of 1998. While approximately two thirds of them were concluded between an employers' organisation at the sectoral or regional level and a trade union, only around one third were between a firm and a trade union (Franz 1999:237). This suggests that the vast majority of collective agreements is concluded at the level of individual industries in Germany. Actually, trade unionism in Germany is dominated by the German Trade Union Confederation (DGB) – the umbrella organisation of the German industry trade unions. In 1998, the DGB covered around 80% of the economy-wide union members (cf. Franz 1999:240). At present it includes eleven trade unions that are mainly organised as industry trade unions. In terms of union membership, the three most important among them are the 'Metal Workers' Union' (IG Metall), integrating one third of all DGB members, 'Public Services, Transport and Traffic' (ÖTV), integrating 19%, and the industry union 'Mining, Chemicals, Energy', including 11% of all DGB members (see http://www.dgb.de).[137]

Theory indicates that the degree of centralisation of wage setting affects the influence of trade unions on the aggregate real wage. Calmfors and Driffill (1988), for example, formulate the hypothesis of a hump-shaped relationship between the degree of centralisation and the aggregate real wage level and support it with empirical evidence. The hump-shaped hypothesis suggests that intermediate bargaining leads to a higher aggregate real wage and – provided labour demand decreases with higher real labour costs – to higher economy-wide unemployment than decentralised or centralised wage setting.[138]

If wages are negotiated at the decentralised level (i.e. at the level of individual firms) the firms' output goods are close substitutes to each other so that a single firm is faced with a high elasticity of product demand. Hence higher nominal wage costs that increase the output price lead to a significant decrease in the firm's output and labour demand. As this is a far-reaching effect for the individual trade union, it will enforce only a low wage rate. To conclude, strong market forces and high competitive pressure favour real wage moderation in the case of decentralised bargaining.

The Calmfors/Driffill hypothesis further suggests that in the case of centralised wage bargaining the aggregate real wage is relatively low as well. The authors argue that

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[137] The balance of power within the DGB will change through the formation of the influential trade union 'ver.di' which was born from the merger of five trade unions that all cover mainly service sectors (see http://www.verdi-net.de).

[138] See also Layard et al. (1991), Calmfors (1993), and Booth (1995).

inter-union and inter-employer co-operation imply internalisation of wage externalities (a central confederation of unions, for example, is aware of its impact on the aggregate price level and employment and will thus take into account that higher nominal wages lead to higher unemployment).

In the case of industry-level bargaining, however, neither market forces nor internalisation effects restrain wages. Since industry demand is relatively inelastic (because of a relatively low degree of substitutability between products of different industries), industry output demand and employment drop only marginally in response to higher nominal wage claims and higher sectoral output prices. As the employment effect is insignificant for an individual trade union, it is reasonable to assume that the union does not take into account the impact of its wage claim on the aggregate price level and on aggregate output demand. On the assumption that all industry trade unions behave in the same way, the aggregate price level rises and, given constant nominal money supply, aggregate demand and employment are reduced considerably.

Apart from the degree of centralisation, the *degree of co-ordination* of wage offers and wage claims among the different employers' associations and trade unions affects the wage setting process. If industry trade unions try to co-ordinate their bargaining activities, for example by wage leadership, the external effects on the economy-wide consumption price level generated by industry-level wage bargaining might be partly internalised as well. This is shown in a recent study by Grandner (2000). He finds that – given an oligopolistic product market structure and firm-level bargaining – wage leadership increases the utilities of all trade unions involved, but, ultimately, it cannot substitute full centralisation. In Germany, the degree of union co-ordination is in the middle range, and that of employer co-ordination is high (cf. Nickell/Layard 1999:3041). Discussions on the 'going rate' are typically held in advance of the annual wage round between a leading powerful trade union (e.g. the Metal Workers' Union) and an employers' federation. This wage agreement then serves as a guideline for the majority of negotiating partners in the whole economy; a departure from the 'pilot' agreement can be explained only by sector specific features. In this context, Franz (1999:294) emphasises: "Zwar finden Tarifverhandlungen auf regionaler und sektoraler Ebene statt, gleichwohl werden die Lohnabschlüsse einer Branche in der Regel völlig oder mit nur geringen Modifikationen in den anderen Tarifgebieten übernommen und besitzen somit einen ausgeprägten Pilotcharakter für die nachfolgenden Lohnverhandlungen anderer Branchen”.

In spite of the high degree of union coverage in Germany and the unions’ tendency to co-ordinate wage agreements, wages differ between sectors and firms according to the wage drift. This empirically observable phenomenon describes the difference (over time) between the standard wage (minimum wage), which is formally codified in the collective agreement, and the actual earnings paid by the individual firms. The wage drift can be explained theoretically, for example, with the efficiency wage hypothesis or the presence of high fluctuation costs (e.g. search costs) of high skilled labour (cf. Franz 1999:295).

When modelling trade unions, a further important issue is the *degree of union power* and the *factors* that are negotiated. Both determine which theoretical model of trade union behaviour is appropriate: The wage is negotiated between the union and employers in the right-to-manage model, while employment is unilaterally set by the firm ex post (cf. Layard et al. 1991, Manning 1994). In the monopoly union model the union has the power to unilaterally determine the wage level subject to labour demand (cf. Booth 1995). Furthermore, the union and the employer bargain over both wage and employment level in the efficient bargaining model (cf. McDonald and Solow 1981). Certainly, the latter approach can be ruled out to describe wage bargaining in Germany since the employment level is rarely explicitly negotiated (cf. Franz 1999:291). Taking into account that union density is limited at a level of 30-40% and that employers’ associations are powerful in Germany, the degree of union power is limited too.[139] This gives empirical support for the right-to-manage model which, in fact, is applied in most double dividend studies that consider imperfections on European labour markets (cf. Section 2.3.3.3).

In summary, we need to know how unions operate in Germany. First, wage formation is dominated by collective agreements, which are primarily made between industry trade unions and employers’ associations. Second, wage leadership plays a role, and wage settlements are co-ordinated to a certain extent. Third, nearly all employees obtain standard wages, even though sector and firm specific wage differentials

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[139] In this context, Calmfors (1993:173-174) remarks: “Union membership in a given firm determines how large a fraction of the labour force can go on strike, and hence also the damage that the union can inflict on the employer in the case of a conflict. Therefore, a decrease in union membership weakens the relative bargaining strength of the union and thus tends to restrain wages and increase employment”.

represent important elements of decentralisation. This implies that wage setting in Germany takes place at both levels, the level of industry and the level of individual firms.

In the following of this chapter, I first omit the effects of the wage drift on wage formation and, second, assume that the union acts as a monopolist that is able to unilaterally set the nominal wage level, while the employer only decides on employment. Even if empirical evidence in Germany rather supports the right-to-manage model, I will apply the monopoly union model as this is an easy to model first approximation to wage setting behaviour of trade unions. It represents a special case of the right-to-manage model and can be expanded to account for bilateral wage bargaining.

5.2.2 Empirical evidence on real wage resistance and the unemployment benefit system

In the context of the EDD analysis the incidence of labour taxes on real labour costs (real wage resistance) is an essential point of interest. The empirical evidence on the influence of different wedge[140] terms on wage formation has been examined in a series of recent econometric works. Literature, however, offers a mixed empirical picture. The studies that oppose any permanent effects of wedge elements on the equilibrium wage and the unemployment rate in Germany are, for example, Bean et al. (1986), Turner et al. (1993), and Brunello (1996). In contrast to this, Tyrväinen (1995) comes to the conclusion that the long-run elasticity of real labour costs with respect to changes in different wedge factors is unity. Steiner (1998) corroborates this result and finds that a proportionate increase in any element of the tax wedge leads to an increase in real labour costs to the same extent in the long run.[141] According to some other studies, which are cited in Nickell and Layard (1999:3060), the degree of

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[140] As previously mentioned, the wedge describes the difference between real labour costs paid by the firm and the real take home pay received by the employee and, typically, includes all labour and consumption taxes (Tyrväinen 1995:7). Frequently, the wedge factors considered in the econometric literature are employers' social security contributions, consumption taxes and income taxes (including employees' social security contributions).

[141] Furthermore, Tyrväinen (1995) shows that – provided the real value of non-wage income can fall – a revenue-neutral shift from income taxes to consumption taxes reduces the producer wage and increases employment in Germany. According to Steiner (1998), a revenue-neutral shift from social security contributions to indirect or direct taxes may have positive wage and employment effects in the short run as well, but in the long run these effects disappear.

real wage resistance in Germany lies somewhere between zero and one (cf. Knoester and Van der Windt 1987, Alesina and Perotti 1994).

In summary, most econometric works principally support the argument that income and payroll taxes (including employees' and employers' social security contribution rates) have an impact on real labour costs in Germany. The precise size of real wage resistance, however, remains uncertain. Whereas some studies support real wage resistance in the long run, others find only short- or mid-term effects. In this context, Layard et al. (1991:210) summarise that "we have a plenty of evidence that taxes and import prices have very long-lasting effects on product wages, and hence on the equilibrium of the economy, operating via real wage resistance". Referring to the evidence reported in the OECD Employment Outlook (1990) the authors further note that "it is hard to imagine that real wage resistance really is permanent", but that "a change in the wedge can have a significant impact on unemployment for at least a decade".

According to economic theory, the size of real wage resistance depends on both the way of indexation of unemployment benefits and on the labour tax structure (cf. Pissarides 1998).[142] In particular real wage resistance arises if the replacement ratio, i.e. the ratio between the real net wage and real unemployment benefits, is variable and tax shifting effects from workers towards the unemployed are possible (cf. Section 2.3.3.3). In the GEM-E3 standard model all taxes (including income taxes and social security contributions) show linear tax rates. Unemployment benefits are indexed to the nominal after-tax wage, while the benefit replacement ratio is fixed at a 57% level for Germany, i.e. nominal unemployment benefits which are paid within a period are calculated as a fixed share in the (equilibrium) nominal net wage of the same period.[143] In Germany, however, a complete indexation of unemployment benefits at the going net wage cannot be observed, at least not in the short and mid run. Unemployment benefits and unemployment assistance, which are paid by the German Federal Labour Office, are granted as a share in the 'generalised' net income[144] which was received before dismissal. In nominal terms, unemployment

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[142] Empirical evidence on the hypothesis that a higher degree of progression of the labour tax leads to lower wage pressure is reported in Lockwood and Manning (1993).

[143] A replacement ratio of 57% is close to reality. Nickell and Layard (1999:3045) estimate an average benefit replacement ratio of 63% over the period 1989-1994. Using a data sample of pooled cross sections and time series over 1978-89 and eight EU countries Brunello (1996) estimates a replacement ratio of 54% in Germany.

benefits are rather fixed for a while and are calculated according to the previously received gross earnings and the particular income tax class.

Taking this into account, I will assume – alternatively to a fixed replacement ratio – that nominal unemployment benefits are constant over the simulation period. Under this assumption, the replacement ratio is variable and the degree of real wage resistance is higher. Whether positive employment effects are higher as well will be tested in Section 5.3.2.

5.2.3 Specification of an aggregate wage equation for the German labour market

In this section, I present a simple trade union model from which an aggregate wage equation for the German labour market is derived. The model is stylised and neglects essential features of the German labour market (such as the wage drift), which have been discussed above. However, it serves as a first attempt to introduce labour market imperfections into the neo-classical framework of the GEM-E3 model. Even if wage bargaining mainly takes place at the industry level in Germany, an aggregate wage bargaining model might be a reasonable first approximation to reality.[145]

First, I assume that the whole working force is covered by collective agreements and that wages are determined by wage bargaining at the level of individual industries. I further assume that a particular industry union (the Metal Workers' Union) acts as the wage leader. Wage leadership is modelled in a simple way: The leading trade union does not take into account the impact of its wage claim on the aggregate price and wage level; in other words, it is not aware of being the wage leader and does not internalise wage externalities. The other industry unions simply adopt the wage outcome without modifications; i.e. the wage outcome is directly binding for all other sectors of the economy within the same period. Contrary to empirical evidence on

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[144] Unemployment benefits, which are granted for a limited period only, represent 60-67% of the previously earned (generalised) net income in Germany. Unemployment assistance, which follows the unemployment benefits whenever the person was not able to find a job and for which payments are not limited in time, is calculated as 53-57% of the (generalised) net income that was received before unemployment (see http://www.arbeitsamt.de). In the following, the term 'unemployment benefits' is used to subsume all governmental payments to the unemployed without differentiating between unemployment benefits and unemployment assistance.

