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Climate Change Policy and Burden Sharing in the European Union
- Applying alternative equity rules to a CGE-framework

Tobias F.N. Schmidt, Henrike Koschel

Non-technical summary

Many conflicts in international climate change negotiations are linked to the question of how to allocate the burden associated with a substantial reduction of greenhouse gas emissions. These distributional aspects arise on several levels: globally, regionally (e.g. within the European Union) and nationally. As the review of equity rules exhibits, the range of principles and preferences that can be applied is wide. With respect to the self-interest of nations it is therefore no surprise that international agreements are difficult to attain.

Tradable pollution permits could be one attempt to address equity aspects without affecting economic efficiency: As theoretical contributions show, the equity rule applied to the initial allocation of permits is independent of the efficient, i.e. cost-minimzing realization of the emission reduction target as the latter is ensured by the international trade of permits. Nevertheless, our empirical analysis of the burden sharing issue within the European Union (EU) indicates that the equity rule applied plays an important role for the potential impacts (i.e. costs), even though both aspects are treated separately.[1]

The ability-to-pay rule, which favours the poorer and puts the richer countries at a disadvantage, implies higher overall welfare costs for the EU than the sovereignty rule, where permits are grandfathered with respect to a uniform reduction rate. Certainly, this effect is linked to the weights given to the country-specific welfare. For the computations no inequality aversion is applied, i.e. weights are uniform. On the other hand, the analysis of national impacts gives two insights that are not biased by this kind of evaluation: First, if big countries (i.e. countries that are powerful in terms of economic activity) are affected considerably, the interconnection of countries through bilateral trade might make the underlying burden sharing rule less attractive even for those countries which are favoured by the particular equity rule in terms of the initial allocation. And second, the recycling of the surplus of permits emerging for some countries in the ability-to-pay allocation has crucial impacts on consumer welfare. Using the revenues from selling this surplus on the international market to reduce public deficit leaves the rest of the economy more or less untouched and therefore gives no positive signal to welfare.

With respect to economic and environmental welfare, the sovereignty rule seems to be the most acceptable for an implementation of an EU-wide permit

[1] The simulations and their assessment are based on the GEM-E3 model, a multi-country and multi-sectoral general equilibrium model framework for the European member states.

system. All countries show a positive welfare effect and the overall EU benefit is greater than under egalitarianism and ability-to-pay.

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Abstract

The objective of this paper is to present different equity rules that can be applied to the initial allocation of greenhouse gas entitlements and to analyse the potential impacts of these rules EU-wide as well as on the level of member states. The methodological framework used in the empirical part of the paper is based on the GEM-E3 model, a multi-country and multi-sectoral computable general equilibrium model for fourteen EU-member states. The major finding of the paper is that being *ex ante* favoured with respect to the initial allocation of permits might not hold *ex post*, i.e. when trade of permits and actual emission reductions are carried out. The reason can be found in two effects. First, the interdependence of the EU economies allows smaller economies not to make full use of the advantages they get through the ability-to-pay allocation: The negative impact on the economic perfomance of the big economies leads to a drop of export demand in the smaller economies, which in turn lowers the expected positive impact on welfare in the latter ones. Second, the way of how a surplus of permits in a particular country is used has considerable impacts on consumer welfare. Selling the surplus of permits on the international market and use the receipts to reduce public deficit is one way, but it has no direct impact on demand. Other, more demand stimulating recycling strategies of the surplus (e.g. a lump-sum transfer to households) might be more promising if welfare losses are to be minimzed. Both effects may outweigh the positive effect realized *ex ante* in some countries due to a more ’fair’ initial allocation of permits. The outcome emphasizes the importance of a consideration of full general equilibrium effects across countries.

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ertheless, we take responsibility for all errors and omissions that might have remained.

1 Introduction

The recent developments in climate change policy reveal once more the importance of the burden sharing issue in fleshing out an internationally binding commitment to reduce greenhouse gas emissions. The heterogeneity of interests involved stems from national and/or sectoral differences in wealth, the current stage of development, the energy intensity of production and/or consumption, the resource allocation, and so on. The debate on how to allocate the burden entailed by climate protection revolves around international and regional commitment efforts. For the climate change policy of the European Union (EU) this issue arises on both levels. At the Kyoto Conference in December 1997, the EU as a whole voted for a 15% reduction of greenhouse gas emissions in industrialized countries to be reached in 2010.[2] This decision was preceded by deliberations about the EU-internal allocation of burdens. Considering the standstill on the international level, the EU-internal consensus is exceptional as even the burden sharing issue was solved at least for the first 10%.[3]

On both levels, regionally and internationally, pollution permits are often considered to be the most appropriate policy instrument for an efficient implementation of reduction targets for global pollutants. While the international trade of pollution permits equalizes marginal costs of emission reduction across countries and, therefore, provides an efficient solution, the initial allocation of permits enables various opportunities to tackle the equity aspect.

This paper deals with both efficiency and equity, whereas the main emphasis lies on the latter. The objective is to review and analyse the potential impacts of different equity rules applied to the EU-internal burden sharing.

The first part of the paper (Sections 2 and 3) gathers and discusses the principle concepts and alternatives of the equity issue from a methodological point of view and refers to the initial allocation of pollution rights in particular. The second part of the paper applies a selection of equity rules to a given EU reduction target (10% reduction of CO_2 by 2010 based on 1990 emissions) (Section 4) and assesses the potential impacts with respect to welfare and other macroeconomic aggregates on both EU-wide and national levels (Section 5). All simulations are undertaken with the computable general equilibrium model GEM-E3. The final section (Section 6) draws some conclusions.

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[2] Finally, the EU agreed on an 8% reduction to be realized between the years 2008 to 2012.

[3] See EC(1997) for the country specific obligations the Council of Ministers has agreed on.

2 Equity and efficiency

An effective protection of global common goods requires an international agreement whereby countries commit themselves to emission reductions on a more or less voluntary basis. As countries will not be willing to cooperate if they feel that the international sharing of economic costs of the global warming policy is unfair, international agreements should be based on equity criteria that are accepted by all negotiators. In general, international equity issues arise in view of substantial differences between countries, e.g. in terms of population, wealth and consumption, purchasing power, emissions of greenhouse gases in the past, present and future, or vulnerability to climate change (Banuri et al. 1996, p. 91). The choice of the equity rule has significant consequences for the distribution of the costs of environmental protection amongst countries.

No political consensus on who should pay for abatement of CO_2 at the international level has been developed yet. As equity issues are not a topic of economic theory, equity principles have to be based on ethical and normative judgements. However, studying the potential impacts of different burden sharing mechanisms might give some insights that could contribute significantly to reach an international consensus.

As long as the theoretical conditions for an efficient allocation prevail, economic efficiency, defined in terms of Pareto-optimality, is neutral with respect to distributional issues. The economically efficient allocation of emission reductions is independent of how the total costs of these reductions are shared between countries, or which equity rule is applied. Empirical analysis supports the theoretical finding of the independency of the Pareto-optimal emissions trajectory from the initial allocation of emission rights.

Manne and Richels (1995, p. 23), for instance, note that "the rules for the allocation of emission rights imply that there will be wealth transfers, but empirically we have found that the general equilibrium effects of these transfers are too small to influence the overall level of emissions. In this sense, our results are consistent with the Coase Theorem - the proposition that wealth transfer effects are too small to influence the Pareto-optimal level of provision of a public good (the mean global temperature)".

Conflicts between efficiency and equity principles in global warming policy arise only in the absence of international lump-sum transfers. According to Tinbergen (1952, pp. 27ff.), each policy that is supposed to address both efficiency and equity needs two policy instruments: one instrument for dealing with allocative objectives, e.g. a tax or permit system, and a second for implementing equity issues, e.g. compensation payments or transfers. In this sense, transfers are not only interpreted as financial transfers, e.g. redistribution of tax revenues, but can also be in terms of an initial free-of-charge allocation of emission permits.

According to this, the IPCC report (Banuri et al. 1996) makes a distinction between proposals for distributing abatement costs including international transfers and proposals for fair distribution of emissions separated from any substantive financial transfers.

Under a non-cooperative approach without compensation payments, the initial distribution of emission constraints determines simultaneously both the allocation of emission reductions as well as the distribution of costs. Given the assumption that the international authority has full information concerning national abatement cost functions, a cost-efficient international allocation of emission reductions can be implemented. But even if efficiency of resource allocation is ensured, the resulting distribution of burden sharing might be perceived as unfair as it "does not address the tendency toward national self-interest, the ability of nations to pay the cost, or international political balance" (Rose 1990, p. 927). On the other hand, an equitable allocation of emission constraints is very likely to be inefficient from a global point of view.

Under a cooperative approach, an overall emission reduction target, which is defined for the whole group of the contractual partners, is implemented by a common economic instrument, such as an international CO_2 tax or an international tradable permit system. Here, efficiency and equity aspects can be addressed seperately and treated as complementary principles. Whereas the allocation/price mechanism of the economic instrument leads to an efficient allocation of emission reductions, equity concepts are used to determine how the tax revenue is distributed or how the permits are allocated initially across countries.

