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A Quantification of Carbon Taxation and Nuclear Energy Substitution Effects

Working Paper

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Publication date:
2013-01

Permanent link:
https://doi.org/10.3929/ethz-a-007606189

Originally published in:
KOF Working Papers 327

KOF

KOF Working Papers

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No. 327
January 2013

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Energy Reform in Switzerland: A Quantification of Carbon Taxation and Nuclear Energy Substitution Effects

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This draft: January, 2013

Abstract

We develop a general equilibrium model of trade with multiple countries and industries in the spirit of Eaton and Kortum (2002) and Bernard, Eaton, Jensen, and Kortum (2003). We structurally estimate the parameters of the model and calibrate it to data on 33 OECD countries and one country that covers the rest of the world. Industries differ by their relative energy intensity and the level of pollution. Accordingly, the implementation of policy instruments to reduce pollution at the country level induces heterogeneous effects across industries within and across countries. We utilize the model to compare alternative environmental tax instruments and to evaluate their consequences for the level of carbon emissions, welfare costs, industry-specific prices and demand in various policy scenarios. Among the latter, we particularly distinguish between policies that are implemented in isolation (by single countries) or en bloc (in groups of countries or even world wide). This study pays specific attention to the implementation of various energy policies, in particular, in Switzerland. Beyond implementation of the Copenhagen Accord pledges, the study quantifies an implementation of extra taxes on carbon emissions at the amount of 1,140 Swiss Francs per ton of carbon and the substitution of nuclear energy production.

Keywords: Carbon taxation; Energy policy; International trade.

JEL-codes: F11; F14; Q43; Q48.

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1 Introduction

Reducing the level of carbon emissions has become a major goal to both national and international politics in many countries. Most importantly, carbon emissions nourish the greenhouse effect which is supposed to contribute to the global climate change and the general deterioration of the planet's environment. It is therefore generally agreed that reducing the level of CO_2 in the atmosphere is one of the top domestic and international priorities for health and safety reasons. The most important obstacle to the pursuit of a uniform international strategy towards reducing carbon emissions is the global public good character of the quality of environment. Hence, an individual country's pollution emission efforts induce large national costs at a small contribution to the global good, the more so for smaller countries. In addition, international agreements are hard to achieve and virtually impossible to enforce.[1] Yet, in any case, international cooperation (implicit or explicit) in the sense of a global implementation of more restrictive carbon emission policies will be crucial for a sizable impact on global emissions and, ultimately, the greenhouse effect.

In 2009, 114 countries (including all members of the OECD) agreed to the Copenhagen Accord – a document that includes pledges of the participating countries to reduce their carbon emissions to a certain level. While the accord is not legally binding and its enforcement is prone to the lack of explicit international policy instruments, it entails one of the most explicit commitments to reduce carbon emissions to date. We develop a multi-country, multi-industry general equilibrium model of international trade in the spirit of Eaton and Kortum (2002) to quantify consequences of the Copenhagen Accord.[2] In particular, we utilize the model to quantify (i) the tax rates necessary to achieve the targeted levels of carbon emissions in the accord, (ii) the economic welfare loss associated with the distortive taxation of carbon-intensive production, (iii) the difference between various types of taxes in terms of their effects on CO_2 emissions and economic welfare costs and (iv) country-industry-specific

[1]See Cai, Riezman, and Whalley (2009) for a discussion of the problem of credible commitments to international cooperation against environmental damage.

[2]See Shikher (2010), Caliendo and Parro (2011), and Levchenko and Zhang (2011) for multi-industry extensions of that model.

effects of environmental tax policies on prices and demand.

By pursuing this strategy, we contribute to the literature on the effects of carbon emission policies in quantitative general equilibrium in three broad ways.[3] First, we quantify the exact tax brackets (in terms of percentage and local currencies per ton of carbon) required to achieve the reductions in carbon emissions as pledged in the Copenhagen Accord. Our estimates offer a reasonable benchmark for policy makers as far as carbon tax implementation is concerned. Second, we estimate the impact of the required taxes not only on the level of carbon emissions but also on welfare, industry-specific prices and demand. Third, we analyze different policy scenarios that include tax implementation under and without international cooperation for a subset of countries (Norway and Switzerland as two small countries and Germany and the United States as two large ones).

We introduce two types of the counterfactual environmental taxes: one on the *consumption* of (final and intermediate) carbon-intensive inputs and, alternatively, one on the *production* of carbon-intensive inputs. The former is currently in use in some countries (for example Finland, Norway, and Switzerland) and its implementation is on the policy agenda of many OECD countries. The latter form of tax has not be analyzed to a significant extent. It turns out that under a sufficient international alignment of the inception of carbon emission taxation, the tax on the production of carbon-intensive inputs may be preferable over the tax on consumption from a welfare perspective. However, this tax is very sensitive to the extent of international policy alignment. Hence, countries should not use such a tax without consent and might prefer implementing an input consumption tax.