[145] This argument can be also found in Carruth and Schnabel (1993) who stress the importance of economy-wide rather than industry specific variables in the wage setting process in Germany and thus clearly support an aggregate analysis of wage bargaining. As Booth (1995:264) mentions, however, the macro-modelling of wage setting behaviour has been a neglected research area.

wage differentials between skills, sectors, and regions, I maintain the assumption of homogeneous labour and a uniform wage rate for all workers. Furthermore, I assume that wage mark-ups are not productivity enhancing, like in the efficiency wage model, but that they only lead to higher labour costs.

In Chapter 2 I argue that the existence of economic rents which can be shared between the union and the firm is a necessary condition for a contract wage above the competitive level (remember the sufficient condition that the union has the power to appropriate a share of this surplus). I maintain the assumption of perfectly competitive product markets in the GEM-E3 model and assume that firms net a profit which arises from quasi-fixed sectorally and internationally immobile capital stocks. The assumption that product markets are competitive, whereas the labour market is non-competitive allows me to concentrate on the effects of labour market imperfections on the EDD outcome. I should qualify that by saying that in the real world imperfections in labour markets are very likely to be correlated with imperfections in product markets (cf. Booth 1995:95, Weiss 1998). In this context, an interesting result of Layard et al. (1991), who consider both non-competitive product and labour markets, is that the firm level wage mark-up over alternative income increases with declining product market competitiveness.

Concerning the relative bargaining power of industry unions and employers' associations, I assume that the leading industry trade union has the power to unilaterally set the wage level, whereas the representing firm of the same industry chooses the employment level ex post. Hence the wage/employment outcome is on the labour demand curve of this industry. As previously mentioned, considering powerful employers' associations and the rather poor degree of union density in Germany, the right-to-manage model in which unions and firms bargain over the wage is closer to reality. Thus the introduction of a right-to-manage model into the GEM-E3 framework should be reserved for future work.

In the following, I describe the basic structure of the model. The utility of the industry trade union is given by a Stone-Geary function of the type (cf. Farber 1986, Goerke/Holler 1997:162):[146]

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[146] Sectoral indices are omitted in the following equations. Equation (5-1) assumes that the minimum employment level is zero and that the minimum wage is represented by the reservation wage, $\overline{w}$. Note that the commonly used utilitarian objective function represents a special case of (5-1). According to the utilitarian objective function the trade union maximises the sum of individual utilities of employed union members, L, and unemployed union members, $UM\text{-}L$: $U(w,L)=Lu(w)+(UM\text{-}L)u(\overline{w})$. On the assumption that the number of union members, UM, is

(5-1) $V(w, L) = (w - \overline{w})^{\alpha} L$

where w is the real net wage, $\overline{w}$ is the reservation wage, L is the level of sectoral employment, and α represents the relative importance of wages for the utility of the trade union.[147] Wages are interpreted in real terms, which implies that the trade union correctly predicts the consumption price level. The reservation wage is specified according to:

(5-2) $\overline{w} = (1-u)\tilde{w} + ub$

where $\tilde{w}$ is the alternative real net wage that is paid on average in other economic sectors, and b stands for real unemployment benefits that are supplied by the government. The variable u is the economy-wide unemployment rate that is intended to represent the probability of being unemployed; accordingly, (1–*u*) is interpreted as the probability of finding a job outside the leading sector. I assume that the leading industry union does not take into account that its wage setting behaviour has an impact on the outside option, i.e. it takes the alternative wage, $\tilde{w}$, and the economy-wide unemployment rate, *u*, as exogenous.

As previously mentioned, I suppose that the industry trade union has sufficient monopoly power to set the real net wage (without bargaining with an employers' federation). This implies that the union is able to fully control the supply of labour to this sector. The representative firm of the sector, however, chooses employment according to its labour demand schedule. The first-order condition from maximisation of (5-1) with respect to *w* and subject to labour demand *L* is:[148]

(5-3) $$\frac{\partial V}{\partial w} = \frac{\partial L}{\partial w}(w - \overline{w})^{\alpha} + L \cdot \alpha \cdot (w - \overline{w})^{\alpha - 1} \overset{!}{=} 0$$

$$= \frac{\partial L}{\partial w}\frac{w}{L} \cdot (w - \overline{w})^{\alpha}\frac{L}{w} + L \cdot \alpha \cdot (w - \overline{w})^{\alpha - 1} \overset{!}{=} 0$$

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exogenous and that individual utility, *u*, is linear in wages (i.e. risk neutrality of workers) the utilitarian utility function implies rent maximisation (cf. Booth 1995). For α =1 (i.e. employment and wages enter utility with equal weights) the Stone-Geary utility function (5-1) implies rent maximisation, too (the relevant maximand becomes $L(w - \overline{w})$). The conceptual difference between both specifications is that the Stone-Geary utility function is not derived from the individual preferences of (identical) union members but rather from the objectives of trade union officials.

[147] A similar union utility function is used by de Mooij (2000:183), see footnote 149.

[148] A similar monopoly union model is presented in Booth (1995).

$$= -\varepsilon_{LL} \cdot \frac{(w-\overline{w})^{\alpha}}{w} + \alpha \cdot (w-\overline{w})^{\alpha-1} \overset{!}{=} 0$$

where ε_{LL} is the own-price elasticity of labour demand which is defined by $\varepsilon_{LL} = -\frac{\partial L}{\partial w}\frac{w}{L} = -\frac{\partial L}{\partial p_L}\frac{p_L}{L}$; p_L is the nominal producer wage (see Appendix III for the derivation of the labour demand elasticity for the four-level nested CES production function used in GEM-E3). Rearranging (5-3) yields:

(5-4) $$w = \overline{w} + \frac{w\alpha}{\varepsilon_{LL}}.$$

Expression (5-4) indicates that the real net wage is determined by the real outside option (real income during unemployment, $\overline{w}$) plus a mark-up in the monopoly union model. In order to derive the aggregate wage equation I assume in a next step that all other industry unions exert monopoly power on the industry employers' association as well. According to the hypothesis of wage leadership, they directly follow the wage claim of the leading industry and – ignoring own sector specific circumstances – enforce sectoral wages that are equal to w ($\tilde{w} = w$). With this symmetry condition, the reservation wage is defined by $\overline{w} = (1-u)w + ub$. Reformulation of (5-4) leads to the following two expressions for the wage equation:[149]

(5-5) $$w = b + \left(\frac{w\alpha}{u \cdot \varepsilon_{LL}}\right)$$

(5-6) $$w = b \cdot \left(\frac{u}{u - \alpha / \varepsilon_{LL}}\right).$$

According to (5-5) the real net wage is a mark-up on real unemployment benefits, *b*, which increases with a decreasing elasticity of labour demand in the leading sector (for given *u* and *b*). Intuitively this is clear, since the trade union can set a relatively higher wage rate without suffering too many employment losses with a relatively

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[149] From a right-to-manage approach, in which a firm and a trade union bargain over the wage rate, de Mooij (2000:186) obtains the following wage equation:

$$w = b + \alpha / u \cdot w \cdot \left[(\beta/(1-\beta)) \cdot (1-t_L)w/\pi + \varepsilon_{LL}\right]^{-1}$$

where π represents profits (arising from fixed capital) and β is the bargaining power of the firm. As is common in literature, the wage equation is derived from the first-order conditions from a Nash bargaining maximisation problem which is described by: $\max_{w} \pi^{\beta} V^{1-\beta}$ where *V* is defined by (5-1). For $\beta = 0$ (i.e. no bargaining power of the firm) the wage equation turns into (5-5) of the monopoly union model.

lower labour demand elasticity. The mark-up also increases with the relative weight α that the union attributes to wages in its utility function.

Since $\frac{\partial w}{\partial u} = -(b \cdot \alpha / \varepsilon_{LL}) / (u - \alpha / \varepsilon_{LL})^2 < 0$, an increase in the unemployment rate ceteris paribus reduces the real net wage, i.e. the wage curve – which describes the relationship between the real net wage and the unemployment rate in *w*/*L* space – is bending upward.

Furthermore we see from (5-6) that the real net wage rate grows (ceteris paribus) with *b*, provided that $(u - \alpha / \varepsilon_{LL}) > 0$.

Moreover, solving (5-5) or (5-6) for *u* yields:

$$(5\text{-}7) \qquad u = \frac{\alpha}{\varepsilon_{LL}} \cdot \frac{1}{1 - b / w}.$$

Obviously, the economy-wide unemployment rate grows (ceteris paribus) with the replacement ratio b / w, or – as the following equation (5-8) can be derived from (5-2) – with the reservation rate $\overline{w} / w$:

$$(5\text{-}8) \qquad \frac{\overline{w}}{w} = (1 - u) + u \frac{b}{w}.$$

Equation (5-7) illustrates the channel through which real wage resistance affects employment: As previously mentioned, real wage resistance can be observed if a lower tax on labour income enlarges the gap between income during employment and unemployment. This weakens the union’s bargaining position, reduces wage pressure and favours employment.

In Section 5.3.2 the aggregate wage equation (5-6) is implemented into the single-country version of the GEM-E3 model. I assume that the leading union sets the wage for all employees who belong to one of the three GEM-E3 sectors: the ferrous and non-ferrous ore industry (6), electrical goods industry (9), and transport equipment industry (10). This sectoral classification was chosen to approximate the sphere of influence of the German Metal Workers’ Union (IG Metall), which, in reality, mainly covers the metal and engineering industry, the electrical industry, the timber and plastics industry, and the automobile industry.

5.3 Sensitivity of GEM-E3 model results to different mechanisms of wage formation

In the next two sections I present simulation results of the *Scenario* D_TAX20. As in Chapter 3, I apply the single-country version of the GEM-E3 model for Germany. First, I introduce in Section 5.3.1 an exogenous real wage model; then the monopoly union model is implemented in Section 5.3.2. In all simulations below, I assume that individual labour supply (representing labour supply in the absence of labour market institutions) is variable. The unemployment rate is calculated as the ratio of the involuntarily unemployed (measured by individual labour supply minus labour demand) to individual labour supply (cf. Section 2.3.3.1). Labour supply is computed as the difference between exogenous time resources and endogenous demand for voluntary leisure.

5.3.1 Exogenous real wage rigidities

The most simple approach to introducing involuntary unemployment is to assume that real wages are fixed above the market-clearing level (cf. Section 2.3.3.2). By applying this ad hoc specification, I provide a first test of the sensitivity of model results with respect to different wage fixing rules. In particular it can be shown for which real wage range the EDD hypothesis is accepted in the single-country version of the GEM-E3 model for Germany.

In order to introduce an exogenous real wage into the GEM-E3 model, the equilibrium condition for the real wage rate is replaced by a wage equation that fixes the real wage level. The equilibrium employment level is determined by labour demand at this fixed real wage, while equilibrium involuntary unemployment is calculated as a residuum which results from the difference between individual labour supply and labour demand. Concerning the unemployment benefit regime it is assumed for the following simulations of this section that the replacement ratio is fixed (see Section 5.3.2).

