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Authors
Karp, Larry
Liu, Xuemei

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WELFARE GAINS UNDER TRADEABLE CO_2 PERMITS

by
Larry Karp

and

Xuemei Liu

California Agricultural Experiment Station
Giannini Foundation of Agricultural Economics
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Welfare Gains under Tradeable CO_2 Permits*

Larry Karp and Xuemei Liu

Abstract

Most environmentalists favor the reduction in CO_2 emissions but oppose international trade in emissions permits. Although economic theory provides a strong case in favor of trade in permits, there is little empirical evidence of the size of potential benefits. We estimate the benefits of this trade for OECD countries.

Key words: tradeable permits, greenhouse gasses, carbon reductions
JEL Classification Numbers: F17; Q28; Q43.

Address correspondence to

Larry Karp
Department of Agricultural and Resource Economics
207 Giannini Hall
University of California
Berkeley Ca 94720
email: karp@are.berkeley.edu

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1 Introduction

It is easy to understand the opposition to liberalized trade in established markets: Domestic producers loose from increased foreign competition. It is harder to understand the opposition to creating markets, including international markets, where they currently do not exist. Many economists and policymakers have proposed establishing tradeable carbon permits to decrease the cost of reducing global carbon emissions. Since there currently are no enforceable ceilings on emissions, the right to emit carbon has no market value. Emissions permits are not a commodity. The usual forces that oppose market liberalization are obviously not present in this (proposed) market.

Environmentalists, who favor reducing carbon emissions, frequently oppose international trade in emissions permits. It is puzzling that the group most in favor of a proposed change (reductions in emissions) is also the most opposed to a method of achieving that change cheaply (via trade). There may be a rational basis for this opposition. The theory of the second best alerts us to the possibility that in a world with distortions, opening a new market may lower welfare. If there is a plausible second-best argument against trade in carbon permits, we have not found it. There is probably an emotional basis for environmentalists' opposition to tradeable permits. The environmental problems we face are related to growth, with is related to the existence of liberal markets. A misunderstanding of the relation between markets and pollution may lead some environmentalists to incorrectly equate environmental deterioration with market liberalization of *any kind.* Certainly there is a deep skepticism amongst environmentalists regarding the merits of markets.

Economists advance the usual abstract arguments in favor of markets to explain why internationally tradeable permits would be helpful in achieving reduced carbon emissions. These arguments are probably correct, but they are not convincing to people who are ill-disposed towards markets in general. Economists' involvement in the debate over tradeable permits differs from their involvement in previous debates over trade liberalization, e.g. during the Uruguay Round of the GATT negotiations. In both cases, the fundamental argument for market liberalization is theoretical. However, during previous trade negotiations, these theoretical arguments were backed by many empirical studies. Those studies attempted to measure, either econometrically or by means of simulation, the trade and welfare effects of various forms of liberalization. The validity of these empirical results is always debateable, but their concreteness sometimes makes them persuasive.

Although trade in carbon permits is potentially important, the possibility of this trade has led to little empirical work. The obvious explanation for the absence of empirical work is that the relevant market is missing. The existence of a world market for wheat makes it relatively straightforward to estimate supply and demand curves that can be used to study the effects of liberalized trade in wheat. We cannot use the same procedure to study the effects of creating a market where none currently exists.

Nevertheless, we do observe cross-country and intertemporal variation in carbon emissions, together with changes in inputs such as capital and labor. We can use this data to estimate a relation between emissions and income, and thus obtain an estimate of the marginal value of carbon emissions in different countries.

These estimates enable us to compare the level of income when each country's emissions are restricted to a given level, with the level of income achieved when the country is able to trade permits. The difference in income is a measure of the welfare gains from trade. We also compare the amount of reductions in total emissions that could be achieved with and without trade when each country's income is held fixed at a given level. This comparison may be especialy interesting to people who care more about reducing emissions than about increasing income.

The conclusions from this empirical exercise are speculative. However, they give us an idea of the magnitude of the importance of trade in carbon permits. The simplicity and transparency of our model is appealing. More complicated models, e.g. those based on optimization and engineering estimates, do a better job of describing some aspects of the world. However, those models are usually difficult to penetrate.

In the following, we estimate a system of simultaneous equations in which national income and CO_2 emissions are endogenously determined by country-specific characteristics, including levels of capital, labor and technology. We view pollution and GDP as joint outputs of a production function that depends on capital, labor and technology, variables which we treat as exogenous. We estimate a national revenue function by regressing GDP on capital, labor, technology and emissions. This function represents the efficiency frontier between income and emissions, for given levels of the exogenous variables. A country's environmental policies and economic structure, which we proxy using per capita energy consumption, determine the equilibrium level of GDP and of emissions.

We use the estimated model to simulate prices and efficiency gains under tradeable emissions permits. We suppose that countries enter into an international agreement which allocates CO_2 emissions permits, and that this agreement supersedes the mechanism that would otherwise determine the country's emissions (the point on its efficiency frontier). The joint production function (which depends on technology and factor endowments) has not been altered by the agreement. Thus, we can use the estimated revenue function to determine the effect on GDP of a change in emissions. This function implies a demand for emissions permits, which we use to calculate the price of permits when trade is permitted. We simulate the efficiency gains resulting from trade in permits.