The rest of the study is organized as follows. We outline the model in the next section and describe its structural estimation and calibration in Section 3. In Sections 4-8, we conduct various counterfactual exercises and report the results of thereof. Section 9 offers a discussion of the results, and the last section concludes.

[3]For example, see Babiker (2005), Carbone, Helm and Rutherford (2009), Bohringer, Lange and Rutherford (2010), Elliott, Foster, Kortum, Munson, Pérez, and Weisbach (2010), Egger and Nigai (2011), Aichele and Felbermayr (2012) and others.

2 The Model

We formulate a general equilibrium model of international trade along the lines of Eaton and Kortum (2002), Bernard, Eaton, Jensen, and Kortum (2003), and Alvarez and Lucas (2007).

There are N countries in the world. Each country n is endowed with country-specific factor endowment L_n which we interpret as a composite "labor-plus-capital" factor of production. Each country is active in $I = 43$ industries.[4] Each industry is comprised of a continuum of firms. We *order* industries such that $i = (1, ..., 25)$ is a set of tradable industries and $i = (26, ..., 43)$ is a set of non-tradable industries. The complete list of industries is in Table 1.

Firms in each industry are heterogeneous in terms of their total factor productivity which is drawn at random from a country-industry-specific productivity distribution with mean parameter λ_n^i and dispersion parameter θ_n^i, where superscript $i = 1, ..., I$ indexes industries. In accordance with the OECD classification and the literature we classify industries into two broad groups, tradable and non-tradable. Goods in the tradable industries are traded subject to country-pair-industry-specific iceberg trade cost $t_{nj}^i \geq 1$ on goods imports of country n from j in industry i. Trade costs are subject to the usual assumption of no arbitrage. In addition, we define two broad classes of instruments: τ_{nj} as an import tariff that country n levies on imports from j, and v_n^i as an ad-valorem tax rate that country n places on the domestic producers in industry i.

[4] The number of industries is dictated by the granularity of accorded input-output tables available for OECD countries.

2.1 Consumption

Consumers in country n buy goods from each of the I industries. Their optimization problem is to maximize utility according to the following function:

$$U_n = \Pi_{i=1}^{I} (q_n^i)^{s_i}, \text{ where } \sum_i^I s_i = 1, \tag{2.1}$$

subject to the budget constraint:

$$\sum_i^I p_n^i q_n^i = w_n + r_n, \tag{2.2}$$

where q_n^i is the quantity of goods from industry i consumed by consumers in n, s_i is a parameter of the utility function that represents the share of income spent on such goods, p_n^i is the price of the composite good produced by industry i. Total income per consumer in n consists of the total factor income from production, w_n, and total per-capita lump-sum transfers, r_n, which subsume total tax and tariff revenues as well as potential international transfers.

2.2 Production

Production of non-tradables

We define an industry to be non-tradable if there are no data on bilateral goods trade flows recorded.

Consistent with the literature, we formulate the production technology such that firms in all non-tradable industries employ the primary (composite) production factor as well as aggregate output of all other sectors in the economy as a produced input. In general, we assume that production of non-tradables involves constant returns to scale. Then, we can specify the cost function of a non-tradable industry i in country n as

$$c_n^i = v_n^i w_n^{\alpha^i} \left(\Pi_k^I (p_n^k)^{\beta_n^{i,k}}\right)^{1-\alpha^i} \quad \text{s.t.} \quad \sum_k^I \beta_n^{i,k} = 1, \alpha^i \in (0,1), n = 1, ...N, i = 26, ..., I, \tag{2.3}$$

where v_n^i is a country-industry-specific tax rate, α^i is a Cobb Douglas cost share parameter on primary factor rewards, $1-\alpha^i$ is the one on produced input costs, and $\beta_n^{i,k}$ is a Cobb-Douglas weight parameter on costs associated with goods from industry k as used by industry i in country n. The main difference between the non-tradable and the tradable industries, which we discuss in detail below, is the assumption of the productivity dispersion. Aligned with earlier work, we assume that total factor productivity parameters in this sector do not vary across countries.

Production of tradables

The micro-structure of the production of tradables is in the spirit of Eaton and Kortum (2002). Each firm in a tradable industry of country n produces a unique variety. Firms that produce the same variety in different countries compete with each other. As a result, consumers in i buy goods from the firm with the lowest production cost given industry-specific trade costs. Prior to consumption, all varieties are aggregated into an industry-level composite good according to a standard Spencer-Dixit-Stiglitz function.