Table 45 depicts the simulation results of the *Scenario* D_TAX20 for the neoclassical labour market specification (*Case* 0) and for different exogenous wage models (*Case* 1 to *Case* 3).

Case 1 assumes that the real consumer wage is fixed, i.e. employees can preserve the living standard they had before the tax reform was implemented. This implies that both the incidence of the CO_2 tax and the cut in the employers' and employees' social security contribution rate is borne by the employers. In *Case* 2 and *Case* 3, the additional tax burden associated with the CO_2 tax is still borne by the employer side, but the degree of real wage resistance is reduced: The incidence of a cut in the employees' share in social security contributions is now partially (*Case* 2) or even fully (*Case* 3) borne by employees in terms of a higher real consumer wage. While the real net wage increases compared to the reference run by the half of the reduction in employees' social security contribution rate in *Case* 2, employees can enforce a real net wage in *Case* 3 that is raised by the whole amount of reduction in the employees' social security contribution rate.

Table 45: *Scenario* D_TAX20: macroeconomic aggregates for Germany, exogenous real wage rigidities (numbers indicate percent changes from baseline except if defined otherwise)

Macroeconomic aggregates for Germany												
	Flexible real wage			*Fixed real wage*								
	Case 0			*Case 1*****			*Case 2*****			*Case 3*****		
	1. year	5. year	10. year	1. year	5. year	10. year	1. year	5. year	10. year	1. year	5. year	10. year
Gross domestic product	0.04	0.11	0.00	0.52	2.46	5.19	0.06	0.09	-0.34	-0.10	-0.67	-2.00
Employment	0.12	0.59	1.27	0.92	4.59	10.35	0.15	0.56	0.68	-0.11	-0.70	-2.04
Production	-0.14	-0.75	-1.76	0.24	1.16	2.44	-0.13	-0.76	-2.03	-0.26	-1.38	-3.39
Domestic demand	-0.13	-0.68	-1.58	0.12	0.58	1.24	-0.12	-0.68	-1.76	-0.20	-1.10	-2.69
Private investment	-0.03	-0.17	-0.52	0.23	1.12	2.40	-0.02	-0.18	-0.71	-0.10	-0.61	-1.68
Private consumption	0.09	0.35	0.50	0.32	1.50	3.16	0.10	0.34	0.33	0.02	-0.05	-0.57
Real net income	0.09	0.36	0.52	0.33	1.56	3.29	0.10	0.35	0.34	0.02	-0.05	-0.59
- Labour income	0.43	1.96	3.92	0.95	4.59	10.35	0.42	1.81	3.24	0.25	0.90	1.04
- Non-labour income	-0.19	-0.96	-2.29	-0.16	-0.93	-2.53	-0.16	-0.85	-2.05	-0.16	-0.83	-1.94
Real consumer wage	0.31	1.36	2.61	0.00	0.00	0.00	0.27	1.24	2.54	0.36	1.61	3.15
Real producer wage	-0.10	-0.55	-1.37	-0.94	-4.55	-9.84	-0.13	-0.52	-0.75	0.15	0.79	2.00
Exports	-0.22	-1.17	-2.77	0.73	3.43	7.15	-0.19	-1.19	-3.44	-0.50	-2.67	-6.53
Imports	-0.21	-1.05	-2.40	-0.06	-0.29	-0.65	-0.20	-1.06	-2.50	-0.25	-1.30	-3.05
Terms of trade	0.10	0.55	1.32	-0.34	-1.57	-3.19	0.09	0.56	1.65	0.23	1.28	3.21
CO_2 *tax rate (ECU'85)***	4.4	23.8	60.8	4.9	26.5	68.4	4.4	23.8	60.3	4.2	22.8	57.8
CO_2 *tax revenue**	0.38	1.87	4.21	0.42	2.10	4.78	0.38	1.87	4.16	0.37	1.79	3.97
CO_2 *emissions*	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00

* in % of GDP, absolute difference from baseline

** in value figures

*** in % of base year GDP, cumulative from 1st year

**** *Case* 1: fixed real net wage; *Case* 2: the nominal gross wage is fully indexed to the consumer price index and only partially indexed to the employees' social security contribution rate; *Case* 3: the nominal gross wage is indexed to the consumer price index only (fixed real gross wage).

Table 45 indicates that the employment effects computed with GEM-E3 are quite sensitive to the wage fixing rule. As expected, positive employment effects are the highest in *Case* 1 in which the real net wage is fixed throughout the simulation period: In the 10th year after the introduction of the ecological tax reform, i.e. for a -20% CO_2 emissions reduction target, employment rises by more than 10% in Germany. Associated with this increase is a sharp fall in real labour costs by more than –9%. This effect is extreme, but considering that in the case of a flexible real wage the real net wage rises by 2.61% – indicating large tax shifting effects away from labour – it is easy to explain: A fixed real net wage makes it possible for the firms to employ formerly unemployed people at reduced labour costs. The considerable increase in labour demand mainly reflects technological substitution effects in production.

Employment still increases (although to a significantly lower extent) in *Case* 2, in which employees successfully push up the real net wage by half of the cut in their social security contribution rate: A –20% reduction in CO_2 emissions leads only to a moderate employment increase of 0.68%. Labour demand rises less since the real producer wage drops only by –0.75%. In *Case* 3, employees enforce an increase in the real net wage that even goes beyond the increase in *Case* 0. The rise in the real net wage of 3.15% prevents the real labour costs from falling; labour demand and employment drop by around -2%.

5.3.2 Monopoly union model

Next, I introduce the wage setting equation defined by equation (5-6) to the single-country version of the GEM-E3 model for Germany. This equation differs from the exogenous wage model above in that it relates the real net wage to the performance of the labour market, such as the unemployment rate. An increase in employment raises the real net wage, which, in turn, reduces the effect on labour demand. I assume that the wage setting process is co-ordinated by wage leadership. The leading industry union sets the contract wage for the employed in three GEM-E3 sectors: ferrous and non-ferrous ore (6), electrical goods (9), and transport equipment (10). This wage is then accepted by all other industry unions without modification.[150]

The implementation of the wage setting equation (5-6) requires the specification of the parameter α by calibrating to the benchmark data set:

$$(5\text{-}9) \quad \alpha = \left(1 - \frac{b_0}{w_0}\right) \cdot u_0 \cdot {\varepsilon_{LL}}_0^{6,9,10}$$

where ${\varepsilon_{LL}}_0^{6,9,10}$ is the aggregate labour demand elasticity of the three sectors that are covered by the leading industry union in the base year. By calibration I obtain

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[150] This assumption implies that the other trade unions take utility losses, as they neglect sectoral differences in labour demand elasticities. At any rate, the assumption of a unique wage rate increases labour market inefficiencies compared to the case of sectorally differentiated wage rates.

$\alpha = 0.005$. Labour demand elasticity and the unemployment rate in the base year are computed as ${\varepsilon_{LL}}_0^{6,9,10} = 0.167$ and $u_0 = 8\%$.

In the first simulation run, I assume that the ratio between unemployment benefits and the nominal after-tax wage is fixed at a (calibrated) level of 57% for all periods t:

Case 1: $$\rho_t = \frac{b_t}{w_t} = 0.57 \quad \forall t.$$

As a fixed replacement ratio is less close to reality in Germany and since econometric studies support the existence of real wage resistance (cf. Section 5.2.2), I assume in the second model run that unemployment benefits are fixed in nominal terms over the whole simulation period at the calibrated base year value, B_0. The replacement ratio within a period t is calculated according to:

Case 2: $$\rho_t = \frac{b_t}{w_t} = \frac{\overline{B}_0}{p_{LJ_t}}$$

where p_{LJ_t} is the actual nominal consumer wage and $\overline{B}_0$ represents fixed nominal unemployment benefits (which are not subject to social security contributions).

Table 46 depicts the simulation results of *Scenario* D_TAX20 for the monopoly union model with both cases of unemployment benefits indexation (*Case* 1 and *Case* 2) as well as for the neo-classical labour market specification (*Case* 0). Obviously, two results which can also be found in the literature (e.g. in de Mooij 2000:209-217) can be corroborated immediately:

- Positive employment effects of an ecological tax reform are higher if the initial labour market equilibrium is distorted by trade unions.
- In the presence of wage setting behaviour, employment effects depend on the kind of unemployment benefits indexation. In the case of a fixed replacement ratio, real wage resistance is absent and employment effects are lower than in the case of nominally fixed unemployment benefits, which allows for some degree of real wage resistance.

Table 46: *Scenario* D_TAX20: macroeconomic aggregates for Germany, monopoly union model (numbers indicate percent changes from baseline except if defined otherwise)

Macroeconomic aggregates for Germany									
	Flexible wages			*Monopoly union model*					
	Case 0			*Case 1: b/w*=const.			*Case 2: B*=fix		
	1. year	5. year	10. year	1. year	5. year	10. year	1. year	5. year	10. year
Gross domestic product	0.04	0.11	0.00	0.11	0.21	0.19	0.13	0.33	0.45
Employment	0.12	0.59	1.27	0.20	0.71	1.48	0.23	0.90	1.92
Production	-0.14	-0.75	-1.76	-0.06	-0.62	-1.55	-0.05	-0.53	-1.34
Domestic demand	-0.13	-0.68	-1.58	-0.03	-0.51	-1.34	-0.02	-0.46	-1.20
Private investment	-0.03	-0.17	-0.52	0.01	-0.09	-0.34	0.02	-0.03	-0.19
Private consumption	0.09	0.35	0.50	0.27	0.59	0.83	0.27	0.64	0.96
Real net income	0.09	0.36	0.52	0.28	0.61	0.86	0.29	0.66	1.00
- Labour income	0.43	1.96	3.92	0.75	2.24	4.25	0.78	2.44	4.74
- Non-labour income	-0.19	-0.96	-2.29	-0.11	-0.74	-1.93	-0.12	-0.80	-2.09
Real consumer wage	0.31	1.36	2.61	0.55	1.53	2.73	0.54	1.53	2.76
Real producer wage	-0.10	-0.55	-1.37	-0.05	-0.51	-1.35	-0.09	-0.72	-1.80
Exports	-0.22	-1.17	-2.77	-0.34	-1.29	-2.82	-0.30	-1.06	-2.32
Imports	-0.21	-1.05	-2.40	-0.20	-1.00	-2.29	-0.19	-0.96	-2.20
Terms of trade	0.10	0.55	1.32	0.14	0.60	1.36	0.12	0.50	1.11
CO_2 *tax rate (ECU'85)***	4.4	23.8	60.8	3.9	21.7	57.4	4.0	21.9	57.8
CO_2 *tax revenue**	0.38	1.87	4.21	0.34	1.72	3.99	0.34	1.73	4.02
CO_2 *emissions*	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00

* in % of GDP, absolute difference from baseline

** in value figures

*** in % of base year GDP, cumulative from 1st year

In actual figures, I find that an ecological tax reform in Germany boosts employment by only 1.27% in the standard model while employment increases by 1.48% in the case of a fixed replacement ratio and even by 1.92% in the case of nominally fixed unemployment benefits.

In all simulations, real capital income falls while the real net wage and real labour income go up. In addition, the terms of trade increase in all cases. Hence the ecological tax reform redistributes income from capital and the foreign sector towards workers. Moreover, tax shifting effects from the unemployed to labour are a further source for the rise in employment in the case of nominally fixed unemployment benefits (*Case* 2).