Even if the literature provides different classifications of principles for burden sharing, the "examination of international equity issues is still in its infancy" (Banuri et al. 1996, p. 85). Banuri et al. (1996, p. 104), for example, distinguish between procedural and consequentalist equity; the first has to do with participation, process and treatment before the law, the second refers to the outcome of decisions, i.e. the distribution of burdens and benefits. The latter is split in five categories: parity (all claimants receive equal shares of burdens or benefits), proportionality (distribution of burdens or benefits in proportion to the contributions of claimants), priority (those with the greatest needs should be put first), classical utilitarism (distribution in order to achieve the greatest good for the greatest number), and Rawlsian distributive justice (equal distribution unless an unequal distribution operates to the benefit of the least advantaged).

In the following, different mechanisms for burden sharing, mainly provided by Rose and Stevens (1996), and Rose (1990), are presented and discussed regarding their implications for the international distribution of costs and benefits of global warming policy. Table 1 summarizes the criteria and translates them into operational rules for global warming policy in general and tradable permits in particular. Keeping in mind that economic efficiency and equity issues can be separated in economic theory, the listed principles of burden sharing can also be used to determine reimbursement rules in the case of a CO_2 tax.

First of all, Rose and Stevens classify the equity criteria according to whether they are defined in terms of the initial allocation of emission rights ('allocation-based') or in terms of traditional welfare economics ('outcome-based').

Allocation-based rules are related directly to the distribution of emission rights or to the distribution of gross abatement costs. Within a model framework, allocation-based rules are reflected by each country's initial endowment of emission rights according to the applied equity criterion. The distribution of emission rights may represent an initial stock of tradable permits in case of a cooperative implementation of the global reduction target (i.e. subsequent trading of permits between countries is allowed) or the final allocation of national emission levels in case of a non-cooperative solution (i.e. countries implement given reduction targets independently).

In contrast to allocation-based rules, outcome-based rules take into account the incidence of costs and benefits, i.e. the net welfare change due to global warming policy. Outcome-based rules are defined in terms of the relation of net welfare to sub-criteria such as GDP or GDP per capita. Modelling this rule is more complex as for each country one has to set the net welfare level, the equity rule being simulated demands. Then, the model is solved either for the corresponding initial permit allocation, taking into account the international trading of emission permits (in case of a cooperative implementation of the global reduction target), or for the corresponding final allocation of national emission levels (in case of a non-cooperative implementation of the global reduction target).

Table 1: International equity criteria for sharing the costs and benefits of a global warming policy

Criterion	***Basic Definition***	***General Operational Rule***	***Operational Rule for CO -Permits***
		outcome-based equity criteria	
Horizontal	All nations should be treated equally	Equalize net welfare change across nations (net cost of abatement as proportion of GDP equal for each nation)*	Distribute permits to equalize net welfare change (net cost of abatement as proportion of GDP equal for each nation)*
Vertical	Welfare changes should vary inversely with national economic well-being	Progressively share net welfare change across nations (net cost proportions inversely correlated with per capita GDP)*	Progressively distribute permits (net cost proportions inversely correlated with per capita GDP)*
Compensation	No nation should be made worse off	Compensate net losing nations	Distribute permits so that no nation suffers a net loss of welfare
Rawls's Maxi-min	Maximization of the welfare of the worst-off nations	Maximize the net benefit to the poorest nations	Distribute largest proportion of net welfare change to poorest nations
		allocation-based equity criteria	
Ability to Pay	Mitigation costs should vary inversely with national economic well-being	Equalize abatement costs across nations (gross abate-ment costs as proportion of GDP equal for each unit)**	Distribute permits to equalize abatement costs (gross costs of abatement as propor-tion of GDP equal for each nation)**
Egalitarian	All people have an equal right to pollute and to be protected from pollution	Equalize per capita emissions across countries (in con-temporary or historical form)	Distribute permits in proportion to popula-tion or historical responsibilities
Sovereignty	All nations have an equal right to pollute and to be protected from pollution	Allocation of emission reductions in a proportional man-ner across all nations, i.e. equal percentage emission reductions	Distribute permits in proportion to emissi-ons
Market Justice	The market is fair	Make greater use of markets	Distribute permits to highest bidder
Consensus	The international negotiation process is fair	Seek a political solution promoting stability	Distribute permits in a manner that satisfies the (power weighted) majority of nations

* Net costs equal to the sum of: mitigation benefits - abatement costs + permit sales revenues - permit purchase costs.

** Gross cost refers to abatement costs only.

Source: Rose and Stevens (1996, p. 3), modified.

3 Operationalisation of equity rules

3.1 Outcome-based equity criteria

Horizontal equity calls for an equal treatment of all nations in terms of welfare outcome. Rose and Stevens (1996, p. 11) distinguish two different operational versions of the horizontal equity concept:

- The share of net welfare to GDP is equalized across nations. This implies that countries with a relatively larger share of global GDP receive a relatively greater share of global net welfare.

- The share of net welfare to population is equalized across countries. Consequently, the largest share of global net benefits is distributed to those countries with the largest share of global population.

A third operational rule of horizontal equity can be defined as follows:

- The share of net welfare to GDP per capita is equalized. This implies that countries with a relatively larger share of global GDP per capita receive a relatively greater share of global net welfare.

According to the *vertical equity* rule, the abatement costs of a global warming policy are progressively shared across countries. This means, the country's net welfare is inversely related to the GDP. Countries with a relatively lower GDP (and thus, as a rule, with lower CO_2 emissions) receive a relatively bigger share of global net benefit (i.e. have to bear relatively less costs) than countries with a relatively higher GDP. Thus, "vertical equity expresses greater concern for the disadvantaged" (Rose 1990, p. 930). Examples for vertical equity at the interpersonal level are progressive income taxes.

The *compensation criterion* is based on the concept of Pareto-optimality. This allows a policy to be introduced only if no individual or group of individuals is worse off. The net losers have to be compensated by the net winners, so that no country suffers a negative net benefit. The concrete design of the compensation scheme requires the application of other equity criteria such as the horizontal or vertical equity principle.

Furthermore, there are two additional outcome-based equity concepts, the *basic needs approach* and the *Rawlsian Maximin rule* (see Banuri et al. 1996, p. 104). The basic needs approach grants countries the right to emit the minimum levels of greenhouse gases that safeguard the meeting of their citizen's basic needs. Basic needs can be defined as minimum consumption levels needed to support full participation in society, depending on regional characteristics such as climate. The basic needs approach can be seen in relation to the Rawlsian approach. Taking over the Rawlsian concept of intergenerational equity on an international context, the Rawlsian Maximin rule says that "the welfare of the worst-off individual is to be maximized before all others" (Rose 1990, p. 931). This implies that this equity concept should be used to improve the position of the

poorest countries. Accordingly, Rose and Stevens (1996, p. 14) operationalise this rule by redistributing any positive net benefits for the three industrialized nations in their sample to the three poorest nations. Ultimately, by giving preference to the disadvantaged group, the Rawlsian criterion is closely connected to the vertical equity principle and the egalitarian rule.

3.2 Allocation-based equity criteria

The *ability-to-pay criterion*, or more generally spoken, the principle of comparable burdens, is based on the claim that "allocation should affect all countries similarly or involve 'comparable burdens' or 'sharing the effort equally'" (Banuri et al. 1996, p. 105). Several more or less complex, operational rules of this criterion are discussed in the literature (they reach from 'equal monetary abatement costs' to more general measures of ability-to-pay). Rose and Stevens (1996) operationalise this criterion very simply by choosing an initial allocation of emission rights inversely to the proportions of the GDP.

The *egalitarian criterion* suggests that all human beings should be entitled to an equal share of the global atmospheric resource. The egalitarian rule can take two forms: equal contemporary entitlements and equal historical stock entitlements.

The first implies that the share of emissions to population is equalized, i.e. each human being should have equal rights in terms of per capita emissions. As emission rights (e.g. tradable permits or tax revenues) are distributed in proportion to each nation's current population, countries with per capita emissions below the average will gain an excess entitlement, whereas countries with per capita emissions above will have a deficit.

The second form takes 'cumulative historical emissions', i.e. emissions that have been cumulated over a period of time, as a reference point for per capita entitlements (Rose 1990, p. 929; Krumm 1995, p. 46; Banuri et al. 1996, p. 105). The second form is based on the principle of *historical responsibilities*. It takes into account that greenhouse gas emissions are stock pollutants and that the global stock, the atmosphere, is finite. From an equity point of view, it might be reasonable that not the current emissions determine the responsibility for paying, but rather the emissions which have been built up by a country in the past. Actually, there is a broad consensus in the literature that industrialized countries have made excessive use of their rights to emit CO_2 in the past whereas developing countries are in credit. The principle of historical responsibilities is not restricted to egalitarianism, but can be used, for instance, to determine cut backs from current emission levels in direct proportion to historical, cumulative emissions.