Firms in each industry are heterogenous in terms of their total factor productivity parameters. Following the literature, we assume that the productivity parameter (normalized by industry-specific productivity dispersion parameter θ_i) of producing a variety x, $z_n(x)$, in country n is drawn from a country-industry specific exponential productivity distribution centered around λ_n^i. Then, the price of variety x in country n obeys

$$p_n^i(x) = z_n(x)^{\frac{1}{\theta_n}} c_n^i \text{ ,where } c_n^i = v_n^i w_n^{\alpha^i} \left(\Pi_k^I (p_n^k)^{\beta^{i,k}}\right)^{1-\alpha^i}, \tag{2.4}$$

with $\sum_k^I \beta^{i,k} = 1$ and $\alpha^i \in (0,1)$. Because firms compete for consumers in each country n and industry i the price of a variety x must be the minimum among all producers of x in all countries:

$$p_n^i(x) = \min_{\ell} \left\{ p_\ell^i(x) t_{n\ell}^i \tau_{n\ell}^i \right\}. \tag{2.5}$$

The probabilistic representation of technologies allows formulating the price vector of industry-specific aggregate output using the properties of the exponential distribution and (2.4) together with (2.5) as

$$p_n^i = \Gamma^i \left(\sum_{\ell}^{N} \lambda_\ell^i (v_\ell^i c_\ell^i t_{n\ell}^i \tau_{n\ell}^i)^{-\frac{1}{\theta^i}} \right)^{-\theta^i}, \tag{2.6}$$

where Γ^i is an industry-specific constant. This specification is close to the models of Shikher (2010) and Caliendo and Parro (2010).

2.3 Trade equilibrium

The expression for prices in (2.5) and (2.6) results in gravity equations for each industry i of the form

$$X_{nj}^i = \frac{\lambda_j^i (c_j^i t_{nj}^i \tau_{nj}^i)^{-\frac{1}{\theta^i}}}{\sum_{\ell}^{N} \lambda_\ell^i (c_\ell^i t_{n\ell}^i \tau_{n\ell}^i)^{-\frac{1}{\theta^i}}}, \tag{2.7}$$

where X_{nj}^i is the share of n's total spending on industry i goods from j. Country n's total spending on industry i goods from j in *levels* is proportional to n's total spending on industry i goods, Y_n^i. Define the $I \times 1$ vector of total spending in each individual industry by country n as $\mathbf{Y_n} \equiv (Y_n^1, ..., Y_n^I)$, ι as an $I \times 1$ vector of ones, $\mathbf{B} = (\beta^{i,k})$ as an $I \times I$ matrix consisting of Cobb-Douglas production parameters, and $\mathbf{S} = diag_i(s_i)$ as an $I \times I$ diagonal matrix so as to obtain

$$\mathbf{Y_n^i} = ((\mathbf{A} \otimes \iota') \odot \mathbf{B})\, \mathbf{Y_n^i} + \mathbf{S}(w_n L_n - T_n), \tag{2.8}$$

where $\otimes$ and $\odot$ denote Kronecker and Hadamard products, respectively, $w_n L_n$ is total primary factor income, and T_n are total net transfers to country n. Equation (2.8) simply states that n's total demand for goods from industry i is the sum of intermediate and final demands. We can reformulate (2.8) so as to obtain

$$\mathbf{Y_n^i} = \left(\mathbf{I} - (\mathbf{A} \otimes \iota') \odot \mathbf{B}\right)^{-1} \mathbf{S}(\mathbf{Y_n} - \mathbf{T}), \tag{2.9}$$

To calculate the share that a country spends on goods from industry i, δ^i, we can use

$$\delta = (\delta^1, ..., \delta^I)' = \left[\left(\mathbf{I} - (\mathbf{A} \otimes \iota') \odot \mathbf{B}\right)^{-1} \mathbf{S}\right] \iota. \tag{2.10}$$

Then, total nominal imports (M_n) and exports (X_n) of country n in all industries are defined as

$$M_n = \sum_j^N \sum_k^I X_{nj}^k \delta^k (Y_n - T_n); \quad X_n = \sum_j^N \sum_k^I X_{jn}^k \delta^k (Y_j - T_j). \tag{2.11}$$

To close the model, we define the trade deficit of country n as $D_n \equiv M_n - X_n$ and specify the market clearing condition as

$$\sum_j^N \sum_k^I X_{nj}^k \delta^k (L_n w_n - T_n) - D_n = \sum_j^N \sum_k^I X_{jn}^k \delta^k (L_j w_j - T_j). \tag{2.12}$$

2.4 Solution of the model

Several primitives of the model such as trade costs τ_{nj}^i, technology parameters λ_n^i, and even composite primary production factors L_n are not directly observable. However, we can conduct counterfactual exercises without observing these fundamentals as long as we assume that our counterfactual shocks have no impact on τ_{nj}^i, λ_n^i, and L_n (see Dekle, Eaton, and Kortum, 2007). Since we analyze the effectiveness of alternative policy instruments addressing carbon emissions with respect to emissions levels and welfare, the latter assumption seems plausible.

First, let y' denote the counterfactual value of a generic variable whose benchmark value is y. Furthermore, denote the relative change in y in response to a comparative static shock as $\hat{y} = y'/y$. The idea behind the calibration of the comparative static exercise is to express everything in relative changes and use observations on trade shares and real output associated with the observable benchmark equilibrium (the status quo).