2 Background

The Kyoto Protocol requires that industrialized countries reduce their collective emissions of greenhouse gasses by 5.2% of 1990 levels by the period 2008-2012. The country-specific targets in the Kyoto Protocol may be difficult for some nations to achieve. There may be considerable cross-country variation in marginal abatement costs, and the strength of environmental lobbies also differs. *Emissions Trading,* which was proposed to enable signatories to achieve reductions efficiently, allows developed countries to trade emissions credits amongst themselves. This trade makes sense only amongst those countries that have agreed to quotas, predominately the OECD countries. We therefore include only these countries in our empirical model.

The US Acid Rain Program, which allows trade in SO_2 emissions, is an important experiment in tradeable pollution rights [9]. The US experience with the SO_2 program suggests that trade in CO_2 permits could have considerable benefits.

There have been many attempts to estimate the costs of reducing carbon emissions, and several attempts to synthesize the estimation results. If countries were allowed to trade emissions quotas, the equilibrium price would be determined by the costs of reducing emissions. We use the estimates from previous costs studies as a basis for comparison of the estimates of quota prices that we obtain from a simple econometric model.

Nordhaus [7] collects estimates of marginal costs of abatement and estimates a relation between these costs and the percentage reduction of emissions. Bohm and Larsen [1] use this relation to estimate the price of tradeable permits and the efficiency gain for intra-European trade. They estimate an equilibrium price of $240 per ton of carbon if only Western European countries trade. Including the remaining OECD countries, China, Eastern Europe and the former Soviet Union causes the estimated price to fall to $33.5 per ton of carbon. Larsen and Shah [5] calculate the price of emissions if all countries participate in trade ($58 per ton of carbon) and if only OECD countries participate ($181 per ton).

3 The Empirical Model

We estimate a revenue function and an emissions function using 1975-1990 panel data for 24 OECD countries.[1] We assume that GDP and CO_2 emissions are joint products, produced

[1] Karp and Liu [4] describe the data and provide a more complete report of the estimation results. That paper also discusses in detail the "emissions function" and its relation to the literature on the environmental Kuznets curve.

by country-specific factors: capital, labor and technology. This joint production function determines the trade-off between emissions and GDP for given levels of factors. We refer to this frontier as the revenue function. The second equation is the "emissions function", which determines the equilibrium point on the efficiency frontier.

To conserve notation we suppress time and country subscripts in describing the model. The joint production function is $F(Y, E) = G(C, K, L, T, Pop)$, where: Y = GDP (measured in constant 1987 US$); E = Industrial CO_2 Emissions (in kt, i.e. thousands of metric tons)[2] ; C is a country specific dummy; K = Physical Capital Stock (in constant 1987 US$); L = Labor force; T = Patent applications (a proxy for technology[3]); and Pop = Country Population. We invert the relation $F() = G()$ to obtain the revenue function $Y = f(C, K, L, T, Pop, E)$, which represents the feasible trade-off between income and emissions, for given levels of the other variables. We divide all variables (except the dummy) by Pop to obtain per capita variables, and estimate a log-linear relation.

The estimation equation for the revenue function is

$$y_{is} = c_i + \alpha_1 k_{is} + \alpha_2 l_{is} + \alpha_3 t_{is} + \alpha_4 e_{is} + \epsilon_{1is}. \tag{1}$$

Lower case variables y, k, l, t and e are logarithm of the per capita of the corresponding upper case variables, c_i is the country specific dummy, ϵ_{1is} is the error associated with country i in period s, and the parameters α_j, $j = 1, 4$ are to be estimated. We view Y and E as

[2] These include emissions arising from burning fossil fuels and manufacturing cement, and contributions from other solid, liquid and gas fuels and gas flaring. The data also includes emissions from commercial and residential sources, but not from changes in land-use [8], [10]. This data accounts for approximately 94% of the measure of "Total anthropogenic emissions excluding land-use change and forestry" found in [2].

[3] Gardner and Joutz [3] discuss the relative merits of using patent applications and R&D expenditures as proxies for technological innovation, and recommend the former.

endogenous and we treat K, L, T and Pop as exogenous. These explanatory variables are stock variables. Thus, we treat their levels as predetermined in a period. We include the country dummy to account for country-specific variables such as arable land and cultural factors. The revenue function describes the technological trade-off between emissions and income.

A second relation, the emissions function, describes the "social trade-off" between income and emissions. In principle, the emissions function should include variables which proxy political constraints (e.g., membership in environmental groups, relative income of workers in "dirty" industries). Much of this kind of information is not available for our sample. In an effort to improve the specification of the emissions function and maintain identification, we include commercial energy use (kt of oil equivalent), N, as a regressor in the emissions function. We view N as a proxy for the structure of the economy, i.e. an indication of the opportunity cost of reducing emissions.

We estimate a log-linear specification of the emissions function

$$e_{is} = d + \beta_1 y_{is} + \beta_2 n_{is} + \epsilon_{2is}. \tag{2}$$

The variable n_{is} is the log of per capita energy consumption in country i, year s, d is a constant, and ϵ_{2is} is the error term.