The *sovereignty criterion* "represents the basic rights of national entities, often focused on territorial integrity" (Rose 1990, p. 930). In the case of climate change, the sovereignty rule implies equal percentage cuts of current or base year emissions. According to their baseline emission levels, countries have to undertake emission reduction measures on a different scale. The sovereignty rule is closely connected to the proportionality rule, which - as nations are burdened in proportion to their contribution to damage caused - is related to the polluter-pays principle. The sovereignty rule reflects in some respects the claim for keeping the 'status quo' allocation, as it is fully equivalent to an initial allocation of emission rights in proportion to current emissions.

Another 'status quo' rule suggests allocating emission rights proportionally to national GDP, i.e. nations with a larger share in global GDP will be better off than nations with lower shares (Krumm 1995, pp. 44). Those who defend the 'emissions per GDP' criterion argue that economic activities are necessarily connected with the emission of pollutants. Thus, an allocation of emission rights that differs too much from the actual 'status quo' emission scheme might limit global production and could lead to significant reductions in global welfare. Obviously, this argument does not hold if an international reallocation of emission rights is enabled, as the equity rule restricts production of richer countries not in general but due to financial losses caused by side payments. Even so, as will be shown later in our empirical part of the paper, by considering full general equilibrium effects, this argument may have some compellingness.

Following the literature, both criteria, the sovereignty rule and the 'emissions per GDP' rule, are discussed rather as starting points in model analysis but not as serious concepts for international, global burden sharing. Accordingly, Bertram (1996, p. 468) states, that "there is general agreement in the literature that simply 'grandfathering' emission quotas on the basis of current emissions, or on the basis of present GDP, could not provide the basis of a workable international agreement, because it would impose heavy costs on non-OECD countries, while enabling OECD countries to capture rents from the shortage of atmospheric carbon storage capacity for which they themselves have been responsible through high past emissions".

While this assessment might be true for the scientific literature, it contradicts what can be found in practical policy. Neither the agreement of the Council of Ministers of the European Union on how to allocate the Kyoto-targets in greenhouse gas emissions between countries nor the national commitments in SO_2 reduction stated in the Helsinki-Protocol of the Convention on Long-range Transboundary Air Pollution coincide with this general agreement: In both cases, the total burden is shared closely to sovereignty principles. However, the application of the sovereignty criterion might be assessed less critically if an international agreement concerns OECD countries or EU-member states only where differences in economic development are comparably small.

Under the *market justice regime* the emissions are allocated initially according to the 'willingness-to-pay'. In contrast to the burden sharing regimes discussed above, the initial allocation of permits under this rule would have to be based rather on auctioning than on grandfathering. Analogously to an international tax, the international authority, which is responsible for collecting the permit proceeds, can use an international equity rule to reimburse the revenues to the countries.

The *consensus criterion* "arises from the implications that the outcome of the political or diplomatic process is just" (Rose 1990, p. 930). Rose and Stevens (1996, p. 16), for example, operationalise this criterion by estimating weights for distributing the total amount of permits as a linear combination of each country's share of global population and its share of global GDP. The underlying principle claims that nations with concentrated economic and political power should have a greater deal of influence in the decision making process.

3.3 Mixed systems

Apart from single-criterion proposals for a 'fair' distribution of emissions, a number of mixed systems have been presented in literature. Combining different equity rules might support the agreement of all countries to participate. Krumm (1995, p. 49) proposes a linked system of emissions per historical emissions, emissions per GDP and emissions per population; Welsch (1993) suggests a combination of population and current emission factors. Nevertheless, even if countries agree upon a combination of different criteria, the determination of the weight factors and their change over time remain a major subject for negotiation.

In practice, a mix of several equity concepts (namely the proportionality, historical responsibilities and ability-to-pay approach) was chosen in the Framework Convention on Climate Change. The same is supposed to hold for the burden sharing proposal of the EC-Council of Ministers given in March 1997. The following chapter will address this aspect in more detail.

Model simulations indicate that the speed of transition from the status quo situation to an allocation according to an internationally accepted equity rule, e.g. equal per capita emission rights, has significant influences on the international distribution of costs. Manne and Richels (1995), for example, analyse two alternative burden sharing rules which differ alone in the speed of transition from one equity principle to another and compare the impacts. Under the 'standard' allocation scheme, carbon rights are initially distributed among regions in proportion to their 1990 level of emissions (status quo). Gradual changes in these shares over time lead to a distribution in proportion to 1990 population levels by 2030 ('quicker' transition to egalitarian rule). Under the 'status quo' allocation, the gradual transition to equal per capita emission rights is slowed down and is realized not before 2200 ('slower' transition to egalitarian rule). Under the quicker transition scenario, the burden would fall on the more industrialised regions (OECD and former Soviet Union), whose share in global CO_2 emissions fall from 66% in 1990 to 22% in 2030, whereas the less industrialised countries (China and the rest of the world) would win. However, a slower transition leads to a preferential treatment of industrialised countries, which would still allow them to emit 60% of total CO_2 emissions in 2030.

4 The burden sharing issue in the EU context

The burden sharing issue of climate change protection arises on the global level as well as on the regional or national level. This aspect is of particular interest with respect to the decision of the EU to vote for a 15 per cent reduction of greenhouse gas (GHG) emissions in the industrialised countries by the year 2010 at the Kyoto Conference in December 1997. For the EU this goal is supposed to be reached coordinated according to a political consensus of burden sharing. In March 1997, the Council of Ministers agreed on an allocation of 10% between the EU-member states. Table 2 shows the national GHG reductions the Council decided on.

Table 2: The burden sharing proposal of the Council of Ministers (based on 1990 emissions, to be realized in 2010)

	Allocation of a 10% reduction in the EU
Austria	-25
Belgium	-10
Denmark	-25
Germany	-25
Finland	0
France	0
Greece	30
Ireland	15
Italy	-7
Luxemburg	-30
Netherlands	-10
Portugal	40
Sweden	5
Spain	17
United Kingdom	-10
EU-15	-10

As the Council announces, this allocation takes into account a wide range of criteria such as cost-effectiveness, differences in starting points, economic development, economic structures or resource bases (EC 1997). The proposal considers expectations about growth and technical progress (in both energy efficiency and productivity). Analysing the potential impacts of this proposal is therefore difficult, as the model framework used might be based on other assumptions concerning efficiency, growth, and so on.

To enable a comparison of the impacts of alternative equity rules on the EU-level, the equity rules analysed are kept as simple as possible. Three allocation-based criteria are evaluated with the GEM-E3 model: sovereignty, ability-to-pay and the egalitarian principle.

Supposed that a given EU-wide emission target (e.g. 90% of the EU-wide CO_2 emissions, normalised to 100) should be realized by an EU-wide permit scheme, then the figures in the columns of the following Table 3 indicate how many permits should be allocated to a country under a particular equity rule. The particular operational criteria used are given in the table as well.

Table 3: Allocation-based burden sharing in the EU

	Sovereignty (uniform reduction rate)	**Consensus** (Proposal of Council of Ministers)	**Egalitarianism** (equal per capita emissions)	**Ability-to-pay** (inverse GDP per capita)
Austria	2.2	1.8	2.2	5.7
Belgium	3.9	3.9	2.9	3.3
Germany	23.9	19.7	17.8	0.1
Denmark	2.3	1.9	1.5	9.9
Finland	1.2	1.3	1.4	12.2
France	14.9	16.4	16.1	0.1
Greece	1.4	2.0	2.9	10.1
Ireland	0.8	1.0	1.0	39.1
Italy	13.6	13.9	16.7	0.1
Netherlands	3.1	3.0	4.2	1.5
Portugal	0.6	0.9	2.9	13.8
Spain	6.8	8.7	11.2	0.5
Sweden	2.9	3.4	2.4	3.6
United Kingdom	22.4	22.1	16.6	0.1
EU-14	100.0	100.0	100.0	100.0

Source: EUROSTAT(1994), EC(1997), own calculations.

As the table records, the burden-sharing proposal of the Council of Ministers fits in between the sovereignty and the egalitarian principle with a tendency to sovereignty. The following analysis, therefore, refrains from this particular consensus rule and emphasises more principal rules like sovereignty, egalitarianism and ability-to-pay.

Table 4 depicts the equity rule based allocations for a 10% reduction of EU-wide CO_2 emissions in terms of the national CO_2 emissions in 1990. The corresponding figures of the Council of Ministers proposal have been given in Table 2 already.

Table 4: Net permit allocation (difference to 1990 emissions in %)

	Sovereignty (uniform reduction rate)	**Egalitarianism** (equal per capita emissions)	**Ability-to-pay** (invers GDP per capita)
Austria	-10.0	-8.1	138.8
Belgium	-10.0	-33.5	-23.9
Germany	-10.0	-33.0	-99.7
Denmark	-10.0	-41.4	287.6
Finland	-10.0	5.4	793.9
France	-10.0	-2.6	-99.3
Greece	-10.0	84.6	542.3
Ireland	-10.0	15.9	4275.7
Italy	-10.0	10.7	-99.1
Netherlands	-10.0	24.8	-56.2
Portugal	-10.0	345.8	2019.1
Spain	-10.0	48.9	-93.5
Sweden	-10.0	-25.1	9.3
United Kingdom	-10.0	-33.4	-99.5
EU-14	-10.0	-10.0	-10.0

Source: EUROSTAT(1994), EC(1997), own calculations.