We can determine the changes in industry-specific trade flows as

$$\hat{X}^i_{nj} = \frac{(X^i_{nj}\hat{c}^i_j\hat{\tau}^i_{nj})^{-\frac{1}{\theta^i}}}{\sum_\ell^N (X^i_{nj}\hat{c}^i_\ell\hat{\tau}^i_{n\ell})^{-\frac{1}{\theta^i}}}, \tag{2.13}$$

where

$$\hat{c}^i_n = \hat{w}_n^{\alpha^i}\left(\Pi_k^I(\hat{p}^k_n)^{\beta_n^{i,k}}\right)^{1-\alpha^i}, \tag{2.14}$$

measures the relative change in the input bundle for industry i in country n with a relative change in price of tradables in industry i and country n of

$$\hat{p}^i_n = \left(\sum_\ell^N X^i_{nj}(\hat{c}^i_\ell\hat{\tau}^i_{nj})^{-\frac{1}{\theta^i}}\right)^{-\theta_i}, \tag{2.15}$$

and the relative change in promary factor rewards of

$$\sum_j^N\sum_k^I X'^k_{nj}\delta^k(\hat{w}_nY_n - T_n) - D_n = \sum_j^N\sum_k^I X'^k_{jn}\delta^k(\hat{w}_jY_j - T_j). \tag{2.16}$$

This significantly simplifies This approach requires data on benchmark observations of Y_i and X^i_{nj} and parameters s^i, α^i, and θ^i only. One particular advantage of this strategy is that the model can be calibrated so as to fit key data on endogenous variables extremely close to empirical data.

3 Structural estimation and calibration

This section provides details on how the model is calibrated to and parameters are estimated structurally on data data of 34 large open economies and 43 industries.

3.1 Data sources

Most of our data come from the OECD Structural Analysis Database (STAN). This is true for bilateral goods trade data pertaining at the industry level as well as for input-output tables. Data on tariffs stem from the MacMap database and are aggregated according to the STAN industry classification. Whenever the tariff data were missing from that source we imputed values based on the data from Mayer, Paillacar, and Zignago (2008). The data on GDP and current account balances are from the World Bank's World Development Indicators (WDI) database. The reference year of all the data is 2000.

We use industry-level data on value added and gross production from the OECD's STAN database to pin down s^i, β^i, and α^i, and estimate τ^i_{nj} and θ^i using industry-level data on nominal trade flows and manufacturing absorption from the same source. For the latter, data on GDP and current account balances from the World Bank's WDI database are employed as well.

3.2 Utility, technology, and trade cost parameters

Let us start with commenting on the calculation and estimation of the utility and technology parameters of the model:

$$\left\{s^i, \beta_n^{i,k}, \alpha^i\right\}. \tag{3.1}$$

Parameters $\left\{s^i, \beta_n^{i,k}, \alpha^i\right\}$ can be calibrated directly to the data from the input-output tables. To estimate s^i we use data on final consumption by household available at the industry level. We take the average across OECD countries and normalize industry averages so that they sum to one. These estimates are reported in Table 1. We also report α^i which was estimated as the ratio of total valued added to the industry output on average across all OECD countries.

To calculate $\beta_n^{i,k}$ we utilize the input-output tables as well. Here, we normalize intermediate input usage for each industry by the total value of intermediate inputs used by that industry.

Table 1: ESTIMATES OF s^i AND α^i

numb.	Industry	$\hat{s}^i$	$\hat{\alpha}^i$
1	Agriculture, hunting, forestry and fishing	0.02000	0.4900
2	Mining and quarrying	0.00000	0.6100
3	Food products, beverages and tobacco	0.08000	0.2500
4	Textiles, textile products, leather and footwear	0.03000	0.3300
5	Wood and products of wood and cork	0.00000	0.3300
6	Pulp, paper, paper products, printing and publishing	0.02000	0.3700
7	Coke, refined petroleum products and nuclear fuel	0.01000	0.1100
8	Chemicals excluding pharmaceuticals	0.01000	0.3000
9	Pharmaceuticals	0.00000	0.3400
10	Rubber and plastics products	0.00000	0.3500
11	Other non-metallic mineral products	0.00000	0.3900
12	Iron and steel	0.00000	0.2700
13	Non-ferrous metals	0.00000	0.2500
14	Fabricated metal products, except machinery and equipment	0.00000	0.4000
15	Machinery and equipment, nec	0.01000	0.3600
16	Office, accounting and computing machinery	0.00000	0.2300
17	Electrical machinery and apparatus, nec	0.00000	0.3200
18	Radio, television and communication equipment	0.01000	0.2900
19	Medical, precision and optical instruments	0.00000	0.4000
20	Motor vehicles, trailers and semi-trailers	0.03000	0.2500
21	Building and repairing of ships and boats	0.00000	0.3300
22	Aircraft and spacecraft	0.00000	0.3600
23	Railroad equipment and transport equip nec.	0.00000	0.3000
24	Manufacturing nec; recycling (including furniture)	0.02000	0.3500
25	Electricity, gas, and water	0.03000	0.4700
	Subtotal	0.2960	
26	Construction	0.0044	0.3948
27	Wholesale and retail trade; repairs	0.1714	0.5653
28	Hotels and restaurants	0.0798	0.4585
29	Land transport; transport via pipelines	0.0231	0.5129
30	Water transport	0.0035	0.2875
31	Air transport	0.0065	0.3048
32	Supporting and auxiliary transport activities; activities of travel agencies	0.0136	0.4343
33	Post and telecommunications	0.0275	0.5134
34	Finance and insurance	0.0603	0.5662
35	Real estate activities	0.1764	0.7412
36	Renting of machinery and equipment	0.0047	0.5576
37	Computer and related activities	0.0019	0.5216
38	Research and development	0.0003	0.557
39	Other Business Activities	0.0082	0.5374
40	Public admin. and defence; compulsory social security	0.0096	0.6344
41	Education	0.0151	0.7713
42	Health and social work	0.0492	0.6598
43	Other community, social and personal services	0.0486	0.5109
	Total	1.0000	