4 Estimation Results

In order to provide a basis for comparison, we first estimate equation (1) using ordinary least squares (OLS), and then jointly estimate equations (1) and (2) using three stage least

α_1 (k)	α_2 (l)	α_3 (t)	α_4 (e)	R^2
.534 (21.874)	.3385 (15.336)	.0558 (8.49)	.0452 (3.53)	.99

Table 1: OLS Estimates of Equation 1

α_1 (k)	α_2 (l)	α_3 (t)	α_4 (e)	β_1 (y)	β_2 (n)
.517	.287	.0625	.106	-.216	1.179
(20.82)	(9.44)	(8.74)	(4.07)	(-5.55)	(31.47)

Table 2: 3SLQ Estimates

squares (3SLQ).

Tables 1 and 2 report the OLS and 3SLQ results, respectively, with t statistics in parentheses.

Our parameter estimates for equation (1) are comparable to the augmented Solow growth model estimated by Nonneman and Vanhoudt [6] for OECD countries. Their estimated production function is $Y = K^{.33}L^{.4}\tilde{T}^{.08}H^{.15}$, where their measure of technology, $\tilde{T}$, uses R&D expenditures and H is a measure of human capital. Our estimate of the elasticity with respect to capital is larger, and our estimate of the labor elasticity is smaller, relative to [6]. Although we use a different variable to measure technology, our elasticity estimate is similar to theirs.

5 Simulation Results

We use the structural model – particularly the revenue function, equation (1) – to estimate the effect of trade in permits. It is convenient to rewrite this equation as

$$Y_i = A_i E_i^{\alpha_4}; \text{with } A_i \equiv F_i Pop_i^{\sigma}; \sigma \equiv (1 - \Sigma_j \alpha_j); F_i \equiv \exp(c_i) K_i^{\alpha_1} L_i^{\alpha_2} T_i^{\alpha_3}. \quad (3)$$

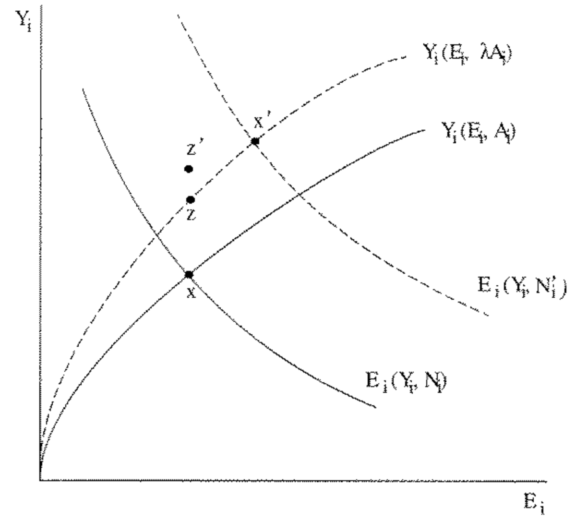

Figure 1: Equilibrium with and without quotas

The positively sloped solid curve in Figure 1 shows the graph of the revenue function for a particular country in the year 1990, and the negatively sloped solid curve shows the emissions function. The intersection of these curves, point x, represents the 1990 equilibrium. If factors of production and population [and thus the variable A defined in equation (3)] increase, then the revenue function shifts out as shown by the upwardly sloping dashed curve in Figure 1.

To reflect the view that emissions would increase in the absence of an agreement, the dashed curve labelled $E_i(Y_i, N_i')$ represents the future (e.g., year 2010) emissions function. The point x' is the equilibrium combination of emissions and income in the absence of an agreement to constrain emissions.

An international agreement changes the regime that determines the level of emissions. If the agreement restricts emissions in the year 2010 to its 1990 level, the country's level of income without trade is given by the point z. If a country receives an allocation equal to its 1990 emissions, but is able to trade permits, it can achieve a higher level of income, such as the point z'.[4]

When we use the model to calculate the equilibrium price of tradeable permits, we assume that the percentage increase in A_i over the period 1991-2010 is the same for all countries. That is, $A_{i,2010} = \lambda A_{i,1990}$ for $\lambda > 1$. There is a simple relation, described below, between the equilibrium price of permits and the value of λ. Therefore, in the next section we report the simulated equilibrium price under the (implausible) assumption that $\lambda = 1$. The reader can adjust these prices depending on the value of λ that seems reasonable. The efficiency gains due to trade are independent of the value of λ (i.e., independent of the growth of factors of production).

5.1 Estimates of Prices and Efficiency Gains

With tradeable emissions and perfect competition, the value of marginal product of emissions in each country equals the world price of permits, denoted P. Using equation (3), country i's value of marginal product (its equilibrium inverse demand) for emissions is $P = \alpha_4 A_i E_i^{\alpha_4 - 1}$, which implies the demand

$$E_i = \left(\frac{P}{\alpha_4 A_i}\right)^{\frac{1}{\alpha_4 - 1}}. \tag{4}$$

Using our 3SLQ point estimate (Table 2) $\alpha_4 = .106$, the elasticity of demand (both for a single country and for the aggregate of all countries) is 1.12. Summing equation (4) over i and setting the result equal to the aggregate level of emissions $\bar{E}$ gives the equilibrium price

[4] The horizontal coordinate of z' represents the country's quota allocation, which differs from its actual emissions by the amount of trade. The vertical coordinate repesents the value of production $Y_i(E_i, \lambda A_i)$ plus of the value of sales of quota licenses.