As indicated by Table 4, the amount of permits received differs considerably with respect to the equity rule chosen. Under the ability-to-pay rule Germany, France, Italy, Spain and the United Kingdom would potentially suffer with respect to the initial allocation of permits. These countries would get only a small amount of permits free-of-charge. Belgium and the Netherlands receive at least a part of the emission rights they actually would need to maintain their economic activity. The winners are low-income countries, in particular Ireland and Portugal. Under the egalitarian principle, the number of countries that contribute to the actual burden of the EU-wide emission target increases. While Austria, Belgium, Germany, Denmark, France, Sweden and the United Kingdom are discriminated with respect to the 1990 emissions, the remaining EU countries obtain more rights than needed on the 1990 basis. The sovereignty criterion gives the same reduction share to each country, i.e. each nation receives 90% of the emissions in 1990.

With respect to these allocations, the potential burden of a country (or a sector) is alleviated or reinforced. If a country gets more permits than it would actually need, the sale of these permits to other countries makes it better off (all other things being equal). If a country receives much less than it would actually need to keep its economic activity, it is obligated to either buy additional permits from other countries and/or to reduce its emissions significantly. According to the equity rules used for the initial allocation of permits, the reallocation through international trade establishes an international transfer system that favours some countries and puts others at a disadvantage.

5 Simulation of an EU-wide permit scheme under alternative equity rules

The emphasis of this study lies on the analysis of the potential impacts of alternative equity rules given a particular emission target. It is not intended to contribute to the political discussion of equity and distributional fairness in general. The analysis approaches the subject from a rather positive way of thinking. Hence, the issue of concern is: If one would choose a particular initial allocation, what would be the impact for the member states and for the EU as a whole?

The analysis is based on simulation results obtained with the computable general equilibrium model GEM-E3. GEM-E3 is a computable general equilibrium model that considers the economies of 14 EU-member states (EU-15 except Luxembourg) explicitly. The national country models are linked through bilateral trade flows. Production is distinguished by 18 sectors or products; a representative household consumes 13 consumption categories. The economic model is enlarged by an environmental module that covers emission computation, transboundary air pollution and environmental damage calculation of a set of pollutants including CO_2, SO_2, NO_x, VOC and tropospheric ozone. A more detailed description of the model structure is given in the Appendix.[4]

5.1 Definition of policy scenario and instrument

The policy goal imposed throughout the simulations is an EU-wide reduction of 1990 CO_2 emissions by 10 per cent in 2010. This reduction will take place by implementing an EU-wide scheme of tradable permits for CO_2 emissions in 2001. The goal is reached gradually (linear) within the following 10 years. The allocation-based rule refers to the initial allocation of permits.

It is worthwhile to explicitly mention some of the features of the permit market specified in the model:

[4] See also Capros et al. (1997a) or Conrad and Schmidt (1997).

- While international burden sharing uses different equity criteria, grandfathering (sovereignty) is used on the country level throughout all simulations. Hence, if the amount of permits given to a country covers only x per cent of the emissions in 1990, all polluters receive permits to this extent only, i.e. x per cent of their emissions in 1990 (uniform rate of reduction within the country).

- If a country obtains more permits than it actually requires (i.e. the amount of permits available exceeds the 1990 emissions), all polluters receive permits free-of-charge to the extent of their needs (actual emissions). The rest (which is the total national share minus national emission) remains with the government. This amount is supplied and sold at the international permit market. The receipts are kept by the government to reduce public deficit.

- Irrespective of the initial allocation, all polluters decide on the basis of their individual costs (marginal costs) whether to abate emissions and sell permits, to emit to the extent of the permits obtained (and keep them) or to emit more and buy additional permits. According to this decision, polluters supply or demand permits at the international market.

- The specification considers opportunity costs of holding permits, i.e. polluters take into account that even those permits that they have received free-of-charge by the initial allocation are costly as they could be sold on the market to other polluters if abatement measures are undertaken. Hence, the decision in production and consumption does not take into account the rents obtained due to the free-of-charge allocated permits. The rents a sector receives are passed on to demand by reducing the output price appropriately. The permit transactions of households are covered by the energy sectors, i.e. they are modelled similar to value added taxes with lump-sum refunding.

- In any case, free trade of permits between sectors and countries guarantees a cost-minimizing implementation of the EU-wide reduction target. The efficiency of the instrument (equalized marginal costs) is (theoretically) not affected by the burden sharing issue.

5.2 Simulation results of alternative allocation rules

The presentation of results starts with a discussion of the EU-wide effects of the three allocation rules. All simulation results presented hereafter refer to the year 2010, i.e. to the economic and environmental situation when the emission target is fully implemented.

This target is uniform in all cases: 10% reduction of CO_2 in 2010 based on 1990 emissions. The goal is reached by reducing the 10% compared to 1990 plus the emission growth that is linked to the economic growth within the period 1990 to 2010. For the EU an emission growth rate of 8% is assumed.[5] Hence, the actual reduction effort that has to be undertaken is 18%.

Table 5 shows the economic impacts of the three allocation principles. In terms of the EU-wide economic welfare, the sovereignty criterion is preferable. Expressed in per cent of the GDP, a positive welfare effect of 0.32% is obtained. The egalitarian rule gives a smaller but still positive effect of 0.17%. The ability-to-pay allocation reduces EU economic welfare. A loss of 0.50 (as percentage of the GDP) is indicated. Including the welfare effect that is induced by higher environmental quality improves the overall welfare effect, but the signs do not change; the welfare effect of the ability-to-pay allocation remains negative.

Table 5: Macro-economic impacts of alternative burden sharing allocations for EU-14

	Sovereignty	Egalitarianism	Ability-to-pay
Gross domestic product	-0.80%	-0.73%	-0.42%
Employment*	-787	-683	85
Private investment	-0.18%	-0.33%	-1.01%
Private consumption	-0.10%	-0.61%	-2.64%
Exports in volume	-5.73%	-4.37%	0.16%
Imports in volume	-0.72%	-1.55%	-4.54%
Intra trade in the EU	-5.74%	-4.38%	0.15%
GDP deflator in factor prices	4.14%	2.30%	-5.28%
Marginal abatement cost**	230.5	213.9	165.1
Economic welfare***	0.32%	0.17%	-0.50%
Economic and environmental welfare***	0.49%	0.33%	-0.34%

* in thousand employed persons
** in ECU'85/tC (ton of carbon)
*** as percentage of GDP

[5] Pre-Kyoto Study (Capros et al. 1997b, EIS 1997).

The impacts on welfare can be explained by changes in the components of utility, i.e. consumption and leisure. While the allocations under sovereignty and egalitarianism lead to a decrease in both employment (which is equivalent to an increase in leisure) and consumption, more work has to be supplied for less consumption in the ability-to-pay allocation. Hence, utility is decreasing. The negative impact on the GDP is highest under sovereignty and lowest under ability-to-pay. The variation in GDP is linked mainly to changes in foreign trade. The GDP deflator in the EU increases by 4.1% in the sovereignty rule as all countries are affected in the same way. Due to the price increase, extra-EU exports are decreasing by more than 5.7%. In contrast, the GDP deflator decreases in the case of the ability-to-pay allocation. As it will be shown below, this drop in prices is induced by those countries which are only partly compensated by the allocation rule, i.e. which are characterized by a high GDP per capita. The different development in prices explains why the extra-EU exports remain on a higher level in the ability-to-pay case than in the sovereignty allocation. Nevertheless, the price increase under the sovereignty rule realizes a reduction in EU-extra imports as the output effect dominates the substitution effect. This holds for the egalitarian rule as well.

The permit prices (marginal abatement costs) obtained at the end of the reduction period vary considerably between allocation rules. The permit price is highest under the sovereignty allocation (230 ECU/tC or 63 ECU/tCO_2)[6] and lowest under ability-to-pay (165 ECU/tC or 45 ECU/tCO_2). The outcome under the egalitarian regime is almost 214 ECU/tC (or 59 ECU/tCO_2). This ranking is striking, as the welfare effects are inversly related to the permit prices, i.e. a higher permit price leads to a better outcome in terms of welfare. To explain this effect, a country-specific analysis has to be undertaken.

Table 6 locates the sources of the EU-wide negative welfare impact in the ability-to-pay allocation: negatively affected are Germany, France, Italy, the Netherlands, Spain and the United Kingdom. The egalitarian allocation reveals negative economic welfare effects for Denmark and the United Kingdom, while applying the sovereignty rule generates positive welfare effects for all countries, even though the permit price is highest in the latter one. Receiving more permits under a particular rule is not equivalent to a more positive or less negative impact on welfare. Austria, Finland, Ireland and Sweden would prefer the sovereignty allocation, even though they would receive less permits in the initial allocation than under ability-to-pay. The reasons for this effect will be made more obvious later on.