5.4 Conclusion

In this chapter, I investigate whether the labour market effects of an ecological tax reform in Germany change if labour market forces are restrained by wage setting institutions, such as trade unions. Several conclusions can be drawn from the previous analysis:

1. Germany is characterised by a degree of union coverage above 90%; this strongly suggests the application of a trade union model in order to describe involuntary unemployment. Although bargaining mainly takes place on an industry-by-industry basis, unions' wage claims are partly co-ordinated between sectors and regions by wage leadership. Notwithstanding a rather low degree of union density (below 50%) and the presence of influential employers' associations, I apply a textbook standard monopoly union model instead of the more realistic right-to-manage model for reasons of simplicity. The monopoly union model, however, represents a special case of the latter and can be extended to a bilateral bargaining model. Apart from the assumed degree of union bargaining power, other critical points of the wage setting model presented above are the exclusion of the wage drift and different labour types, such as labour skills. In addition, wage leadership is modelled in a simplified way. All these critical aspects point to the necessity of extending the GEM-E3 labour market model in future work.
2. Nevertheless, the model represents a good first approximation to the wage setting process in Germany and is sufficient to illustrate the influence of labour market imperfections on the equilibrium employment level. According to the derived wage setting rule, the aggregate wage level depends on the economy-wide unemployment rate, the unemployment benefit system, and the aggregate labour demand elasticity of the three sectors for which the wage is set by the leading industry union. I assume that the Metal Workers' Union (IG Metall) acts as the wage leader.
3. For a first test of the sensitivity of the EDD outcome with respect to the wage setting rule, I introduce exogenous real wage rigidities into the model. Simulation results show that the employment effects are quite sensitive to the particular wage fixing rule. As expected, positive employment effects are the highest if the real net wage is fixed throughout the whole simulation period. In this case, the model computes a positive employment effect of around 10% for the –20% CO_2 emissions reduction target. Associated with this increase is a sharp decline in real labour costs by more than –9%. Whereas in the case of flexible real wages an increase in employment (by 1.27%) is associated with a rise in the real net wage (by 2.61%), additional labour demand (stimulated by technological substitution effects) can now be saturated by formerly unemployed workers at significantly lower labour costs. The increase in employment is moderated considerably

(0.68%), or even turns into a decrease (–2.04%), for two further wage fixing rules cnsidered. These are based on the assumption that the real net wage increases by half, and the whole respectively, of the cut in employees' social security contributions. Since this lowers the degree of real wage resistance, labour costs are reduced to a lower extent or even rise.

4. In line with the EDD literature, the simulation results obtained from the monopoly union model show that labour market imperfections may enlarge the opportunity for an EDD. In the case of the single-country version of the GEM-E3 model – which computes positive employment effects even for a competitive labour market – an ecological tax reform leads to stronger positive employment effects if the labour market is initially distorted by trade unions.
5. Simulation results further indicate that employment effects are higher if real wage resistance exists (i.e. if the ecological tax reform makes the income position of the unemployed worse compared to that of the workers). This is the case for nominally fixed unemployment benefits for which the benefit replacement ratio is variable. Actually, a degeneration of the relative income position of the unemployed reduces the union's wage pressure and leads to lower unemployment.
6. Finally, I would like to make the point that future research with the GEM-E3 model should not only concentrate on a better labour market specification, but also on the introduction of imperfect output markets, since product market and labour market imperfections are correlated. Imperfect competition on output markets, however, will not explode but rather confirm the basic result that labour market imperfections tend to increase the chance for an EDD.

Appendix III

Derivation of the own-price elasticity of labour demand for the four-level nested CES production function

Consider a representative firm that produces a single output good *x*. It faces a four-level nested constant elasticity of substitution (CES) production function with capital, *K*, and the *LEM* aggregate at the first level of nesting; electricity, *EL*, and the *LFM* aggregate are at the second level of nesting; and labour, *L*, the material aggregate, *M*, and the fossil fuels bundle, *F*, are at the third nesting level (recall Figure 3 in Section 3.2.3.2 that illustrates the nesting levels).[151]

For reasons of simplicity, I introduce the following notation for the CES substitution elasticities of the first three nesting levels:

$$\sigma_1 = \sigma_{K,LEM}\,, \quad \sigma_2 = \sigma_{EL,LFM}\,, \quad \sigma_3 = \sigma_{LFM}\,.$$

The first nesting level is described by the following primal CES production function in the GEM-E3 model:[152]

$$(5\text{-}10)\quad x = \left[d_K \cdot \left(K \cdot e^{\gamma_K \cdot t} \right)^{\frac{\sigma_1 - 1}{\sigma_1}} + d_{LEM} \cdot LEM^{\frac{\sigma_1 - 1}{\sigma_1}} \right]^{\frac{\sigma_1}{\sigma_1 - 1}}$$

where d_K and d_{LEM} are share parameters that are calibrated to the benchmark data set ($d_K + d_{LEM} = 1$). Exogenous technical progress of capital is represented by the parameter γ_K; *t* denotes a time index.[153] In the GEM-E3 model the dual concept of the cost function is used. In order to obtain the unit cost function p_x which is dual to the primal production function given by (5-10), I derive the factor demands for *K* and

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[151] At the fourth nesting level, the firm decides on the composition of the materials and the fossil fuels bundle. This lowest aggregation stage, however, is irrelevant in the context of the own-price elasticity of labour demand.

[152] For the sake of simplicity, sectoral indices are omitted in all following equations.

[153] In the GEM-E3 model, autonomous factor augmenting (or, respectively, price diminishing) technical progress is considered at the lowest level of the individual input (not at the level of the aggregates).

LEM from the first-order conditions of profit maximisation and insert them into (5-10). Solving (5-10) for p_x then yields the dual unit cost function:[154]

(5-11) $$p_x = \left[\delta_K \cdot \left(p_K \cdot e^{-\gamma_K \cdot t}\right)^{1-\sigma_1} + \delta_{LEM} \cdot p_{LEM}^{1-\sigma_1}\right]^{\frac{1}{1-\sigma_1}}$$

where $\delta_K = d_k^{\sigma_1}$ and $\delta_{LEM} = d_{LEM}^{\sigma_1}$.

Applying Shephard's lemma to the cost function, i.e. derivation of $p_x x$ with respect to the price of the *LEM* aggregate, p_{LEM}, leads to the factor demand function for the *LEM* aggregate:

(5-12) $$LEM = x \cdot \frac{\partial p_x}{\partial p_{LEM}}$$

where $\frac{\partial p_x}{\partial p_{LEM}} = x \cdot \delta_{LEM} \cdot \left(\frac{p_x}{p_{LEM}}\right)^{\sigma_1}$.

In close analogy, the unit cost function of the *LEM* aggregate and the factor demand function for the *LFM* aggregate are derived:

(5-13) $$p_{LEM} = \left[\delta_{EL} \cdot \left(p_{EL} \cdot e^{-\gamma_{EL} \cdot t}\right)^{1-\sigma_2} + \delta_{LFM} \cdot p_{LFM}^{1-\sigma_2}\right]^{\frac{1}{1-\sigma_2}}$$

(5-14) $$LFM = LEM \cdot \frac{\partial p_{LEM}}{\partial p_{LFM}}$$

where $\frac{\partial p_{LEM}}{\partial p_{LFM}} = LEM \cdot \delta_{LFM} \cdot \left(\frac{p_{LEM}}{p_{LFM}}\right)^{\sigma_2}$.

Finally, the unit cost function of the *LFM* aggregate and the factor demand function for labour input, *L*, are calculated as follows:

(5-15) $$p_{LFM} = \left[\delta_L \cdot \left(p_L \cdot e^{-\gamma_L \cdot t}\right)^{1-\sigma_3} + \delta_F \cdot p_F^{1-\sigma_3} + \delta_M \cdot p_M^{1-\sigma_3}\right]^{\frac{1}{1-\sigma_3}}$$

(5-16) $$L = LFM \cdot \frac{\partial p_{LFM}}{\partial p_L}$$

where $\frac{\partial p_{LFM}}{\partial p_L} = LFM \cdot \delta_L \cdot \left(\frac{p_{LFM}}{p_L}\right)^{\sigma_3} \cdot \left(e^{-\gamma_L \cdot t}\right)^{1-\sigma_3}$.

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[154] The derivation of the dual unit cost function from the primal production function is presented, for example, in Schmidt (1999:62-65).

From (5-12), (5-14), and (5-16) the following expressions can be derived:

$$(5\text{-}17)\quad \frac{\partial p_{LEM}}{\partial p_L} = \frac{\partial p_{LEM}}{\partial p_{LFM}} \cdot \frac{\partial p_{LFM}}{\partial p_L} = \frac{LFM}{LEM} \cdot \frac{L}{LFM} = \frac{L}{LEM}$$

$$(5\text{-}18)\quad \frac{\partial p_x}{\partial p_L} = \frac{\partial p_x}{\partial p_{LEM}} \cdot \frac{\partial p_{LEM}}{\partial p_L} = \frac{LEM}{x} \cdot \frac{L}{LEM} = \frac{L}{x}\,.$$

The wage elasticity of labour demand with respect to the producer wage p_L is defined by:[155]

$$(5\text{-}19)\quad \varepsilon_{LL} = -\frac{\partial L}{\partial p_L}\frac{p_L}{L}\,.$$

Inserting (5-12) into (5-14) and (5-14) into (5-16) leads to the following expression for labour demand:

$$(5\text{-}20)\quad L = x \cdot \delta_{LEM} \cdot \delta_{LFM} \cdot \delta_L \cdot \left(e^{-\gamma_L \cdot t}\right)^{1-\sigma_3} \cdot \left[p_x^{\sigma_1} \cdot p_{LEM}^{\sigma_2-\sigma_1} \cdot p_{LFM}^{\sigma_3-\sigma_2} \cdot p_L^{-\sigma_3}\right].$$

Differentiating of (5-20) with respect to p_L yields (for given x):

$$(5\text{-}21)\quad \begin{aligned} \frac{\partial L}{\partial p_L} = {} & x \cdot \delta_{LEM} \cdot \delta_{LFM} \cdot \delta_L \cdot \left(e^{-\gamma_L \cdot t}\right)^{1-\sigma_3} \Bigg\{ \sigma_1 \frac{p_x^{\sigma_1}}{p_x} \cdot \frac{\partial p_x}{\partial p_L} \cdot p_{LEM}^{\sigma_2-\sigma_1} \cdot p_{LFM}^{\sigma_3-\sigma_2} \cdot p_L^{-\sigma_3} \\ & + p_x^{\sigma_1} \Bigg[(\sigma_2 - \sigma_1) \cdot \frac{p_{LEM}^{\sigma_2-\sigma_1}}{p_{LEM}} \cdot \frac{\partial p_{LEM}}{\partial p_L} \cdot p_{LFM}^{\sigma_3-\sigma_2} \cdot p_L^{-\sigma_3} + p_{LEM}^{\sigma_2-\sigma_1} \Bigg((\sigma_3 - \sigma_2) \cdot \frac{p_{LFM}^{\sigma_3-\sigma_2}}{p_{LFM}} \cdot \frac{\partial p_{LFM}}{\partial p_L} \cdot p_L^{-\sigma_3} \\ & + p_{LFM}^{\sigma_3-\sigma_2} \cdot (-\sigma_3) \cdot \frac{p_L^{-\sigma_3}}{p_L} \Bigg) \Bigg] \Bigg\}. \end{aligned}$$

After rearranging (5-21) and considering equations (5-16), (5-17), and (5-18) I obtain:

$$(5\text{-}22)\quad \begin{aligned} \frac{\partial L}{\partial p_L} = {} & x \cdot \delta_{LEM} \cdot \left(\frac{p_x}{p_{LEM}}\right)^{\sigma_1} \cdot \delta_{LFM} \cdot \left(\frac{p_{LEM}}{p_{LFM}}\right)^{\sigma_2} \cdot \delta_L \cdot \left(\frac{p_{LFM}}{p_L}\right)^{\sigma_3} \cdot \left(e^{-\gamma_L \cdot t}\right)^{1-\sigma_3} \Bigg[\sigma_1 \cdot \frac{L}{p_x \cdot x} \\ & + (\sigma_2 - \sigma_1) \cdot \frac{L}{p_{LEM} \cdot LEM} + (\sigma_3 - \sigma_2) \cdot \frac{L}{p_{LFM} \cdot LFM} - \frac{\sigma_3}{p_L} \Bigg]. \end{aligned}$$

With (5-12), (5-14), and having (5-16) in mind, the product before the square bracket in (5-22) reduces simply to labour demand, L. Hence the labour demand elasticity with respect to the producer wage can be written as follows:

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[155] Note that in contrast to Chapter 3 the own-price labour demand elasticity, ε_{LL}, is defined with a minus sign.