Notes: s^i and α^i are calculated using the data on Australia, Austria, Belgium, Canada, Germany, Denmark, Finland, France, Ireland, Italy, Japan, Korea, New Zealand, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and the United States; θ_i are calculated using all countries in the sample

Notably, the resulting matrices have higher values along the diagonal. However, few sectors such as energy seem to constitute an important production input for many, if not all, other industries as well. In order to keep the predictions of the model as accurate as possible, we use country-specific input-output matrices to calibrate $\beta_n^{i,k}$.[5] We plot the normalized input-output matrix based on averages of $\beta_n^{i,k}$ across all countries in Figure 1.

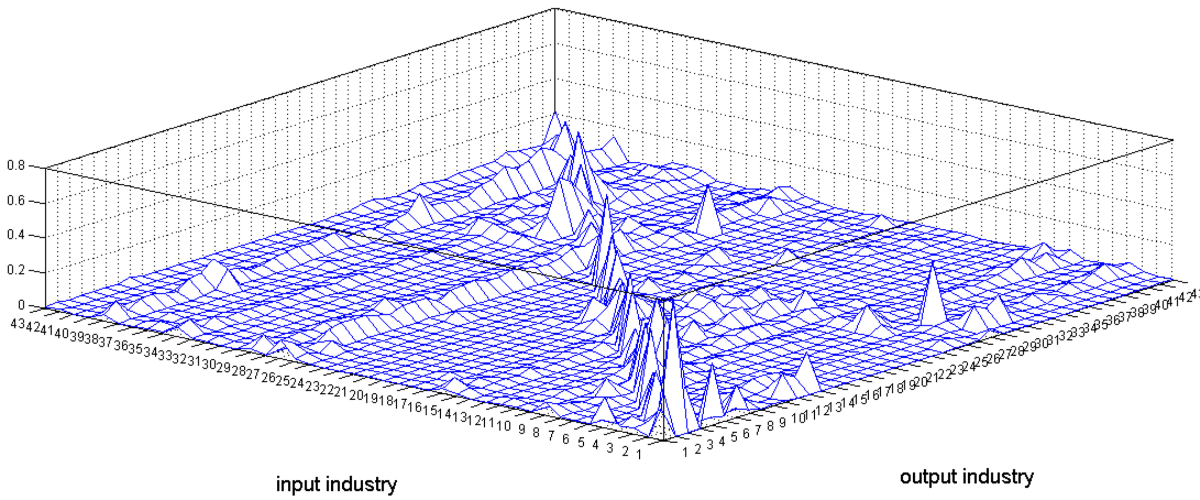

Figure 1: Normalized Input-Output Matrix for the Average Country

Estimation of t_{nj}^i and θ^i

Multi-country, multi-industry models of trade in the spirit of Eaton and Kortum (2002) often assume that $\theta^i = \theta$ for all i. For instance, Donaldson, Costinot, and Komjuner (2011), and Shikher (2011) follow this approach.[6] This assumption, of course, can be problematic as it implies that trade flows in all industries respond identically to shocks (such as changes in trade costs). For example, industry-level gravity equations normally find different elasticities of trade flows to trade cost proxies such as distance. We utilize the data on tariffs – as the most important example of ad-valorem trade costs – between the countries in our sample to estimate θ^i for each tradable industry separately.

[5] For $\beta_n^{i,k}$ of the rest of the world (ROW), we use the GDP-weighted average of the input-output matrices of eight non-OECD countries (China, Brazil, Argentina, India, Indonesia, Poland, Romania, Vietnam). Together they account for more than 50% of ROW's GDP.

[6] A notable exception is work by Caliendo and Parro (2011) who estimate industry-specific θ^i using data on tariffs between Canada, Mexico and USA in the pre-NAFTA period.