coefficients	OLS (Table 1)	3SLS (Table 2)
price per metric ton of CO_2	\$57.5	\$156.8
price per metric ton of carbon	\$210.84	\$574.94

Table 3: Simulated Prices

$P^*(\bar{E})$ as the solution to

$$\bar{E} = \Sigma_i E_i = \sum_i \left(\frac{P^*}{\alpha_4 A_i}\right)^{\frac{1}{\alpha_4 - 1}}. \tag{5}$$

Table 3 reports the simulated price (1987 US\$ per metric ton of CO_2) when OECD aggregate emissions and country i's factors (and thus A_i) equal their 1990 levels, using the OLS and the 3SLQ parameter estimates. (Here we set $\lambda = 1$.) The second row of the table reports the simulated price for CO_2; and the third row converts this into a price of carbon.[5] The price estimates summarized in Section 2 refer to tons of carbon, so the third row of Table 3 should be used for comparison.

Figure 2 graphs each country's 1990 marginal product of emissions in the absence of trade and shows the equilibrium price (using the 3SLQ estimates). The thirteen countries whose marginal product of emissions is higher than the price would buy permits. Switzerland and Sweden have the highest marginal product of emissions. Eleven countries, including the US, gain from selling permits.

The estimated equilibrium price is primarily useful as a means of comparing our results with the previous literature. Our price estimates (using the assumption $\lambda = 1$) are substantially higher than those we summarized in Section 2. The more interesting economic question concerns the welfare effects of allowing trade in permits. Fortunately, the answer

[5] CO_2 has a molecular weight of $12 + 2(16) = 44$. Thus the ratio of the weight of CO_2 to carbon is $\frac{44}{12} = 3.6667$.

to this question is independent of the value of λ.

In order to estimate the efficiency gain due to tradeable permits, we compare a country's estimated GDP with and without tradeable permits, given a quota allocation equal to its 1990 emissions level. Denote Y_i^* as country i's GDP when it uses the efficient level of emissions, E_i^* [i.e., the value given by equation (4)]. ($Y_i^* = A_i E_i^{*\alpha_4}$.) The value of its exports of permits, given an allocation equal to its actual 1990 emissions, $E_{i,1990}$, is $P^*(E_{i,1990} - E_i^*)$, where P^* is the equilibrium price from equation (5). Under tradeable permits country i's total income is Y_i^{TP} :

$$Y_i^{TP} = Y_i^* + P^*(E_{i,1990} - E_i^*). \tag{6}$$

The estimated level of income without trade is $Y_{i,1990} = A_i E_{i,1990}^{\alpha_4}$. A measure of the efficiency gain due to trade is thus $\frac{Y_i^{TP} - Y_{i,1990}}{Y_{i,1990}}$.

Figure 3 shows the efficiency gains for the countries in our sample, using the 3SLQ parameter estimates of equation (1). For most countries the gains are below 2% of GDP; only three countries gain more than 3%. For some countries, e.g. Germany, the gain is negligible; the United States gains 0.53%. The unweighted average of the gains for the 24 countries is 1.36%.

The results above held A_i at its (estimated) 1990 level. If A_i increases in the future (the time at which the quota becomes binding) the equilibrium price would be higher. For example, suppose that A_i is replaced by λA_i, $\lambda \geq 1$ to represent an increase in factors of production and population. Using equation (4) and the equilibrium condition $\bar{E} = \Sigma_i E_i$, it is easy to show that $\frac{dP^*}{P^*} = \frac{d\lambda}{\lambda}$.

The estimated equilibrium shares and efficiency gain are independent of λ (provided that the value of λ is the same for each country). In the absence of trade, income is $\lambda A_i E_{i,1990}^{\alpha_4}$. With equal proportional growth in A_i for all i, each country's demand for emissions shifts up by the same amount, and its equilibrium share with trade remains the same. Since the percentage increase in price equals the percentage increase in λ, income under trade (Y_i^{TP}) increases by the same proportion as income in the absence of trade: the efficiency gain due to tradeable permits is independent of λ.

5.2 Estimates of Potential Reductions and Quota Shares

Another way to measure the efficiency gains of permit trading is to calculate the maximum additional reduction in emissions that can be achieved by allowing trade, without reducing income. If countries were to agree to limit emissions to their 1990 level, then their estimated future income, *in the absence of trade*, is $\lambda A_i E_{i,1990}^{\alpha_4}$. The parameter $\lambda > 1$ represents the increase in their factors of production, relative to 1990 levels.

If the countries then agree to allow trade in permits, and attempt to reduce aggregate emissions, $\bar{E}$ below the 1990 level, the constraint that no country is worse off can be written

$$\lambda A_i E_i^{*\alpha_4} + P^*(\bar{E};\lambda)(\mu_i \bar{E} - E_i^*) \geq \lambda A_i E_{i,1990}^{\alpha_4}. \qquad (7)$$

Here μ_i is country $i's$ share of aggregate emissions. The first term on the left side of (7) is the value of domestic production, given the efficient level of emissions (a function of P^*). The second term is the value of net exports of permit. The equilibrium price $P^*(\bar{E};\lambda)$ is proportional to λ and the equilibrium shares E_i^* are independent of λ. Therefore we can divide both sides of equation (7) by λ and write the constraint on income as independent of the growth parameter λ.