(5-23) $$\varepsilon_{LL} = -L \cdot \left[\sigma_1 \cdot \frac{L}{p_x \cdot x} + (\sigma_2 - \sigma_1) \cdot \frac{L}{p_{LEM} \cdot LEM} + (\sigma_3 - \sigma_2) \cdot \frac{L}{p_{LFM} \cdot LFM} - \sigma_3 \cdot \frac{1}{p_L} \right] \cdot \frac{p_L}{L}.$$

Finally, I obtain the following expression for ε_{LL}:

(5-24) $$\varepsilon_{LL} = -\sigma_1 \cdot \omega_1 + (\sigma_1 - \sigma_2) \cdot \omega_2 + (\sigma_2 - \sigma_3) \cdot \omega_3 + \sigma_3$$

where ω_1, ω_2 and ω_3 denote cost shares defined by

$$\omega_1 = \frac{p_L \cdot L}{p_x \cdot x}, \quad \omega_2 = \frac{p_L \cdot L}{p_{LEM} \cdot LEM}, \quad \text{and } \omega_3 = \frac{p_L \cdot L}{p_{LFM} \cdot LFM}.$$

Table 47 depicts sectoral wage elasticities of labour demand which are computed with the GEM-E3 single-country version for Germany and are evaluated at base year data.

Table 47: Own-price labour demand elasticities for GEM-E3 sectors, Germany (base year)

GEM-E3 Sector	$-\varepsilon_{LL}$
Agriculture (1)	-0.130
Solid fuels (2)	0.083
Liquid fuels (3)	-0.085
Natural gas (4)	-0.066
Electricity (5)	0.022
Ferrous and non-ferrous metals (6)	-0.440
Chemical industry (7)	-0.393
Other energy-intensive ind. (8)	-0.351
Electrical goods (9)	-0.094
Transport equipment (10)	-0.156
Other equipment goods (11)	-0.121
Consumer goods (12)	-0.193
Building and construction (13)	-0.116
Telecommunication services (14)	-0.027
Transports (15)	0.070
Credit and insurance (16)	-0.085
Other market services (17)	-0.148
Non-market services (18)	-0.040

6 Summary and final remarks

This work addresses a question that has been on the top of the political agenda for the last ten years: the employment double dividend (EDD) hypothesis. This hypothesis claims that an ecological tax reform leads to both a reduction in the unemployment rate and to lower pollution. Since the beginning of the nineties, energy/CO_2 taxes have been unilaterally introduced in several EU countries – frequently embedded within an ecological tax reform that is designed to reduce unemployment. Whether or not an ecological tax reform boosts employment is, however, disputed in the theoretical and empirical economic literature.

The theoretical research on the EDD hypothesis has widely developed during recent years and has reached a point where more empirical applications and quantitative evaluations are required. Hence the central interest of this thesis is to assess the employment effects of ecological tax reforms in a recursively dynamic computable general equilibrium (CGE) model framework. The ecological tax reforms considered refer to a shift from labour taxes (strictly speaking: social security contributions) to CO_2 emission taxes which are imposed on all energy consumers (firms and households).

Chapter 2 generally introduces to the functioning of energy taxes and recalls the common economic arguments in favour of energy taxes and tradable permits for use in national and international climate policies. It shows that both environmental instruments minimise overall abatement costs and provide innovative incentives. Some recent studies find that environmental taxes are superior over tradable permits in terms of innovation incentives. A discussion of the fiscal motives of energy taxes leads to a survey on the theoretical literature on ecological tax reforms. Theory suggests that the EDD hypothesis might be accepted only if specific model assumptions hold. In the case of a perfectly competitive labour market with an upward sloping labour supply curve, employment rises only if the ecological tax reform boosts the real consumer wage. This requires that, from a public finance point of view, labour is taxed with a too high rate compared to energy in the initial equilibrium (reflecting a sub-optimal tax system) so that tax shifting effects from labour to other sources of private income can outweigh the negative tax burden effect (caused by the energy tax) on labour income. A further interesting finding of the literature survey is that labour market distortions which are caused by wage setting behaviour may enlarge the opportunity for an EDD. If both the degree of real wage rigidity (i.e. the inflexibility of the real wage with respect to changes in employment) and the size of real wage resistance (i.e. the extent to which the incidence of a cut in social security contributions falls on employers in terms of lower labour costs) are sufficiently large to restrain the real wage, labour demand and employment may increase.

The EDD literature identifies three ways of tax shifting away from labour income: tax shifting to other factor income (e.g. to capital owners), tax shifting to the foreign sector (e.g. to foreign users of domestic intermediate and final goods), and tax shifting to non-wage income (e.g. to the unemployed).

Accordingly, it depends in CGE models on a number of model assumptions – such as the production structure, substitution and supply elasticities of factors, the foreign trade specification, or the specification of labour markets and the unemployment benefit regime – whether (and to which extent) employment will increase or not in response to a shift from labour to energy taxes. Since it is nearly impossible to understand all transmission mechanisms that lead to a particular EDD outcome in empirical models, the qualitative results of the theoretical models, surveyed in Chapter 2, serve as an indispensable guideline for the interpretation of numerical model results.

The employment effects of a shift from labour to energy taxes are evaluated in the Chapters 3 to 5 of this work. The overall framework used is the CGE model GEM-E3 which was developed by the ZEW, Mannheim, and other European research institutes on behalf of the European Commission (DG XII). The GEM-E3 EU-14 version covers 14 EU countries (linked via bilateral trade flows) and the rest of the world. While the production side is highly disaggregated (including 18 sectors), the consumer side is described by a single representative household. In the standard version of the model the labour market and all commodity markets are perfectly competitive. Invested physical capital is immobile across countries and sectors; the capital stock is quasi fixed. Capital income is partially owned by the representative household. The model includes a number of pre-existing tax distortions.

The EDD outcome in the standard GEM-E3 model version

For testing the sensitivity of model results to substitution patterns in production in Chapter 3 and to different labour market specifications in Chapter 5 I use the GEM-E3 single-country version for Germany. The ecological tax reform scenario applied (*Scenario* D_TAX20) assumes that Germany realises a CO_2 emissions reduction of -20% over a period of ten years (with –10% after the first five years) by means of a unilateral (endogenous) tax on households' and firms' CO_2 emissions. Revenue neutrality is secured by a fixed ratio of public deficit to gross domestic product; excess tax revenues are used to reduce the employers' and employees' social security contribution rates.

Since terms-of-trade effects are more important for large countries, like the European Union which has some power on world markets, the effects of different foreign trade specifications on the EDD outcome are analysed within the GEM-E3 EU-14 model framework (Chapter 4). The ecological tax reform scenario applied (*Scenario* EU_TAX10) assumes an EU-wide reduction target of households' and firms' CO_2 emissions of –10%; this target is close to the EU's commitment under the Kyoto Protocol.

Table 45 summarises the simulation results of the scenarios if these are applied to the standard versions of the GEM-E3 EU-14 model and the single-country model for Germany, respectively.

Table 48: Summary of simulation results, GEM-E3 standard version

	Scenario D_TAX20 GEM-E3 single-country version		*Scenario* EU_TAX10 GEM-E3 EU-14	
	Germany		EU-14	Germany
CO_2 emissions	-10.00	-20.00	-10.00	-8.78
Employment	0.59	1.27	0.58	0.51
Economic welfare	0.03	-0.06	0.23	0.34
Gross domestic product	0.11	0.00	-0.04	-0.07
Real consumer wage	1.36	2.61	-	0.99
Real capital income	-0.96	-2.29	-	-0.68
Terms of trade	0.55	1.32	1.03	-

Table 45 illustrates that the EDD hypothesis is accepted for both scenarios. In *Scenario* D_TAX20, German employment rises by 0.59% if CO_2 emissions are reduced by –10% (within 5 years) and by 1.27% if CO_2 emissions decrease by –20% (within ten years). Real capital income and the real producer wage fall, while the real net wage and terms of trade rise. For the –10% reduction target, economic welfare rises by 0.03%, i.e. the welfare loss caused by lower leisure is overcompensated by the welfare gain from higher consumption levels. Welfare decreases (by -0.06%), however, in *Scenario* D_TAX20 for the –20% reduction target.

In *Scenario* EU_TAX10, the EU-wide employment level increases by 0.58% and EU-wide GDP falls by –0.04% for the –10% reduction target. The increase in EU-wide employment is associated with a rise in the real consumer wage and a fall in real capital income in nearly all EU countries. The EU-wide terms of trade rise (by 1.03%) implying income redistribution between the EU-14 and the rest of the world. Moreover, the individual country figures for Germany show that employment goes up by 0.51% under the co-ordinated policy, while GDP falls by –0.07%.

Generally, in both scenarios positive employment effects can be explained by tax shifting effects from labour to the foreign sector – i.e. to foreign consumers of exported (intermediate and final) goods – and by tax shifting effects towards capital income. Since in the standard model version the labour market is perfectly competitive, labour supply depends positively on the real consumer wage and negatively on the real non-labour income. Thus both a loss in capital income (which partly accrues to the representative household) and a higher real consumer wage stimulate labour supply. On the other hand, labour demand increases due to substitution processes in response to the changed ratio of labour to fossil fuel prices. Obviously, in the GEM-E3 model, substitution effects towards labour input dominate negative output effects caused by the increase in the energy tax burden.

In Chapters 3 to 5 the single-country and multi-country standard version of GEM-E3 is changed with respect to the specification of several functional forms and the parameterisation of key elasticity values. The main interest is to test the sensitivity of model results to the employment effects of a shift from labour to energy taxes.

The EDD and substitution patterns

Chapter 3 investigates the influence of substitution patterns in production on the EDD outcome in the GEM-E3 single-country version for Germany. Since econometric estimates of substitution elasticities in German production and service sectors are rarely available, I started with estimating substitution elasticities between capital, labour, material, electricity, and fossil fuels using a translog cost function. Empirical basis is a pooled time-series cross-section data sample for 49 German producing and service sectors over the period 1978-90. Four sector aggregates are constructed including the energy supply sectors, the energy-intensive manufacturing sectors, the nonenergy-intensive manufacturing sectors, and the service sectors. First, I estimate the non-nested translog cost function, second, I estimate a three-level nested translog cost function that fits into the nesting structure of the GEM-E3 model. Even if estimates of the non-nested translog cost function have no direct connection with the GEM-E3 model, they still are interesting in the context of the general double dividend debate and fill a gap of empirically substantiated, sectorally disaggregated substitution elasticities in German production and service sectors.

Since the estimation of the non-nested translog cost function yields significantly positive own-price elasticities for some sector aggregates and energy inputs, I impose local concavity restrictions on the parameters. A comparison of results, however, indicates that differences between the unrestricted and the local concavity restricted model are of minor importance. The constant-output own-price elasticity is (in absolute terms) highest for capital demand, whereas electricity and fossil fuel demand seem to be less price elastic (except for the energy supply sectors aggregate). Positive Morishima elasticities of substitution below unity are obtained for the majority of sectors and input pairs. This indicates an overall dominance of weak substitutability relationships. In particular the results support the hypothesis that capital and energy are substitutes. An interesting result of the one-stage estimation is that it is only for nonenergy-intensive manufacturing and the service sectors aggregate that labour seems to be a better substitute for electricity than capital or material; in most other cases, labour is more difficult to substitute for energy than capital or material. Besides, the estimation of sectoral economy-of-scale elasticities yields the result that it is only for 17 of 49 sectors (mainly energy-intensive manufacturing sectors) that the hypothesis of constant returns to scale cannot be rejected at a 5% level of significance, indicating that the majority of sectors are described by decreasing returns to scale (mainly nonenergy-intensive manufacturing sectors) or increasing returns to scale (mainly energy supply and service sectors). Testing for homotheticity and homogeneity shows that the aggregates are characterised by non-homothetic and non-homogeneous production functions.