We propose using the following gravity equation in levels pin down θ^i as a parameter on log bilateral tariff rates. Let M^i_{nj} be the total nominal export flow from j to n in industry i. Using the structural gravity equation in (2.11) and the absorption variable Y^i_n from (2.9), we can express M^i_{nj} as follows:

$$M^i_{nj} = Y^i_n \frac{\lambda^i_j (c^i_j t^i_{nj} \tau^i_{nj})^{-\frac{1}{\theta^i}}}{\sum_\ell^N \lambda^i_\ell (c^i_\ell t^i_{n\ell} \tau^i_{n\ell})^{-\frac{1}{\theta^i}}}. \tag{3.2}$$

Typically, non-tariff bilateral trade costs $(t^i_{nj})^{-\frac{1}{\theta^i}}$ are modeled as a product of ingredients, similar to total trade costs, which are $(t^i_{nj}\tau^i_{nj})^{-\frac{1}{\theta^i}}$. In a log-linearized version of (3.2), tariffs as ad-valorem trade costs τ^i_{nj} carry the coefficient $-\dfrac{1}{\theta^i}$. Since t^i_{nj} is not directly observable, we follow the literature to employ the usual multiplicative elements and postulate a specification thereof. The latter involves symmetric trade cost proxy variables such as bilateral geographical distance, and binary indicator variables for two countries' adjacency and common language. Asymmetric trade costs will be captured by country-specific fixed effects of the importer and the exporter, respectively. A stochastic version of (3.2) which permits estimating t^i_{nj} and θ^i is the following:

$$M^i_{nj} = \exp(d^i_n + d^i_j + \left(\kappa^i_1 \ln(distance_{nj}) + \kappa^i_2 adjacency_{nj} + \kappa^i_3 language_{nj}\right) - \frac{1}{\theta^i}\ln(\tau^i_{nj}) + error^i_{nj}, \tag{3.3}$$

where $(t^i_{nj})^{-\frac{1}{\theta^i}} = \exp\left[(\kappa_1 \ln(distance_{nj}) + \kappa_2 adjacency_{nj} + \kappa_3 language_{nj})\right]$. The estimates of θ^i and $\{\kappa^i_1, \kappa^i_2, \kappa^i_3\}$ along with the industry-specific $Pseudo - R^2$ are reported in Table 2.

Table 2: STRUCTURAL GRAVITY EQUATION ESTIMATES

industry number	κ_1^i	κ_2^i	κ_3^i	θ^i	$Pseudo-R^2$
1	0.11 (0.15)	0.35 (0.15)	-1.17 (0.11)	-11.64 (2.62)	0.93
2	0.40 (0.36)	0.02 (0.46)	-1.21 (0.19)	-0.75 (0.35)	0.90
3	0.35 (0.12)	0.33 (0.13)	-1.04 (0.10)	-8.01 (2.29)	0.93
4	0.56 (0.16)	0.34 (0.11)	-0.78 (0.10)	-16.26 (2.02)	0.93
5	0.37 (0.15)	0.49 (0.15)	-1.45 (0.09)	-3.77 (2.24)	0.96
6	0.43 (0.11)	0.30 (0.10)	-0.95 (0.08)	-10.97 (2.01)	0.95
7	2.79 (0.30)	0.15 (0.20)	0.50 (0.20)	-1.72 (0.12)	0.92
8	0.05 (0.14)	0.24 (0.11)	-0.82 (0.07)	-7.25 (2.19)	0.94
9	0.05 (0.11)	0.28 (0.12)	-0.38 (0.09)	-4.56 (2.11)	0.92
10	0.24 (0.11)	0.49 (0.09)	-1.01 (0.06)	-11.36 (1.83)	0.96
11	0.14 (0.12)	0.56 (0.10)	-1.07 (0.07)	-4.12 (1.57)	0.95
12	0.27 (0.11)	0.43 (0.07)	-1.20 (0.06)	-7.93 (2.39)	0.95
13	-0.29 (0.30)	0.81 (0.16)	-0.67 (0.10)	-12.80 (3.16)	0.86
14	0.45 (0.10)	0.50 (0.09)	-1.03 (0.07)	-9.85 (1.85)	0.96
15	0.21 (0.11)	0.38 (0.08)	-0.72 (0.06)	-5.97 (1.69)	0.96
16	0.57 (0.15)	-0.13 (0.16)	-0.53 (0.10)	-18.94 (2.84)	0.94
17	0.38 (0.11)	0.30 (0.12)	-0.83 (0.07)	-12.51 (1.83)	0.96
18	0.48 (0.14)	0.25 (0.12)	-0.56 (0.10)	-17.19 (2.67)	0.94
19	0.20 (0.09)	0.22 (0.11)	-0.60 (0.06)	-5.88 (1.63)	0.96
20	-0.12 (0.18)	0.37 (0.16)	-0.83 (0.13)	-20.28 (2.98)	0.95
21	-0.24 (0.33)	1.10 (0.32)	-0.13 (0.18)	-10.31 (4.19)	0.75
22	-0.11 (0.12)	0.90 (0.27)	-0.21 (0.12)	-0.14 (0.14)	0.94
23	0.51 (0.16)	0.61 (0.23)	-0.52 (0.26)	-11.48 (4.05)	0.91
24	0.08 (0.20)	0.68 (0.17)	-0.64 (0.09)	-14.64 (2.42)	0.92
25	1.62 (0.50)	0.52 (0.45)	-2.71 (0.45)	-45.23 (11.65)	0.96

Standard errors (in parenthesis) are robust to an unknown form of heteroskedasticity.