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[6] tC: ton of carbon, tCO_2: ton of carbon dioxide.

The EU-wide emission reduction in 2010 corresponds to the policy target by definition, as the endogenous permit prices match the exogenous total supply of permits (90% of 1990 emissions) and the endogenous demand of permits (i.e. the actual emissions). The actual reduction effort including both the target related to 1990 plus the growth of emissions induced by economic growth, lies for all countries (and allocation rules) within the range of 13% to 23% (based on the emissions of 1990). The net contribution of countries to the common goal is usually much lower, depending on the growth that is assumed to take place in the different countries if no policy would take place.[7] The effects of the policy on emissions of other pollutants are not shown in the table, as the reductions are nearly stable throughout all three cases: EU-wide the actual reductions account for nitrooxide (NO_x) around 14%, for sulfur dioxide (SO_2) around 25%, for volatile organic compounds (VOC) around 9% and for particulates (PM) around 28% of the emissions in 1990.

Table 6: Welfare effect and emission reduction in the EU-member states

	Economic welfare*			CO_2 emissions**		
	Sovereignty	Egalitarianism	Ability-to-pay	Sovereignty	Egalitarianism	Ability-to-pay
Austria	0.62%	0.62%	0.56%	-15.60%	-14.79%	-12.27%
Belgium	0.65%	0.26%	0.39%	-3.71%	-3.88%	-0.91%
Germany	0.36%	0.08%	-0.56%	-25.73%	-25.92%	-25.58%
Denmark	0.27%	-0.03%	0.34%	-6.66%	-7.74%	-3.42%
Finland	0.18%	0.19%	0.16%	16.81%	17.63%	20.26%
France	0.40%	0.40%	-0.36%	-9.90%	-9.16%	-9.34%
Greece	0.10%	0.13%	0.25%	16.83%	17.57%	19.89%
Ireland	1.29%	1.24%	1.00%	4.61%	5.45%	8.03%
Italy	0.26%	0.27%	-0.58%	1.36%	2.07%	1.37%
Netherlands	0.18%	0.22%	-0.10%	9.38%	10.09%	11.00%
Portugal	0.06%	0.10%	0.22%	38.21%	39.01%	41.34%
Spain	0.38%	0.37%	-0.72%	18.99%	19.76%	18.63%
Sweden	0.47%	0.31%	0.43%	14.15%	14.39%	17.18%
United Kingdom	0.17%	-0.29%	-1.28%	-17.23%	-18.39%	-20.00%
EU-14	0.32%	0.17%	-0.50%	-10.00%	-10.00%	-10.00%

* as percent of GDP
** observed in 2010 based on 1990

Looking at the country-specific development of CO_2 emissions and the underlying emission reductions gives no clear answer to the welfare changes obtained under a particular rule. The reduction in Germany, for instance, is almost inelastic to the allocation rule, but welfare is highest under sovereignty and lowest

[7] As mentioned before, the growth assumptions follow the estimates given by the Pre-Kyoto Study of Capros et al. (1997b).

(even negative) under ability-to-pay. While Austria or Belgium reduce more under sovereignty than under ability-to-pay, they realize a lower welfare impact under the former. For Greece and Portugal this relation is the other way round. Hence, there is no clear relation between the burden a country obtains and the actual reduction effort undertaken.

The weakness of this relation is driven by the cost-minimizing behaviour of firms and households, as the principal decision of reducing emissions or keeping (or buying) permits is not altered by the amount of free-of-charge permits obtained (opportunity costs, see above). But receiving fewer permits free-of-charge reduces the ability to use these rents for output price reductions. In this case, prices remain on high levels. Hence, the less permits a country receives initially, the more the distortionary impacts of the permit scheme resemble those of emission taxes. For countries that are affected considerably (i.e. those who receive little), an international permit scheme might be even worse than a national emission tax, as the refunds are going abroad in the former, while they are kept and spent within the country in the latter.

This mechanism explains the situation indicated by the simulation results. Germany, France, Italy, Spain and the United Kingdom receive almost no permits free-of-charge in the ability-to-pay allocation. The Netherlands get less than 50% of the 1990 emissions. All six countries show a welfare loss as no compensation due to free-of-charge permits is available. The increase in output prices leads to a sharp decrease in domestic demand. As Table 7 indicates, private consumption falls in particular in those countries which lose in terms of welfare (from 0.88% in the Netherlands to 5.37% in the United Kingdom). The same holds for the decrease in investment, which ranges from 0.44% in the Netherlands to 1.82% in the United Kingdom.

Table 7: Impacts on private consumption and private investment

	Consumption			Priv. Investment		
	Sovereignty	Egalitarianism	Ability-to-pay	Sovereignty	Egalitarianism	Ability-to-pay
Austria	0.64%	0.67%	0.65%	-0.30%	-0.19%	0.06%
Belgium	0.37%	-0.55%	-0.08%	-0.23%	-0.50%	-0.15%
Germany	-0.13%	-1.09%	-3.12%	-0.25%	-0.56%	-1.18%
Denmark	-0.34%	-1.63%	0.16%	-0.21%	-0.57%	0.09%
Finland	-0.24%	-0.19%	-0.11%	-0.21%	-0.17%	-0.08%
France	0.03%	0.14%	-2.46%	-0.41%	-0.34%	-1.00%
Greece	-0.24%	-0.16%	0.18%	0.18%	0.21%	0.30%
Ireland	1.91%	1.89%	1.56%	-0.13%	-0.04%	0.14%
Italy	-0.26%	-0.19%	-2.11%	-0.16%	-0.11%	-0.90%
Netherlands	-0.23%	-0.06%	-0.88%	-0.18%	-0.14%	-0.44%
Portugal	-0.68%	-0.56%	-0.18%	-0.84%	-0.74%	-0.40%
Spain	0.05%	0.05%	-3.46%	-0.12%	-0.09%	-1.68%
Sweden	0.34%	-0.24%	0.58%	-0.28%	-0.37%	0.09%
United Kingdom	-0.33%	-1.95%	-5.37%	0.25%	-0.40%	-1.82%
EU-14	-0.10%	-0.61%	-2.64%	-0.18%	-0.33%	-1.01%

Due to the drop in demand, domestic production for domestically produced goods and imports fall. Hence, there are two opposite effects on prices in the disadvantaged countries: The prices increase due to the purchase of permits but decrease due to the loss in demand. As the deflator of the GDP depicted in Table 8 indicates, the latter overcompensates the former effect in the welfare losing countries.

Table 8: Development of the GDP-deflator

	GDP-deflator		
	Sovereignty	**Egalitarianism**	**Ability-to-pay**
Austria	4.68%	4.11%	1.76%
Belgium	5.11%	2.28%	0.11%
Germany	3.94%	0.86%	-6.24%
Denmark	4.24%	1.10%	1.56%
Finland	3.49%	2.82%	0.60%
France	4.74%	4.29%	-5.45%
Greece	5.28%	4.68%	2.53%
Ireland	6.76%	5.84%	2.46%
Italy	3.97%	3.51%	-5.22%
Netherlands	2.01%	1.58%	-3.08%
Portugal	1.86%	1.45%	-0.50%
Spain	5.51%	4.72%	-8.30%
Sweden	5.00%	3.12%	2.00%
United Kingdom	3.51%	-0.52%	-9.30%
EU-14	4.14%	2.30%	-5.28%

The drop in demand in the rich countries under the abilitiy-to-pay rule explains the differences in permit prices. Compared to the other allocation rules, production and domestic demand decrease in these countries due to the higher burden they have to carry. This loss in economic activity leads to a significant reduction of CO_2-emissions. The output effect in the rich (and big) countries reduces the emission reduction effort to be reached (directly) by the endogenous permit price. Hence, even though the emission target is the same for all allocation rules, the permit price can be lower in the ability-to-pay rule.

The price depression observed under the ability-to-pay allocation in the rich (and big) countries boosts exports (see Table 9), which alleviates the negative effect on the GDP in the rich countries to some extent. In comparison to the trade effects of the sovereignty rule (drop of intra-EU trade by 5.74%, see Table 5), the differences in national price levels in the ability-to-pay allocation stimulate intra-EU trade (small increase by 0.15%).

Nevertheless, the welfare impact is less positive even in some of those countries that are favoured by the allocation rule. The reason can be found in two effects: First, the interdependence of the EU economies allows smaller economies not to make full use of the advantages they get through the ability-to-pay allocation: The negative impact on the economic perfomance of the big economies leads to a drop of export demand in the smaller economies, which in turn lowers the expected positive impact on welfare in the latter ones. But these spill-overs can not explain the whole story, as the current account in the smaller economies is still higher under ability-to-pay than under sovereignty. Hence, a considerable part of the negative welfare effect for the supposed winners of the ability-to-pay allocation traces back to the way how the surplus of permits (i.e. those permits that are not passed on to the polluting firms but remain to the government) is used. Selling those permits on the international market and use the receipts to reduce public deficit is one way, but it has no direct impact on demand. Hence, production and income are not affected at all, which rules out positive effects on welfare. Other, more demand stimulating recycling strategies of the surplus (e.g. a lump-sum transfer to households) might be more promising if welfare losses are to be minimzed. The analysis of alternative recycling strategies is a topic of future research.