In the next step, substitution elasticities are estimated for the nested production function used in the GEM-E3 model for Germany. A comparison with the values previously used in the model indicates considerable numerical differences for several sectors. Testing for weak homothetic separability restrictions proves, however, that inputs can be aggregated only in exceptional cases. Thus the econometric estimates of the multi-stage estimation are surrounded by some uncertainty, and further sensitivity tests are required. Since the econometric tests do not support any alternative nesting structure, I maintain the one previously used in the GEM-E3 model with capital and a labour-energy-material aggregate at the first nesting level, with electricity and a labour-fuel-material aggregate at the second nesting level, with labour, a fossil fuel aggregate, and a material aggregate at the third nesting level, and, finally, with three fossil fuels inputs and 14 nonenergy material products at the fourth nesting level.

I provide sensitivity analyses which are based on the single-country version of the GEM-E3 model for Germany and the *Scenario* D_TAX20. The model computes a double dividend in terms of lower CO_2 emissions and higher employment for all substitution elasticity constellations considered: the previously used values and the new econometric estimates, while the latter are also halved and doubled. A –20% CO_2 emissions reduction goal is, however, associated with a decrease in economic welfare in most cases; welfare rises only (by 0.03%) in the case of doubled substitution elasticity values. Positive employment effects increase with a declining degree of substitutability between the inputs and input aggregates at all four nesting levels. For halved elasticity values, employment rises by 2.31%, for doubled values by 0.73%. This result might be explained with help of the given nesting structure of the GEM-E3 producer model: The more substitution possibilities are restricted at the first nesting level, the lower is the rise in capital demand and the higher is the fall in capital income (indicating tax shifting effects towards capital) in response to an increase in the unit costs of the labour-energy-material aggregate. All in all, the numerical simulations with the single-country version of the GEM-E3 model indicate that the macroeconomic impacts of an ecological tax reform in Germany are – in terms of the sign – relatively insensitive with respect to a change of substitution elasticities in production; the model computes an EDD for a wide range of values.

The EDD and foreign trade

In Chapter 4 I study the influence of different foreign trade specifications on the macroeconomic effects of ecological tax reforms. Since the majority of analytical models rely on the small-country assumption which implies that exogenous world market prices completely determine the domestic price level, the impact of terms-of-trade effects has been widely neglected in the theoretical double dividend literature. Nevertheless, terms-of-trade effects may arise in the case of a large country like EU-14 that exerts market power on world markets. Hence in order to investigate terms-of-trade effects, I apply the GEM-E3 EU-14 model version and the *Scenario*

EU_TAX10 that assumes an EU-wide ecological tax reform. The focus, however, is not only on terms-of-trade effects but also on the effects of varying foreign closure specifications on the EDD outcome.

Even if GEM-E3 EU-14 is a multi-country model, a closure rule is necessary because the behaviour of the rest of the world is exogenous in large parts. The survey on the theoretical literature reveals that the closure rule incorporated in the GEM-E3 EU-14 model is advantageous in empirical applications as it avoids complete specialisation in production, allows for modelling of intra-industrial trade flows, and includes non-traded and traded goods. In particular intra-EU trade activities, which account for around 60% of the whole EU trade, are modelled realistically as they depend on an endogenous EU-price system. In the standard version, the EU-14 is modelled as a small country that cannot influence world market prices. The small-country assumption of exogenous and fixed world market prices, however, is relaxed by the Armington assumption of product heterogeneity for import demands of the EU countries and the rest of the world. According to this approach the EU-wide price level is not completely determined by world market prices, and the rest of the world's import demand is finite price elastic.

Based on the literature survey, I suggest three changes in the foreign trade specification and test them with respect to the employment effects of an EU-wide ecological tax reform.

The first change replaces the assumption of fixed world market prices by a finite price elastic foreign export supply function of the rest of the world. Relaxing the assumption of fixed prices facing EU imports considerably affects the EU terms of trade and the EDD outcome. The simulation results suggest that the EU-14 as a whole gains from more flexible export prices. Sensitivity analyses with respect to the export price elasticity indicate that a lower own-price elasticity of foreign export supply leads to a stronger rise in EU-wide economic welfare and employment. For a foreign export price elasticity of 0.5 for all sectors, employment increases by 0.82% in EU-14, whereas for an elasticity of 2 the increase is only 0.64% – which is still higher than the increase of 0.58% in the standard version with an infinite elasticity. With a declining degree of own-price elasticity of foreign export supply the world market prices increase in response to the EU-wide ecological tax reform – except for energy products for which world market prices drop dramatically. Particularly foreign suppliers of carbon-intensive fossil fuels suffer big income losses (both EU import demand for fossil fuels and world market prices are reduced by the EU-wide CO_2

tax). If world market prices are flexible, the EU-wide terms of trade are affected not only by the policy induced impact on European export prices, but additionally by the effects on foreign import prices. Simulation results show that the terms of trade in EU-14 rise more compared to the standard case, where world market prices are fixed. In the case of a finite price elastic foreign export supply function, positive employment effects are also stronger since cost-effective substitution possibilities to foreign imports are restricted; this reinforces the switch to labour. The stronger rise in labour demand leads to higher real wage rates and to higher labour supply.

The second modification in foreign trade concerns the modelling of import demand of the rest of the world. In the standard GEM-E3 EU-14 model version, (sectoral) foreign import demand only depends on the (sectoral) terms of trade, while income effects in the rest of the world are neglected. In order to approximately account for income effects, I introduce a new specification that establishes a linkage between sectoral foreign import demand and sectoral foreign exports. The new specification only leads to slight impacts on simulation results. Sensitivity analyses with respect to the empirically estimated degree of linkage show that employment remains nearly unaffected compared to the standard version: EU-wide employment rises for the highest degree of linkage considered by 0.02 percentage points, and EU-wide terms of trade increase by 0.03 percentage points compared to the standard version. As expected, the new specification causes a further fall in aggregate EU exports since negative income effects in the rest of the world additionally reduce foreign demand for EU exports.

Both changes, the introduction of a finite price elastic foreign export supply function and of income effects into foreign import demand through a proxy variable, have some shortcomings which can only be overcome by extending the regional scope of the GEM-E3 EU-14 model towards a global model with an endogenous representation of the behaviour of agents in RoW. Recent developments of a world model version (GEM-E3 World) are geared toward this issue.

The third change refers to the empirical specification of Armington elasticities in the import demand function of both the EU-14 and the rest of the world and, thus, to import price elasticities. As expected, the EU increasingly benefits from the ecological tax reform policy in terms of economic welfare and employment with declining Armington elasticity values in foreign import demand. Lower Armington elasticities in foreign import demand offer greater possibilities for EU-14 countries to shift the tax burden abroad. Sensitivity analyses which are based on an EU-wide ecological tax reform scenario (*Scenario* EU_TAX10) indicate that for doubled upper-level Armington substitution elasticity values employment increases only by 0.56% (recall that employment rises in the standard version by 0.58%), while employment rises by 0.60% for halved values. Obviously, the GEM-E3 EU-14 model proves to be rather robust with respect to variations in upper-level Armington elasticities.

The EDD and labour market institutions

Finally, I examine in Chapter 5 whether the employment effects of an ecological tax reform in Germany change in the GEM-E3 model framework if labour market forces are restrained by labour market institutions. Since Germany is characterised by a degree of union coverage above 90%, I employ a trade union model in order to describe aggregate wage setting behaviour and involuntary unemployment in Germany. Although in Germany wage setting mainly takes place at the industry level, unions' wage claims are partly co-ordinated between sectors and regions by wage leadership. Notwithstanding a rather low degree of union density (below 50%) and the presence of influential employers' associations, I apply the monopoly union model which provides a simple representation of wage setting and is a special case of the more realistic right-to-manage model.

According to the derived wage setting rule, the aggregate wage level depends on the economy-wide unemployment rate, the unemployment benefit system, and the aggregate labour demand elasticity of the three sectors for which the wage is set by the leading industry union. I assume that the Metal Workers' Union is a wage leader that sets the wage rate for the employees of the ferrous and non-ferrous ore industry, the electrical goods industry, and the transport equipment industry. This wage is then accepted by all other trade unions without modification.

For a first test of the sensitivity of the EDD outcome with respect to the wage setting rule, I introduce exogenous real wage rigidities into the model. Simulation results show that the employment effects are quite sensitive to the particular wage fixing rule. As expected, positive employment effects are the highest if the real net wage is fixed throughout the whole simulation period, i.e. if the incidence of the cut in social security contributions is fully borne by employers. In this case, the model computes a positive employment effect of around 10% for the –20% CO_2 emissions reduction target. Associated with this increase is a sharp decline in real labour costs by more than –9%. While in the case of a competitive labour market an increase in employment (by 1.27%) is associated with a rise in the real net wage (by 2.61%), additional labour demand (stimulated by technological substitution effects) can now be saturated by formerly unemployed workers at significantly lower labour costs.

The increase in employment (0.68%) is moderated considerably, or even turns into a decrease (-2.04%), for two further wage fixing rules considered. These are based on the assumption that the real net wage increases by half of the amount and the whole amount respectively of the cut in employees' social security contributions. Since this lowers the degree of real wage resistance, labour costs are reduced to a lower extent or even rise.

The simulation results obtained from the monopoly union model show that labour market imperfections may enlarge the opportunity for an EDD. In the case of the single-country version of the GEM-E3 model – which computes positive employment effects for a perfectly competitive labour market – an ecological tax reform leads to stronger positive employment effects if the labour market is initially distorted by trade unions. Simulation results further indicate that employment effects are higher if real wage resistance exists (i.e. if the ecological tax reform makes the income position of the unemployed worse compared to that of the workers). This is the case for nominally fixed unemployment benefits, for which the benefit replacement ratio is variable: Employment rises by 1.92% if CO_2 emissions fall by -20% (compared to 1.27% in the standard version and to 1.48% in the case of monopoly unions and a fixed replacement ratio). Actually, a degeneration of the relative income position of the unemployed reduces the union's wage pressure and leads to lower unemployment.

Restricting assumptions and future needs of research

At the end of the summary of research results, I would like to pick out some restricting assumptions of this work which uncover future needs of research.

First, I theoretically discuss the innovative incentives of energy taxes in Chapter 2, but these incentives are widely ignored in the CGE framework used. In reality, energy taxes can provide a long-run signal effect for firms to search for energy-saving technologies. In the GEM-E3 model, these signal effects are only captured by price induced substitution processes within a given production technology, while technical progress is exogenous. Thus future research is needed in the role of endogenous technical progress and the EDD outcome.

Second, a main driving force in the model are tax shifting effects from labour to capital income. These are possible since invested capital is internationally immobile and cannot be shifted abroad. In particular in the long run, however, this assumption is critical and may lead to an overrating of positive employment effects.

A further limiting assumption of the analysis refers to the proposed specification of the non-clearing labour market. Critical points are not only the use of a monopoly union model instead of a more realistic right-to-manage model, but also the omission of segmented labour markets and different skill types. The assumption of intersectoral mobility of labour is unrealistic, too, and tends to overstate the positive employment impacts of ecological tax reforms (at least in the short run). In addition, wage leadership is modelled in a rough way which does not account for internalisation of wage externalities. Further, the neglect of sectoral wage differentials implies large labour market inefficiencies.