3.3 Fit of calibration

In this section, we assess the fit of the model to the data along key dimensions such as GDP and CO_2 emissions. A good fit of the model to the data would make us more confident about the validity of the quantification of counterfactual experiments. For illustrating the fit, induce a shock to the model of the magnitude of *zero* and let it predict the counterfactual outcome, which corresponds to the observed benchmark values of the data on all endogenous variables.

Let us start with evaluating the fit of the model in terms of predicting country-level GDPs. The counterfactual GDP in each country can be calculated as:

$$GDP_n' \equiv L_n' w_n' = \widehat{w}_n Y_n. \tag{3.4}$$

We plot the fit of calibration in terms of total GDP in Figure 2.

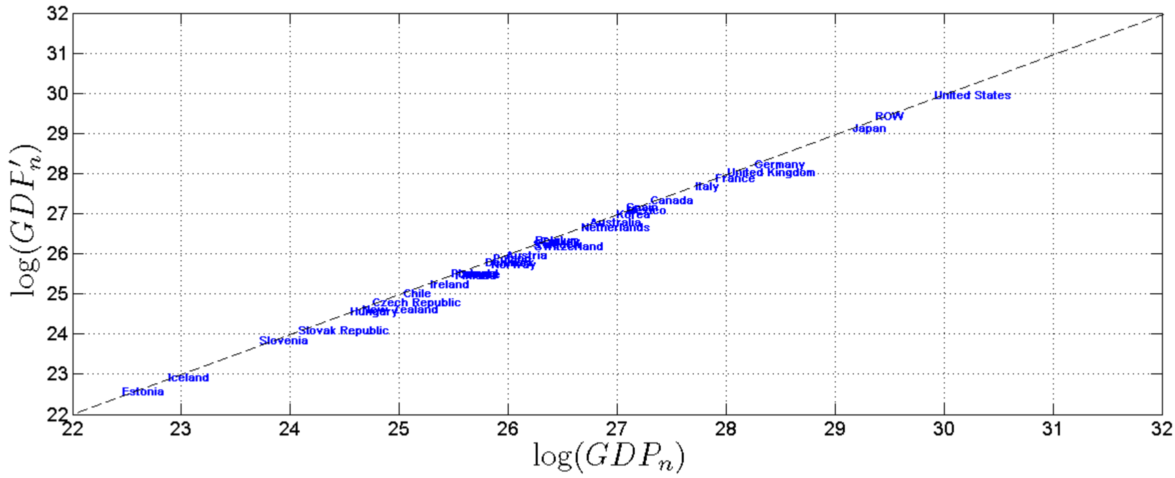

Figure 2: Fit of Calibration: Gross Domestic Product

As can be seen from the figure, the fit of calibration is extremely good. The correlation between the real data and the model's prediction is close to unity. Since the link between GDP and input-output tables is established by fixed coefficients, the model fits industry-level data on sales and intermediate goods purchases similarly well as total GDP of countries.

Another important dimension is intranational and international trade. Let us start with evaluating the fit of the model in terms of the intranational trade flows (or domestic sales). For this, we plot the predicted counterfactual values (at a shock of zero) of the import penetration ratio (total imports over total expenditure) of all industries in all countries versus their respective benchmark values. Recall that there are 25 tradable industries in 34 countries, which gives 25×34 observations. The fit of the model predictions for the data are illustrated in Figure 3.

The correlation between the actual and the predicted import penetration variables is 0.97.

Another important dimension in terms of fitting the model to the data is international trade. For each industry, there are $34 \times (34 - 1)$ unique bilateral international trade pairs. Hence, the total number of observations is $34 \times (34 - 1) \times 25$. To see, whether the model is successful in fitting the corresponding data, we first normalize all counterfactual observations by the respective counterfactual intranational trade shares as follows:[7] $\frac{X_{nj}^{\prime i}}{X_{nn}^{\prime i}}$ and plot these normalized international

[7]The normalization is done purely for graphical illustration purposes.