Table 9: Impacts on foreign trade

	Exports			Imports		
	Sovereignty	Egalitarianism	Ability-to-pay	Sovereignty	Egalitarianism	Ability-to-pay
Austria	-4.53%	-4.21%	-3.11%	-1.97%	-1.75%	-1.12%
Belgium	-3.70%	-3.04%	-2.39%	-2.23%	-2.56%	-1.72%
Germany	-4.38%	-2.43%	2.18%	-1.84%	-2.40%	-3.22%
Denmark	-3.86%	-2.49%	-2.93%	-2.76%	-3.23%	-1.61%
Finland	-3.20%	-2.93%	-2.07%	-1.66%	-1.46%	-0.92%
France	-5.22%	-5.09%	1.95%	-2.23%	-1.96%	-3.14%
Greece	-5.29%	-5.04%	-4.40%	-1.99%	-1.79%	-1.02%
Ireland	-4.71%	-4.23%	-2.77%	-1.73%	-1.38%	-0.58%
Italy	-4.30%	-4.14%	1.64%	-2.77%	-2.53%	-3.75%
Netherlands	-1.59%	-1.54%	-0.37%	-1.24%	-1.04%	-1.05%
Portugal	-1.46%	-1.49%	-1.09%	-1.83%	-1.67%	-0.74%
Spain	-5.90%	-5.53%	4.07%	-2.70%	-2.53%	-5.03%
Sweden	-4.86%	-3.77%	-3.39%	-2.57%	-2.53%	-1.24%
United Kingdom	-3.14%	-0.73%	4.70%	-1.24%	-2.23%	-4.01%
EU-14	-5.73%	-4.37%	0.16%	-0.72%	-1.55%	-4.54%

6 Conclusion

Allocating the burden between parties is at the focus of interest in the international negotiation process on climate protection. As the review of equity rules exhibits, the range of principles and preferences that can be applied is wide. With respect to the self-interest of nations it is, therefore, no surprise that international agreements are difficult to attain. For a comparable homogenous group of countries like the EU, the choice of the operational rule is less decisive. Nevertheless, the simulations undertaken with an EU-wide tradable permit scheme indicate that, even within the EU, the burden sharing issue matters. The ability-to-pay rule, which favours the poorer and puts the richer countries at a disadvantage, implies higher overall welfare costs for the EU than the sovereignty rule, where permits are grandfathered with respect to a uniform reduction rate. Certainly, this effect is linked to the weights given to the country-specific welfare. For the above computations no inequality aversion is applied, i.e. weights are uniform. On the other hand, the analysis of national impacts gives two insights that are not biased by this kind of evaluation: First, if big countries (i.e. countries that are powerful in terms of economic activity) are affected considerably, the interconnection of countries through bilateral trade might make the underlying burden sharing rule less attractive even for those countries which are favoured by the particular equity rule in terms of the initial allocation. And second, the recycling of the surplus of permits emerging for some countries in the ability-to-pay allocation has crucial impacts on consumer welfare. Using the revenues from selling this surplus on the international market to reduce public deficit leaves the rest of the economy more or less untouched and therefore gives no positive signal to welfare. This is the case for Austria, Finland, Ireland and Sweden as these countries would prefer an allocation according to the sovereignty rule, even though they would receive less permits in the initial allocation.

With respect to economic and environmental welfare, the sovereignty rule seems to be the most acceptable for an implementation of an EU-wide permit system. All countries show a positive welfare effect and the overall EU benefit is greater than under egalitarianism and ability-to-pay.

Another, more technical insight of the analysis is linked to the differences in permit prices observed. As the initial allocation of permits might hit domestic demand (and therefore production) considerably, emissions drop due to a reduction in output. The interaction of prices and volumes generates a much lower permit price under the ability-to-pay allocation than under sovereignty or egalitarianism. Hence, the evaluation of full general equilibrium effects seems to be crucial for a consistent assessment of alternative equity rules.

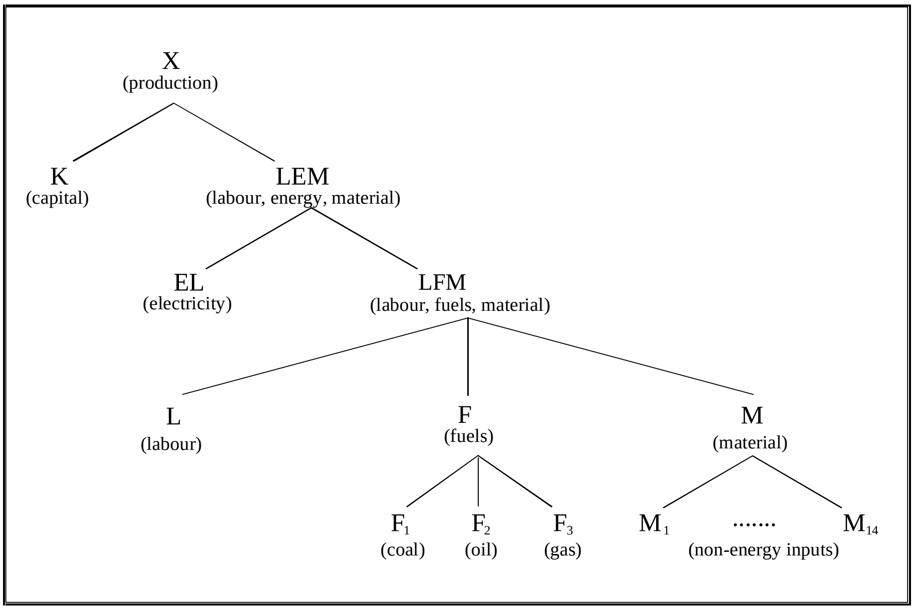
Appendix: Structure of the GEM-E3 model

The following brief description of the model is limited to the analytical specification. For data requirements and parameterization of both the economic model and the environmental module, see Capros et al. (1997a) or Schmidt (1998).

A.1 Production

The technology of a cost minimizing industry is characterized by nested CES cost functions. Figure A.1 gives an overview of the nesting.

Figure A.1: The nested production and factor price scheme



Using the dual formulation, the cost function $C(X,PK,PLEM,g)$ represents 0 the first stage of the problem of the firm in which output X is produced given the input prices for capital, PK, and the labour/energy/material aggregate, $PLEM$, respectively. The price diminishing technical progress g is specified by exponential (exogenous) rates of diminuition. This type of technical change considers autonomous (costless) energy efficiency improvements.

Profit maximization under constant returns-to-scale (in the long-term) implies marginal revenues equal to marginal costs, which explains the output price PX of domestic production in terms of a CES unit cost function:

(1) $PX = PX(PK,PLEM,g)$0.

Applying Shephard's Lemma yields the factor demand functions for K (capital) and LEM (aggregate labour, energy and materials).

Capital input as derived from (1) is the desired capital stock, say K_{des}. In the GEM-E3 model, however, we treat capital as a quasi-fixed stock over the current year at a level from the end of the previous year, say K_{-1}. Hence, the derived demand function for K can be used to determine an endogenous *ex post* price of capital based on a rate of return which the industry has earned *ex post*.

(2) $$PK_{post} = PX \cdot f\left(\frac{X}{K_{-1}}, g\right)$$

PK_{post} is the endogenous shadow price of capital which clears the market for fixed K_{-1}. This price is used to calculate capital income $PK_{post} \cdot K_{-1}$ in period *t*.[8]

Given an *ex ante* price of capital $PK_{ante} = PI \cdot (r + \delta)$, the factor demand function for K can be employed to determine the desired stock of capital K_{des}, 0where PI is the price of investment goods, *r* is the rate of return on risk-free government bonds (in the standard version of the model exogenously given) and δ is the rate of replacement.

Net investment I_{net} with 'adjustment' is given by

(3) $$I_{net} = m(K_{des} - K_{-1})$$ .0

Finally, the capital stock for the next period is

(4) $$K = I_{br} + (1-\delta)K_{-1}$$,0

where $I_{br} = I_{net} + \delta \cdot K_{-1}$ (gross investment).

Next, we specify a CES price function for the aggregate *LEM*:

(5) $$PLEM = PLEM(PEL, PLFM, g)$$,0

where PEL is the price of electricity (EL) and $PLFM$ an aggregation of the prices of labour (L), other fuels (F) and material (M).

One level further down of the nesting the unit cost function for the *LFM* aggregate has to be specified:

[8] It is easy to check that our calculation of PK_{post} is equivalent to calculating it from the zero profit condition.

(6) $PLFM = PLFM(PL,PF,PM,g)$ **.0**

Again, we derive the *LFM* and *EL* aggregates as well as the price-dependent composition of the *LFM* aggregate from Shephard's Lemma. This yields the input coefficients for labour, the material aggregate and the fuels aggregate.