While it is difficult to introduce all these missing features into a CGE model, they need to be borne in mind when interpreting the results. Moreover, they point to the necessity to extend the labour market model in future work. Since product market and labour market imperfections are correlated in reality, the introduction of imperfect competition on output markets represents an important research task as well.

Last, but not least, the study neglects equity issues of ecological tax reforms since only a single representative household is considered. In reality, however, tax shifting effects from workers towards the earners of private non-wage income, such as capital owners or recipients of unemployment benefits, change the income distribution. Thus it might be an interesting point in future model development to introduce different household types in order to consider distributional effects of ecological tax reforms.

Appendix IV: Structure of the GEM-E3 model

GEM-E3 is a multi-country computable general equilibrium model that was developed on behalf of the European Commission, DG XII, in co-operation with several European research institutes including the ZEW, Mannheim. When I started with my thesis at the ZEW, I was in the advantageous situation of being able to utilise a nearly complete version of the model for the EU-14 without being burdened with laborious basic construction work. Thus, I will just give a short description of the model version which I use in this work. Concerning the foreign trade specification in the GEM-E3 EU-14 model, I would like to refer the reader to Chapter 4 in which I also discuss possible model extensions. For a detailed presentation of the model structure and the empirical data basis see Capros et al. (1997) and Schmidt (1999).

A.1 Production sector

As previously mentioned in Chapter 3, the technology of a cost-minimising industry is characterised by nested CES cost functions. Figure 3 in Section 3.2.3.2 already provided an overview of the nesting structure.

Using the dual formulation, the cost function $C(p_{LEM}, p_K, x, t)$ represents the first stage of the problem of the firm in which a sectoral output good x is produced with respect to the input prices for capital, p_K, and the *LEM* (labour-energy-material) aggregate, p_{LEM}.[156] Technical progress, represented by t, is specified by exponential (exogenous) rates of price diminution. This type of technical change considers, for example, autonomous energy efficiency improvements (see Hillebrand et al. 1998).

Profit maximisation under constant returns to scale (in the long run) implies marginal revenues equal to marginal costs, which explains the output price p_x of domestic production in terms of a CES unit cost function:

(A-1) $p_x = p_x(p_{LEM}, p_K, t)$.

Applying Shephard's lemma yields the factor demand function for capital, K, and the *LEM* aggregate.

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[156] Sectoral indices are omitted in the following equations.

Capital input as derived from (A-1) represents the desired capital stock, K_{des}. In the GEM-E3 model, however, the sectoral capital stock is quasi fixed over the current year at a level reached at the end of the previous year, K_{fix}. Hence the derived demand function for K is used to determine an endogenous *ex post* price of capital, $p_{K\ post}$:

(A-2) $$p_{K\ post} = p_x \cdot f\left(\frac{x}{K_{fix}}, t\right).$$

$p_{K\ post}$ is the endogenous shadow price of capital which clears the market for the fixed capital stock, K_{fix}. It is used to calculate capital income: $p_{K\ post} \cdot K_{fix}$,[157] which is distributed among households (in form of interest payments from assets, dissemination of firms profits, entrepreneurs' salary), firms, and the government.

Given the *ex ante* price of capital $p_{K\ ante} = p_I \cdot (r + \delta)$, the factor demand function for K can be employed to determine the desired stock of capital, K_{des}, where p_I denotes the price of investment goods, *r* is the rate of return on risk-free government bonds (in the standard version of the model with a flexible current account *r* is exogenous), and δ is the rate of replacement.

Net investment I_{net} is given by:

(A-3) $I_{net} = m(K_{des} - K_{fix})$, where $0 \leq m \leq 1$.

Finally, the capital stock for the next period is:

(A-4) $K = I_{br} + (1 - \delta)K_{fix}$

where $I_{br} = I_{net} + \delta \cdot K_{fix}$ (gross investment).

In the next step, a CES price function for the *LEM* aggregate is specified:

(A-5) $P_{LEM} = P_{LEM}(P_{EL}, P_{LFM}, t)$

where p_{EL} is the price of electricity and p_{LFM} is the price index of the *LFM* (labour-fossil fuel-material) aggregate. Applying Shephard's lemma yields the factor demand function for electricity and the *LFM* aggregate.

One level further down of the nesting, the unit cost function for the *LFM* aggregate is specified:

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[157] It is easy to check that the calculation of $p_{K\ post}$ is equivalent to calculating it from the zero profit condition.

(A-6) $p_{LFM} = p_{LFM}(p_L, p_F, p_M, t)$.

Again, the price dependent, cost-minimising composition of the *LFM* aggregate is derived from Shephard's lemma. This yields the input coefficients for labour, *L*, the material aggregate, *M*, and the fossil fuel aggregate, *F*.

The final level is represented by a CES composition of fuel and material aggregates. The fuel aggregate consists of three fuel inputs (represented by F_1, F_2, F_3 in Figure 3 in Section 3.2.3.2): solid fuels (2), liquid fuels (3), and natural gas (4); the material aggregate contains fourteen nonenergy inputs (corresponding to $M_1, \ldots, M_{14}$ in Figure 3, Section 3.2.3.2): agriculture (1), ferrous and non-ferrous metals (6), chemical industry (7), other energy-intensive industries (8), electrical goods (9), transport equipment (10), other equipment goods (11), consumer goods (12), building and construction (13), telecommunication services (14), transports (15), service of credit and insurance institutions (16), other market services (17), and non-market services (18).[158]

(A-7) $p_F = p_F(p_{\tilde{Y}_{F1}}, p_{\tilde{Y}_{F2}}, p_{\tilde{Y}_{F3}}, t)$

(A-8) $p_M = p_M(p_{\tilde{Y}_{M1}}, \ldots, p_{\tilde{Y}_{M14}}, t)$

where $p_{\tilde{Y}_{Fi}}$ denote the prices of domestic supply of coal, oil, and gas plus indirect taxes including environmental taxes and abatement costs (see the definition of $p_{\tilde{Y}_{Fi}}$ in (A-18)), and $p_{\tilde{Y}_{Mi}}$ represent the prices of domestic supply of the nonenergy intermediates plus indirect taxes. The input coefficients are derived by applying Shephard's lemma. By multiplying the input coefficient of the aggregates by the coefficients of their sub-inputs the overall input coefficients with respect to the domestically produced supply are obtained.

A.2 Consumer demand and labour supply

The behaviour of the representative household is assumed to perform a two-stage budgeting procedure: an intertemporal allocation of lifetime wealth endowment between present and future consumption of goods and leisure and an intratemporal allocation of total consumption of goods to durable and non-durable goods. Figure 5 illustrates the household's allocation problem:

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[158] Numbers in parentheses denote GEM-E3 sectors (cf. Table 17 in Appendix I of Chapter 3).

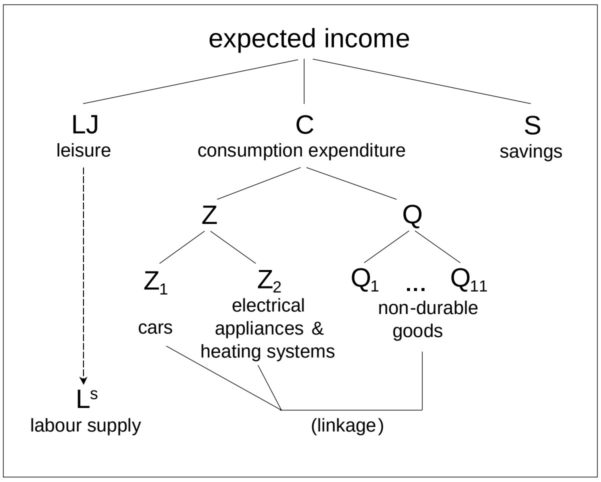

Figure 5: The household's allocation scheme of the GEM-E3 model

The representative household determines an allocation of its resources between present and future consumption by maximising an intertemporal utility function subject to an intertemporal budget constraint:[159]

$$\text{(A-9)}\quad \max_{C_t, LJ_t} \sum_t (1+s)^{-t}\left[\beta_C \ln(C_t - \overline{C}) + \beta_{LJ} \ln(LJ_t - \overline{LJ})\right]$$

$$\text{s.t. } WT = \sum_t (1+r)^{-t}(p_{C_t} \cdot C_t + p_{LJ_t} \cdot LJ_t)$$

where WT is the present value of wealth. C_t is private consumption (in volume) and $\overline{C}$ its subsistence level, LJ_t is leisure (in volume) and $\overline{LJ}$ its subsistence level, s is the discount rate and r the nominal interest rate. The price of leisure, p_{LJ_t}, is calculated according to: $p_{LJ_t} = (1-t_{hss}) \cdot (1-t_{hdir}) \cdot w_t^{nom}$, where t_{hdir} is the marginal tax rate for labour income, t_{hss} is the employees' contribution rate to social security, and w_t^{nom} is the nominal gross wage rate.

Under myopic expectations and the assumption of constant and equal growth rates for both inflation and the nominal wage rate the Fisher relation can be used to reduce the demand functions for consumption and leisure to the following expressions:[160]

$$\text{(A-10)}\quad C = \overline{C} + \frac{s}{r_r} \cdot \frac{\beta_C}{p_C}\left(Y_{disp} + p_{LJ} \cdot LJ - p_C \cdot \overline{C} - p_{LJ} \cdot \overline{LJ}\right)$$

$$\text{(A-11)}\quad LJ = \overline{LJ} + \frac{s}{r_r} \cdot \frac{\beta_{LJ}}{p_{LJ}}\left(Y_{disp} + p_{LJ} \cdot LJ - p_C \cdot \overline{C} - p_{LJ} \cdot \overline{LJ}\right)$$

---

[159] β_C and β_{LJ} are normalized so as to sum up to one.

[160] See Schmidt (1999) for a complete representation of the derivation.

where r_r denotes the real long-term interest rate which is assumed to be constant in the standard version of the model.[161]

In order to obtain leisure demand one has to solve (A-11) for *LJ*. Labour supply L^S is then given by the residual of total time resources minus leisure demand. In the standard version of the GEM-E3 model with a neo-classical labour market, the wage rate serves to balance labour demand of firms and leisure demand of households. The savings of households *S* are determined by the difference of disposable income and consumption expenditures: $S = Y_{disp} - p_C \cdot C$.

The model distinguishes between two types of consumption expenditure: expenditure for non-linked, non-durable goods ($\hat{e}$), which are allocated on the second stage of the consumer decision problem, and expenditure associated with the use of durable goods – covering capital user costs and demand for linked non-durable goods.

The GEM-E3 model considers eleven non-durable consumption categories (corresponding to $Q_1,\ldots,Q_{11}$ in Figure 5): food, beverages, tobacco (1), clothing (2), housing and water (3), fuels and power (4), housing furniture (5), medical care and health expenses (7), operation of transport equipment (9), purchased transport (10), telecommunication services (11), culture (12), and other services (13). Furthermore, the model includes the following two non-durable commodities (corresponding to Z_1 and Z_2 in Figure 5): heating and cooking appliances (6) and transport equipment (8).[162]

Demand for linked non-durable goods and demand for services from durables has to be reconciled with investment demand for the modification of the stocks of durables towards their optimal levels. This requires the employment of a restricted expenditure function with stocks of durables as quasi fixed goods. The expenditure function for (linked and non-linked) non-durable goods and given stocks of durables $e(\mathbf{p},u,\mathbf{Z})$ is derived from the Stone-Geary utility function $u(\mathbf{Q},\mathbf{Z})$ underlying the linear expenditure system (cf. Schmidt 1999:124-130):

$$\text{(A-12)}\quad u(\mathbf{Q},\mathbf{Z}) = \prod_{i=1}^{11} (Q_i - \overline{Q_i})^{\beta_i} \cdot \prod_{j=1}^{2} (Z_j^{fix} - \overline{Z_j})^{\gamma_i}$$

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[161] The long-term interest rate is endogenous if the constraint of a balanced current account is imposed (see Section 4.3.4).