The optimization problem that determines the new agreement is

$$\min_{\bar{E},\mu_i} \bar{E}, \quad \text{subject to} \quad \Sigma_i \mu_i = 1, \text{ and equation (7)}. \tag{8}$$

The equilibrium price and each country's equilibrium use of emissions depend on $\bar{E}$, but are independent of the allocation of quota rights. However, a country's income, and thus it's willingness to sign an agreement, does depend on the allocation.

The solution to (8), i.e. the minimal level of $\bar{E}$, is 8.06% lower than 1990 levels.[6] Thus, tradeable permits makes it possible to achieve a significantly higher reduction in emissions without a loss in income. This model probably overstate the actual gain, because it ignores transactions costs and adjustment costs which would undoubtedly be associated with a reallocation of emissions. Thus, our estimates of gains should be viewed as plausible upper bounds, rather unbiased estimates.

Figure 4 shows: the actual *shares* of emissions in 1990; the equilibrium shares when aggregate emissions are fixed at 1990 levels and trade in permits is allowed (identified as "Simulation 1"); and the optimal shares μ_i implied by the solution to equation (8) (identified as "Simulation 2"). Figure 5 shows the *levels* of emissions in 1990 and when aggregate emissions are minimized.

Several countries (notably Japan and France) receive a share of quota rights (μ_i) less

[6] Recall that in the 1992 Framework Convention on Climate Change, industrialized countries set a target for the year 2010 at 1990 levels. The Kyoto Protocol set a target at 5.2% of 1990 levels.

than their actual share in 1990. However, they emit more under the equilibrium implied by the solution to equation (8) than they did in 1990. For the United States, on the other hand, the optimal quota share under the solution to (8) exceeds it's historical 1990 share, but the equilibrium share of emissions is lower. Thus, Japan and France are net buyers of quota rights, and the United States is a net seller.

The Cobb Douglas functional form for income implies that a country's equilibrium share of emissions, $\frac{E_i^*}{\Sigma_j E_j^*}$, equals it's equilibrium share of income from production, $\frac{Y_i^*}{\Sigma_j Y_j^*}$. Since the United States has approximately 35% of OECD GDP (in 1990), its share of emissions is approximately 35% for all the experiments.

6 Conclusion

We estimated a structural model to assess the likely effects of tradeable permits for CO_2 emissions. One equation in our model describes the relation between GDP and factors of production, including CO_2 emissions. We view these emissions as representing "environmental services", the supply of which is endogenous. The second equation uses income and energy consumption (a proxy for the structure of the economy) to explain the equilibrium supply of these "services".

We assumed that an international agreement supersedes the mechanism that would, in the absence of the agreement, determine the endogenous supply of environmental services (the level of emissions). We used our estimated revenue function to simulate the equilibrium price and efficiency gains of tradeable permits, given a particular level of aggregate emissions.

Our estimated carbon prices are two or three times as large as previous estimates, without accounting for growth in demand (due to growth in factors of production).

Some proposals aim to reduce year 2010 aggregate emissions to 1990 levels. Our results suggest that an additional 8% reduction in aggregate emissions could be achieved, without income loss, by appropriate distribution of emissions rights. This distribution gives the United States a larger share than it's historic level, but the US exports permits, leading to smaller US emissions. Since we ignore transactions costs and adjustment costs, we interpret these measures of the gains from trade as plausible upper bounds, rather than unbiased estimates.