The final level is given by a CES-composition of these aggregates. The fuels aggregate consists of three fuel inputs (1,2,3: solid fuels, liquid fuels, natural gas), whereas the material aggregate considers fourteen non-energy inputs (5-18: (agriculture, ferrous and non-ferrous metals, chemical products, other energy intensive industries, electrical goods, transport equipment, other equipment goods industries, consumer goods industries, building and construction, telecommunication services, transports, services of credit and insurances, other market services, non-market services). The fourth sector (4) is the electricity sector specified already in equation (5).

(7) $PF = PF(P\tilde{Y}_1, P\tilde{Y}_2, P\tilde{Y}_3, g)$ 0

(8) $PM = PM(P\tilde{Y}_5, \ldots, P\tilde{Y}_{18}, g)$,0

where $P\tilde{Y}_i$ denotes the price of domestic supply PY_i plus indirect taxes.[9]

Again applying Shephard's Lemma yields the derivation of the input coefficients. By multiplying the input coefficient of the aggregates by the coefficients of their sub-inputs, one obtains the overall input coefficients a_i with respect to the domestically produced supply. These input coefficients depend on relative prices of inputs.

A.2 The foreign trade specification

The Armington approach is applied to the modelling of intra-industry foreign trade between the EU-member countries: domestically produced goods and imports from different countries are imperfect substitutes. Imposing a CES-structure for the domestic supply Y_c in country c composed by domestic production (for domestically demanded goods) XD_c and imports IM_c gives the following unit cost function.[10]

(9) $PY_c = \left(c_x \cdot PXD_c^{1-\sigma_x} + (1-c_x) \cdot PIM_c^{1-\sigma_x}\right)^{\frac{1}{1-\sigma_x}}$,

[9] See also equation (9).

[10] Note that XD_c is the production for the domestic market only.

where $\sigma_x > 0$ is the elasticity of substitution, c_x a distribution parameter and PY_c, PXD_c, and PIM_c are the corresponding prices of Y_c, XD_c, and IM_c (price of aggregated imports is in national currency of country *c*). From this cost function we derive both the share of domestic production (for domestically demanded goods) and the share of imports in total supply (again by applying Shepard's Lemma).

If the model determines total domestic supply, then we have to allocate aggregate import demand, derived from (9), to the 14 (considered) EU-member states and to the rest of the world (*row*) who contribute to this aggregate import demand. Thus, considering a specific good, the imports of country *c* consist of the exports of the other 13 countries in that good. Therefore, the demands for the 18 goods are also distinguished by place of production. Specifying a CES import unit cost or price function yields (Shepard's Lemma) a matrix of bilateral trade flows $IMP_{c,k}$ with 14 x 15 import demand functions by good and place of production (15 = *row*), where $IMP_{c,c} = 0$.

(10) $$PIM_c = \left(\sum_{k=1}^{15} c_{m,k} \cdot PIMP_{c,k}{}^{1-\sigma_m} \right)^{\frac{1}{1-\sigma_m}}, \qquad c = 1, \dots , 14,$$

where $PIMP_{c,k}$ is the price of imports coming from country *k* in currency of country *c*. As there are import taxes and duties (t_{dut}), it is $PIMP_{c,k} = (1 + t_{c,k,dut}) \cdot PEX_{k,c} \cdot e_c / e_k$, where all exchange rates are in national currency per ECU and $PEX_{k,c}$ is equal to the price of domestic supply in country k including subsidies, if applicable, i.e. $PXD_k = (1 + t_{k,sub}) \cdot PX_k$. Given the price index PIM_{row} and the exchange rates $e_{row,c}$, the fifteen prices PIM_c can be calculated.

The country specific imports $IMP_{c,k}$ have to match the export demand by definition, i.e.

(11) $$EXP_{k,c} = \frac{IMP_{c,k} \cdot e_k}{e_c}.$$

Aggregation yields the export demand in country c.

(12) $$EXP_c = \sum_k EXP_{c,k}$$

Without price discrimination on the suppliers' side, domestically produced goods are supplied at the same price, no matter what the origin of demand is (i.e. domestic demand or exports).[11] Hence, the equations (9) to (12) and the corresponding prices $PXD_c = PEX_c = (1+t_{c,sub}) \cdot PX_c$ describe the entire system of foreign trade.

To determine the import demand of the rest of the world (*row*), we proceed as in equations (9) and (10) by choosing the index *row* instead of *c*. Assuming fixed world market prices PX_{row} and exogenously given output levels of the rest of the world X_{row}, yields the import demand functions of the rest of the world.[12]

As the nominal exchange rates are assumed to be exogenous, the current account is not balanced. Depending on the scenario to be simulated, the current account might increase or decrease and even change the sign.[13]

A.3 Consumer demand and labour supply

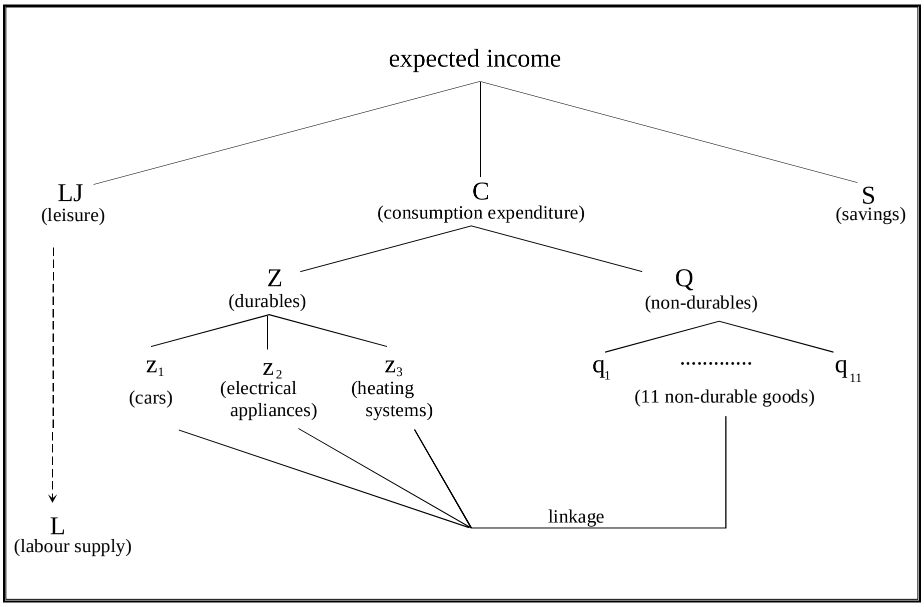
The behaviour of consumers is assumed to perform a two-stage budgeting procedure: an intertemporal allocation of lifetime wealth endowment between present and future consumption of goods and leisure, and an intratemporal allocation of total consumption of goods into durable and non-durable goods. Figure A.2 shows the household's allocation problem.

Figure A.2: The household allocation scheme

[11] Another model version incorporates a constant elasticity of transformation (CET). There, suppliers (i.e. firms) maximize their profits by selling their products to different markets with different prices (see Schmidt 1998).

[12] One of these world prices serves as the numèraire.

[13] Other model versions with constraints on the current account are available but were not used for the study presented above.



The representative household determines an allocation of his resources between present and future consumption by maximizing an intertemporal utility function subject to an intertemporal budget constraint:[14]

$$\textbf{(13)} \quad \max_{C_t, LJ_t} \sum_t (1 + s)^{-t} (\beta_c \ln(C_t - C_0) + \beta_{LJ} \ln(LJ_t - LJ_0))$$

$$\text{s.t. } WT = \sum_t (1+r)^{-t} (PC_t \cdot C_t + PLJ_t \cdot LJ_t),$$

where WT is present value of wealth. C_t is private consumption in volume, C_0 its subsistence level, LJ_t is leisure (in volume) and LJ_0 its subsistence level, s is the subjective discount rate and r is the nominal interest rate. The price of leisure is $PLJ = (1 - t_{hss} - t_{fss}) \cdot (1 - t_{hdir}) \cdot w^{nom}$, where t_{hdir} is the marginal direct tax rate for labour income and t_{hss} and t_{fss} are the contribution rates of employers and employees to social security. Under myopic expectations and the assumption of constant and equal growth rates for inflation and the nominal wage rate, the Fisher relation can be used to reduce the demand functions for consumption and leisure to the following formulas:[15]

$$\textbf{(14)} \quad C = C_0 + \frac{s}{r_r} \left(\beta_c \frac{1}{PC} \right) (Y_{disp} + PLJ \cdot LJ - PC \cdot C_0 - PLJ \cdot LJ_0)$$

$$\textbf{(15)} \quad LJ = LJ_0 + \frac{s}{r_r} \left(\beta_{LJ} \frac{1}{PLJ} \right) (Y_{disp} + PLJ \cdot LJ - PC \cdot C_0 - PLJ \cdot LJ_0),$$

[14] β_C and β_{LJ} are normalized so as to sum to one.