[162] Numbers in parentheses denote GEM-E3 consumption goods categories.

$$\text{s.t. } p_C \cdot C = \sum_{i=1}^{11} p_{Q_i} \cdot Q_i + \sum_{j=1}^{2} (\tilde{p}_{Z_j} \cdot Z_j^{fix} + p_{Z_j} I_{Z_j}^{net}), \text{ where } \sum_i \beta_i + \sum_j \gamma_j = 1.$$

$$\text{(A-13) } e(\mathbf{p}, u, \mathbf{Z}) = \sum_{i=1}^{11} p_{Q_i} \cdot \overline{Q_i} + u \cdot \prod_{j=1}^{2} (Z_j^{fix} - \overline{Z_j})^{-\gamma_j} \cdot \prod_{i=1}^{11} \left(\frac{p_{Q_i}}{\beta_i} \right)^{\beta_i}$$

where p_{Q_i} and p_{Z_j} indicate market prices of consumption good categories which are derived from supply prices of sectors (including indirect taxes) and the consumption matrix (by product). $\tilde{p}_{Z_j}$ represents the user-cost price of durable good *j*, *u* is the utility level, $\overline{Q_i}$ the minimum required quantity of non-durable consumption good *i*, Z_j^{fix} is the quasi-fixed stock of durable good *j*, $\overline{Z_j}$ is the minimum required quantity of durable good *j*, and $I_{Z_j}^{net}$ denotes net investment in durable good *j*.

Expenditure minimising demand for non-durable goods, given utility *u* and the quasi fixed stocks of the durables, can be derived by partial differentiation of the expenditure function (A-13) with respect to prices (Shephard’s lemma):

$$\text{(A-14) } Q_i = \overline{Q_i} + \frac{\beta_i}{p_{Q_i}} \left(\hat{e} - \sum_{i=1}^{11} p_{Q_i} \cdot \overline{Q_i} \right), \quad i = 1,\ldots,11.$$[163]

A special feature of the GEM-E3 model is the linkage between non-durable and durable goods: two non-durable goods (fuels and power (4) and operation of transport equipment (9)) are linked to the stocks of heating and cooking appliances (6) and transport equipment (8). In these cases, the input of the non-durables is composed into a linked (complementary) part and a disposable part.

The linked part is defined by $Q_i^l = \alpha_{i,j} \cdot Z_j^{fix}$, where $\alpha_{i,j}$ is yearly (fixed) consumption of non-durable good Q_i per unit of purchase price of durable good Z_j^{fix}.[164] The disposable part was already specified in (A-14). Consequently, total demand of non-durable good *i* is given by the sum of Q_i and Q_i^l. As the consumption of linked non-durables does not enter the utility function but increases only the user costs of durables, the expenditure function (A-13) is reduced by $\sum_{i,j} \alpha_{i,j} \cdot p_{Q_i} \cdot Z_j^{fix}$, leading to $\hat{e}$.

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[163] $\hat{e}$ is defined as the expenditure given by *e* minus the expenditure for linked non-durable goods (see below).

[164] See Conrad and Schröder (1991) for more details.

The user-cost concept for durables implies a price $\tilde{p}_{Zj}$ for the services of the durable good Z_j^{fix} which includes the user cost of capital plus the associated costs of linked non-durable goods:

(A-15) $\tilde{p}_{Zj} = p_{Zj}(r+\delta) + \sum_{i=1}^{11} \alpha_{i,j} \cdot p_{Q_i}$.

The desired stocks of durables and the *ex post* service prices of durables can be derived by analogy with the restricted cost function approach. With an exogenous *ex ante* user-cost price of durables $\tilde{p}_{Z_j}$ the desired stock Z_j^{des} follows from:

$$\frac{\partial \hat{e}(\cdot\,, Z_j^{des})}{\partial Z_j} \overset{!}{=} -\tilde{p}_{Z_j}, \qquad \textit{i.e.}$$

(A-16) $Z_j^{des} = \overline{Z_j} + \frac{\gamma_j}{\tilde{p}_{Z_j}} \left(\hat{e} - \sum_{i=1}^{11} p_{Q_i} \cdot \overline{Q_i} \right)$.

Purchases of new durables under partial adjustment restrictions are (cf. (A-3)):

(A-17) $I_{Z_j}^{net} = m_{Z_j} \cdot (Z_j^{des} - Z_j^{fix})$, where $0 \le m_{Z_j} \le 1$.

With this specification one can analyse the impact of environmental policy on the stock of durable goods (e.g. cars). According to (A-18) (see below), a tax on CO_2 (or NO_X) emissions increases, for example, the price of gasoline. The user cost of an already purchased car , $\tilde{p}_{Z_j}$, increases as well, while the long-run optimal stock of cars, Z_j^{des}, and the demand for new cars, $I_{Z_j}^{net}$, decline.

A.4 Demand, supply, and model closure

Since the demand system determines consumption goods by categories and the system of investment functions determines investment demand by destination, transition matrices are required to transform demand into deliveries from the industries. Therefore, the final demand is the result of the transition matrix of the type (branches × categories) multiplied by the consumption categories. Similar to the matching of consumption categories to products, an investment matrix with fixed technical coefficients is used to calculate investment demand by origin (products) from investment demand by destination (branches) as evaluated from the investment behaviour in (A-3), together with investment for replacement and decay, i.e. $\delta \cdot K^{fix}$.

The national accounting identity, which expresses that the private gross domestic production from both the flow of cost approach and the flow of product approach should be equal, is satisfied if and only if total saving, involving income distribution and fiscal policy relationships, equals total investment. Following Walras' Law, this market (n+1) is in equilibrium if an equilibrium price vector is found for the other n markets (supposing that the demand, supply and price functions are specified according to the needs of an Arrow-Debreu economy). Therefore, the saving-investment identity (I=S) and the corresponding global shadow price of capital (mobility of (new) capital between sectors but not across countries is assumed) is automatically given.

A.5 The environmental module in GEM-E3

The scope of the environmental issue considered is limited to the primary pollutants: nitrogen oxides (NO_X), sulphur dioxide (SO_2), volatile organic compounds (VOC), particulate (PM10), and carbon dioxide (CO_2); and the secondary pollutants: ozone (O_3), sulphur (S), and nitrates (N). These emissions are calculated in linear relation to the use of primary energy inputs, i.e. solid fuels, liquid fuels, and natural gas. The consideration of transboundary air pollution and the computation of secondary pollutants yield concentration and/or deposition figures per pollutant and country. These figures serve as input for the evaluation of damages, which, in turn, are used for an integrated *ex post* assessment of a particular environmental policy.

For SO_2, NO_X, and VOC end-of-pipe abatement cost functions $c^{ab}(a)$ are explicitly specified. Policy induced abatement measures (i.e. the degree of abatement a), but also emission/energy pricing through taxes, increase the cost price of using pollution-intensive inputs. This changes price relations and the derived demand for intermediates and final consumption. To include these aspects, the (sectoral) prices of pollution-intensive inputs, $p_{F_i,s}$, are expressed as follows:

$$\text{(A-18)}\quad \begin{aligned} p_{\tilde{Y}Fi,s} &= (1+t_{i,s})\cdot p_{Y_i} + c_s^{en}\cdot ec_i\cdot \chi_{i,s} \\ &\quad + \sum_p \left(\left[(1-a_{p,s})\cdot c_{p,s}^{ef}(a_{p,s}) + a_{p,s}\cdot c_{p,s}^{ab}(a_{p,s})\right]\cdot ef_{p,i,s}\cdot \mu_{i,s}\right) \end{aligned}$$

where

c_s^{en} : tax on energy,

ec_i : coefficient for energy content of energy input i (equal across sectors),

$\chi_{i,s}$: share of energy related use of input i in sector s,

$ef_{p,i,s}$: emission factor for pollutant p using input i in sector s,

$ef_{p,i,s} = 0$ for $i \neq$ emission causing energy input,

$\mu_{i,s}$: share of energetic use of demand of input i in sector s,

$\alpha_{i,s} \cdot X_s$: intermediate demand of input i for output x_s in sector s .

A similar specification is used for the price of linked non-durable goods in private consumption. Inserting these prices in (A-7) and the user cost of durables (A-15) and maximising profits or utility yields both the policy induced changes in (intermediate or final) demand and the optimal degree of end-of-pipe abatement. The sectoral expenditure for end-of-pipe abatement is distributed to demand addressed to delivery sectors through fixed coefficients. These inputs are added to the intermediate demand of the sectors and are priced just like all other intermediate deliveries.

A.6 Welfare measure

The welfare change used for the evaluation of policy scenarios is represented by Hicks' measure of equivalent income variation (*EV*). The *EV* is based on the intertemporal utility maximisation problem and is derived from (A-9) – (A-11). In a single period *t* the *EV* is defined as:

(A-19) $EV_t = FE(p^0_{C_t}, p^0_{LJ_t}, u^1_t) - FE\,(p^0_{C_t}, p^0_{LJ_t}, u^0_t)$

where *FE* is the expenditure function corresponding to (A-9) – (A-11); u^1_t and u^0_t indicate the utility levels observed in the policy and the reference scenario. *EV* gives the change in expenditure at base case prices p^0_C and p^0_{LJ} that would be equivalent to the policy implied change in utility. In order to derive the expenditure function from the utility function, the demand functions (A-10) and (A-11) are inserted into the utility function (A-9) which is solved for the level of utility, u_t:

(A-20) $u_t = \beta_C \cdot \ln\left(\frac{\beta_C}{p_{C_t}} \cdot \frac{s}{r_r}\right) + \beta_{LJ} \cdot \ln\left(\frac{\beta_{LJ}}{p_{LJ_t}} \cdot \frac{s}{r_r}\right) + \ln\left(FE_t - p_{C_t} \cdot \overline{C} - p_{LJ_t} \cdot \overline{LJ}\right)$

where FE_t is total expenditure, i.e. $FE_t = Y_{disp,t} + p_{LJ_t} \cdot LJ_t$.

Solving (A-20) for FE_t yields the expenditure function used in (A-19) to determine *EV*:

$$FE_t(p_{C_t}, p_{LJ_t}, u_t) = \exp\left(u_t - \ln\left[\left(\frac{\beta_C}{p_{C_t}}\right)^{\beta_C} \cdot \left(\frac{\beta_{LJ}}{p_{LJ_t}}\right)^{\beta_{LJ}} \cdot \left(\frac{s}{r_r}\right)\right]\right) + p_{C_t} \cdot \overline{C} + p_{LJ_t} \cdot \overline{LJ} \,.$$

The utility level u_t is calculated from the t^{th} element of the sum of utilities in (A-9). To aggregate the stream of welfare gains (or losses) of the entire time horizon, a present value operator is applied. The overall welfare effect of the policy is then:

$$EV^{tot} = \sum_{t=0}^{T} \left(\frac{1}{(1+s)^{t}} \cdot \left(\exp(u_t^1 - \eta_t^0) - \exp(u_t^0 - \eta_t^0) \right) \cdot \left(\frac{p_{C_0}^0}{p_{C_t}^0} \right)^{\beta_C} \cdot \left(\frac{p_{LJ_0}^0}{p_{LJ_t}^0} \right)^{\beta_{LJ}} \right)$$

where η_t^0 is a function of some reference run data.[165]

If $EV^{tot} < 0$, welfare is lower after the policy measure than in the reference case. The consumer would be willing to pay the maximum amount EV^{tot} at the fixed budget level FE^0 to avoid the decline of utility. Similarly, if EV>0, the consumer would be willing to pay up to EV^{tot} to see the policy implemented.

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[165] See Schmidt (1999) for a complete representation of the derivation.

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