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Figure 2

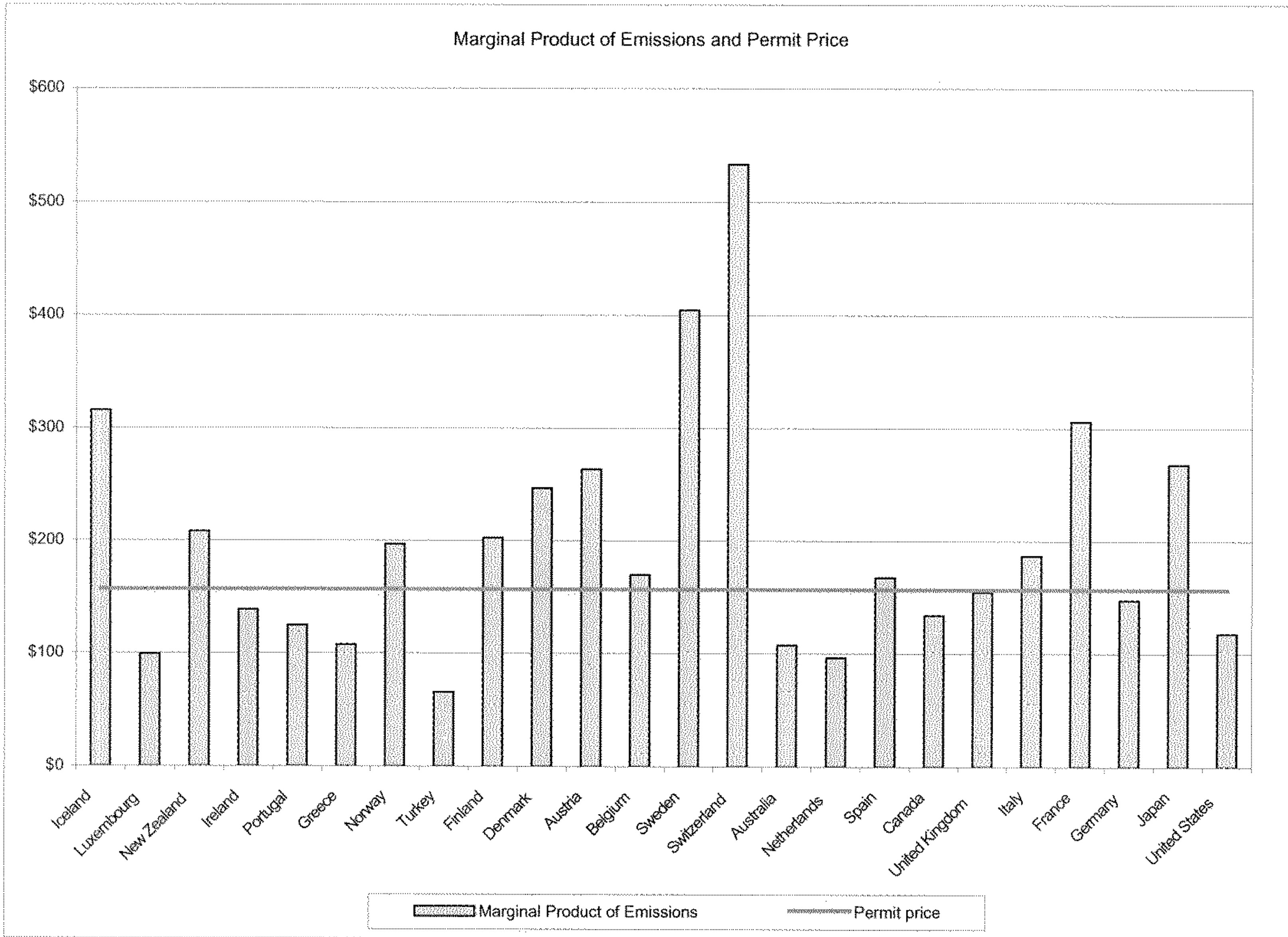

Marginal Product of Emissions and Permit Price
$600
$500
$400
$300
$200
$100
$0
Iceland
Luxembourg
New Zealand
Ireland
Portugal
Greece
Norway
Turkey
Finland
Denmark
Austria
Belgium
Sweden
Switzerland
Australia
Netherlands
Spain
Canada
United Kingdom
Italy
France
Germany
Japan
United States
Marginal Product of Emissions
Permit price