[15] See Schmidt (1998) for a complete representation of the derivation.

where r_r is the real long-term interest rate which is assumed to be constant in the standard version of the model.[16]

The last equation is implicit in *LJ* and has to be solved for *LJ*. Labour supply is given by the remaining time resources, i.e. total time resources minus leisure demand. In the standard neo-classical version of the model, the wage rate serves to match labour demand of firms and leisure demand of households.

The savings of households can then be determined by $S=Y_{disp} - PC \cdot C$.

Two types of consumption expenditure are distinguished: the expenditure for non-linked, non-durable goods (e), which is allocated on the second stage of the consumer decision problem and the expenditure for the use of durables (this covers capital costs and demand for linked non-durables associated with the use of durables). Demand for linked non-durables and demand for services from durables have to be reconciled with investment demand for modifying the stocks of durables towards their optimal levels. We, therefore, employ a restricted expenditure function with stocks of durables as quasi-fixed goods. The expenditure function is derived from the Stone-Geary utility function, which underlies the linear expenditure system.

$$\textbf{(16)} \quad e = e(p_1, \ldots, p_m; u; Z_1, Z_2) = \sum_{i=1}^{m} p_i \cdot Q_{o,i} + u \cdot \prod_{j=1}^{2} (Z_j - Z_{o,j})^{-\gamma_j} \cdot \prod_{i=1}^{n} \left(\frac{p_i}{\beta_i} \right)^{\beta_i},$$

where we denote the prices of consumption categories p_i by small letters to indicate that they do not directly match prices of products $P\tilde{Y}_l$. The variable *u* is the utility level, $Q_{0,i}$ is the minimum required quantity of good *i*, $Z_{0,j}$ is the minimum required quantity of a durable good *j*, and $\sum p_i \cdot Q_{0,i}$ is 'subsistence expenditure'. The expenditure minimizing demand for non-durable goods, given utility *u* and the stocks of the durables, can be derived by partial differentiation of the expenditure function pertaining to the prices:

$$\textbf{(17)} \quad Q_i = Q_{0,i} + \frac{\beta_i}{p_i} \left(e - \sum_{i=1}^{m} p_i \cdot Q_{0,i} \right), \quad i = 1,\ldots,m.$$

The desired stocks of durables and the *ex post* service prices of durables can be derived in an analogous way as used for the restricted cost function approach. With an exogenous *ex ante* user cost of durables p_{Z_j}, the desired stock follows from

[16] The long-term interest rate is endogenised if the constraint of a balanced current account is imposed (other version of the model).

$$\frac{\partial e(\cdot\,,\tilde{Z}_j)}{\partial Z_j} = - p_{Z_j}, \qquad i.e.$$

$$\textbf{(18)} \quad \tilde{Z}_j = Z_{0,j} + \frac{\gamma_j}{p_{Z_j}}\left(e - \sum_{i=1}^{m} p_i \cdot Q_{0,i} \right).$$

Purchases of new durables under partial adjustment restrictions ($0 < \tilde{m}_j \leq 1$) are:

$$\textbf{(19)} \quad I_{Z_j}^{net} = \tilde{m}_j \cdot (\tilde{Z}_j - Z_{-1,j}).$$

We finally obtain the total consumer expenditures $PCE \cdot CE$ including both non-durables and the services from durables:

$$\textbf{(20)} \quad PCE \cdot CE = \sum_{i=1}^{m} p_i \cdot Q_i + \sum_{j=1}^{3} p_{Z_j} \cdot (Z_{-1,j} + I_{Z_j}^{net}).$$

As some non-durable goods such as fuels and power are linked to the stock of durables, we use a composition of these goods into a linked part and into a disposable part. The idea behind such a composition is that demand for gasoline (Q_G) is linked to the use of the stock of automobiles (Z). Or, in algebraic terms, $Q_G = \alpha_{G,Z} \cdot Z + \tilde{Q}_G$, where $\alpha_{G,Z}$ is yearly gasoline consumption per unit of purchase price of the car and $\tilde{Q}_G$ is gasoline consumption from fast driving or bad maintenance of the car.[17] The latter is considered to be a part of the non-linked non-durables and is therefore not further specified. The user concept for durables implies a cost price p_Z of the services of, for example, an automobile which includes the user cost of capital ($PI(r+\delta)$) plus the cost of gasoline, i.e. $\tilde{p}_Z = PI(r+\delta) + \alpha_{G,Z} \cdot p_G$. The introduction of a tax on CO_2 or NO_x will increase the price of gasoline. Hence, the user cost of an already purchased car will increase while the demand for new cars will decline.

For a guess-estimation of the parameters $Q_{0,i}$, β_i and γ_j, we make use of the properties of a linear expenditure system. From guess-estimates of n income elasticities one obtains the n parameters β_i and from guess-estimates of n direct price elasticities one obtains the n parameters $Q_{0,i}$, given the β_i's (and similarly for the parameters of the durables).

[17] For more details see Conrad and Schröder (1991).

A.4 Demand, supply and model closure

Since our demand system determines consumption goods by categories and our 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 has to be seen as the result of the transition matrix of the type (branches x categories) multiplied by the consumption categories. Similar to the matching of consumption categories to products, an investment matrix with fixed technical coefficients serves to compute investment demand by origin (products) from investment demand by destination (branches) as evaluated from the investment behaviour in (5) and (6), together with investment for replacement and decay, i.e. $\delta \cdot K_{-1}$.

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 has been 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 nitrooxides (NO_X), sulfur dioxide (SO_2), volatile organic compounds (VOC), particulates (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 yields concentration and/or deposition figures per pollutant and country. These figures serve as input of the evaluation of damages, which in turn are used for an integrated *ex post* assessment of a particular policy.

For SO_2, NO_X and VOC, end-of-pipe abatement cost functions $c^{ab}(a)$ are specified explicitly. 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, we rewrite the price of pollution-intensive inputs:

(21) $PFU_{i,s} = (1+t_{i,s}) \cdot PY_i + c_s^{en} \cdot ec_i \cdot \chi_{i,s} + \sum_p \left(\left[(1-a_{p,s}) \cdot c_{p,s}^{ef}(a_{p,s}) + a_{p,s} \cdot c_{p,s}^{ab}(a_{p,s}) \right] \cdot ef_{p,i,s} \cdot \mu_{i,s} \right)$,

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 equation (7) or the user cost of durables and maximizing profits or utility yields both the policy-induced changes in (intermediate or final) demand and the optimal degree of end-of-pipe abatement.[18] The sectoral expenditures for end-of-pipe abatement is split in demand addressed to delivery sectors through fixed coefficients. These inputs are added to intermediate demand of the sector and are priced as 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 maximization problem and has to be derived from equations (13) - (15). In a single period *t* we have

(22) $EV_t = FE(PC_t^0, PLJ_t^0, U_t^1) - FE(PC_t^0, PLJ_t^0, U_t^0)$,

where *FE* is the expenditure function corresponding to (13) - (15). U_t^1 and U_t^0 indicate the utility levels observed in the policy (1) and the reference (0) scenarios. *EV* gives the change in expenditure at base case prices PC^0 and PLJ^0 that would be equivalent to the policy-implied change in utility. In order to derive the expenditure function from the utility function, we insert the demand functions (14) and (15) into the utility function (13), and solve for the level of utility, say U_t:

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[18] For further details see Schmidt (1998).

$$\textbf{(23)} \quad U_t = \beta_c \cdot \ln\left(\frac{\beta_c}{PC_t} \cdot \frac{s}{r_r}\right) + \beta_{LJ} \cdot \ln\left(\frac{\beta_{LJ}}{PLJ_t} \cdot \frac{s}{r_r}\right) \cdot \ln(FE_t - PC_t \cdot C_0 - PLJ_t \cdot LJ_0),$$

where FE_t is total expenditure, i.e. $FE_t = Y_{disp,t} + PLJ_t \cdot LJ_t$.

Solving equation (23) for FE_t gives the expenditure function used in (22) to determine EV:

$$FE_t(PC_t, PLJ_t, U_t) = \exp\left(U_t - \ln\left[\left(\frac{\beta_c}{PC_t}\right)^{-\beta_c} \cdot \left(\frac{\beta_{LJ}}{PLJ_t}\right)^{-\beta_{LJ}} \cdot \left(\frac{s}{r_r}\right)\right]\right) + PC_t \cdot C_0 + PLJ_t \cdot LJ_0.$$

The utility level U_t *is* calculated from the t^{th} element of the sum of utilities in (13). 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

$$EV^{TOT} = \sum_{t=0}^{T} \frac{1}{(1+s)^t} \cdot \left(e^{U_t^1 - \eta_t^0} - e^{U_t^0 - \eta_t^0}\right) \cdot \left(\frac{PC_0^0}{PC_t^0}\right)^{\beta_C} \cdot \left(\frac{PLJ_0^0}{PLJ_t^0}\right)^{\beta_{LJ}},$$

where η_t^0 is a function of some reference run data.[19]

If EV^{TOT}<0, welfare after the policy measure is lower 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.

[19] See Schmidt (1998) for a complete representation of the derivation.

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