Figure 3

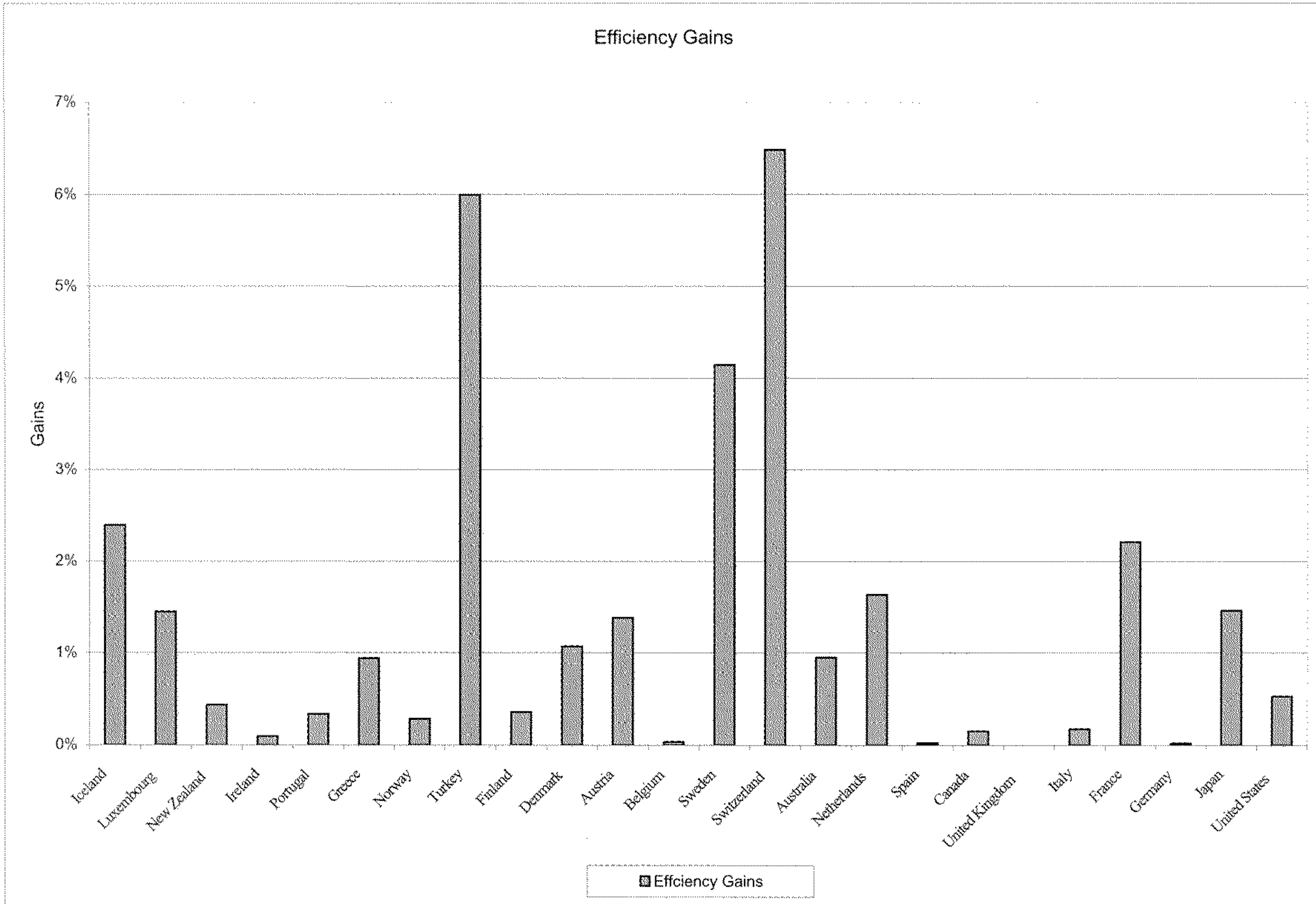

Efficiency Gains
Gains
7%
6%
5%
4%
3%
2%
1%
0%
Iceland
Luxembourg
New Zealand
Ireland
Portugal
Greece
Norway
Turkey
Finland
Denmark
Austria
Belgium
Sweden
Switzerland
Australia
Netherlands
Spain
Canada
United Kingdom
Italy
France
Germany
Japan
United States
Effciency Gains

Figure 4

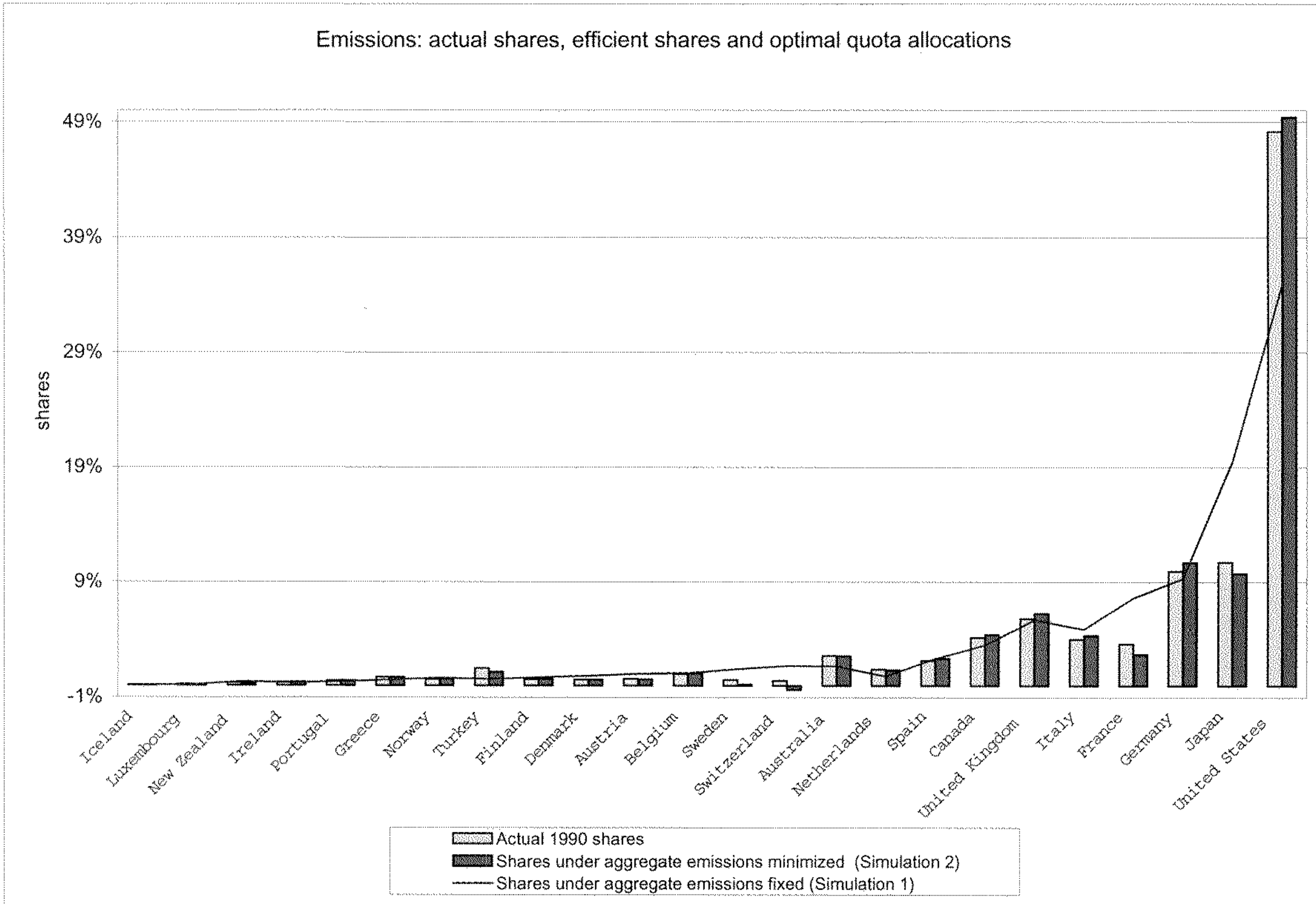
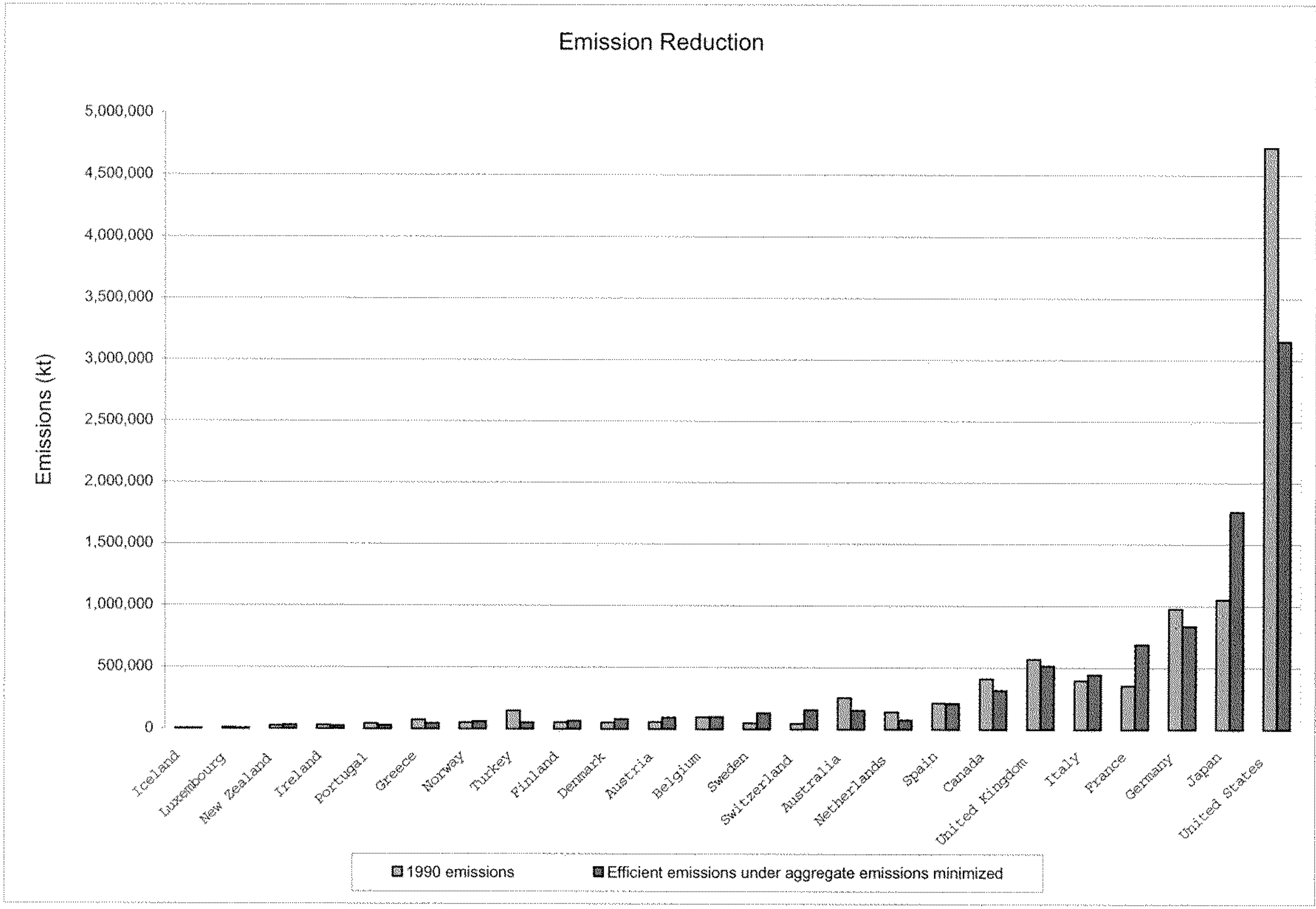

Emissions: actual shares, efficient shares and optimal quota allocations
49%
39%
29%
19%
9%
-1%
shares
Iceland
Luxembourg
New Zealand
Ireland
Portugal
Greece
Norway
Turkey
Finland
Denmark
Austria
Belgium
Sweden
Switzerland
Australia
Netherlands
Spain
Canada
United Kingdom
Italy
France
Germany
Japan
United States
Actual 1990 shares
Shares under aggregate emissions minimized (Simulation 2)
Shares under aggregate emissions fixed (Simulation 1)

Figure 5


Emission Reduction
Emissions (kt)
5,000,000
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Iceland
Luxembourg
New Zealand
Ireland
Portugal
Greece
Norway
Turkey
Finland
Denmark
Austria
Belgium
Sweden
Switzerland
Australia
Netherlands
Spain
Canada
United Kingdom
Italy
France
Germany
Japan
United States
1990 emissions
Efficient emissions under aggregate emissions minimized