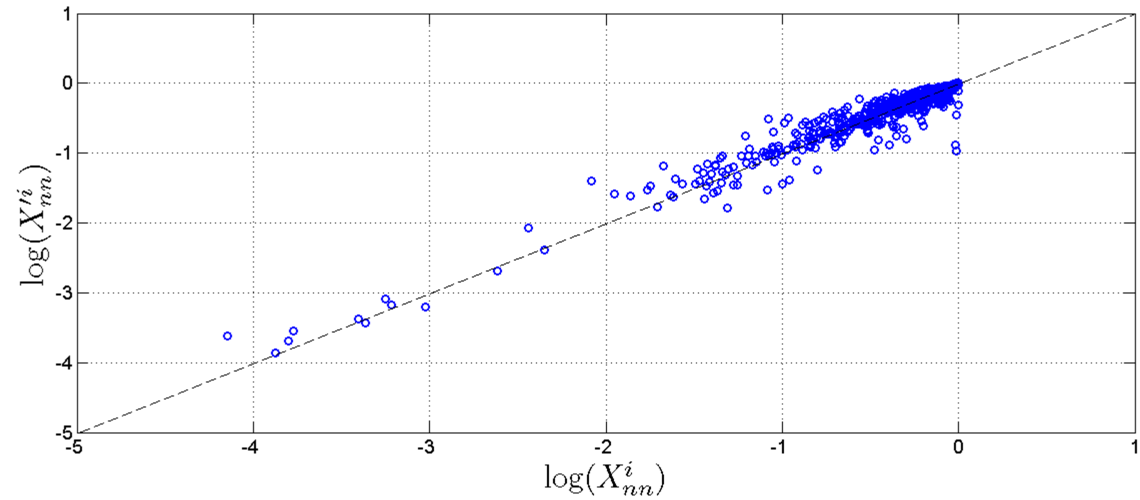

Figure 3: Fit of Calibration: Intranational Trade Flows

industry-specific trade flows against the benchmark $\frac{X^i_{nj}}{X^i_{nn}}$ in Figure 4.

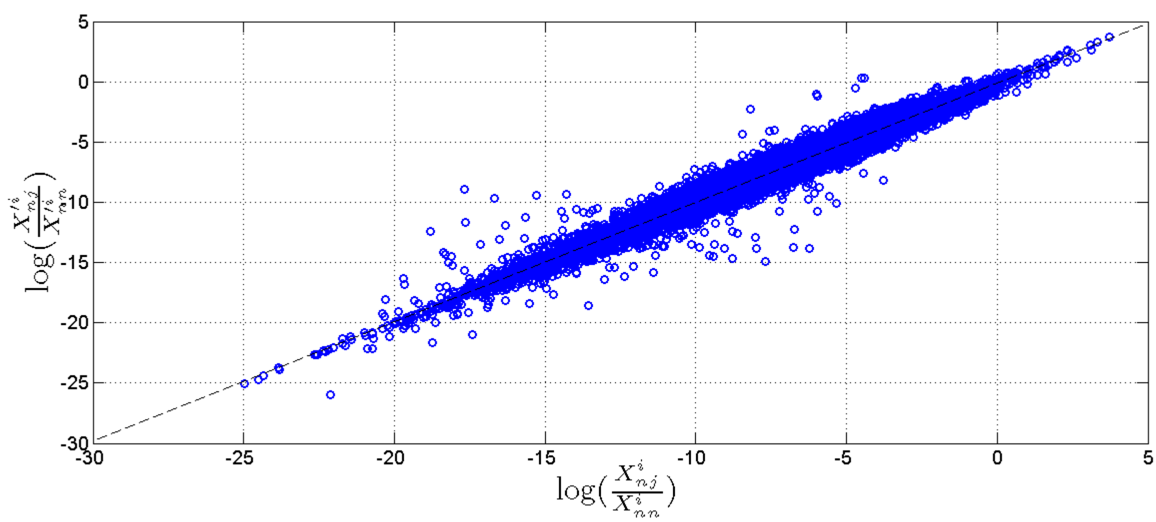

Figure 4: Fit of Calibration: International Bilateral Export Flows

According to Figure 4, the the model fits the industry-level data on international trade very well. The correlation is close to unity.

In a next step, we calibrate the model to the CO_2 emissions. This is not a straightforward task. Accurate calibration of negative environmental externalities is at the heart of our analysis. While energy production and consumption involve many environmental byproducts, we focus on CO_2 emissions, here. Most of the negative effects of production on the environment have been associated with this particular type of emissions.

Table 3: ENERGY SOURCES

country	source 1	source 2	source 3	country	source 1	source 2	source 3
Australia	0.01	0.05	0.94	Japan	0.18	0.01	0.80
Austria	0.13	0.11	0.76	Korea, Rep.	0.15	0.01	0.84
Belgium	0.22	0.02	0.77	Mexico	0.07	0.06	0.87
Canada	0.20	0.05	0.76	Netherlands	0.02	0.02	0.96
Chile	0.06	0.17	0.76	New Zealand	0.24	0.06	0.70
Czech Republic	0.09	0.03	0.88	Norway	0.43	0.05	0.52
Denmark	0.02	0.09	0.89	Poland	0.00	0.05	0.95
Estonia	0.00	0.11	0.89	Portugal	0.04	0.11	0.84
Finland	0.24	0.22	0.54	Slovak Republic	0.26	0.02	0.72
France	0.44	0.04	0.52	Slovenia	0.24	0.07	0.69
Germany	0.14	0.02	0.84	Spain	0.16	0.03	0.81
Greece	0.02	0.04	0.95	Sweden	0.47	0.18	0.36
Hungary	0.15	0.03	0.82	Switzerland	0.40	0.07	0.53
Iceland	0.74	0.00	0.26	Turkey	0.05	0.09	0.87
Ireland	0.01	0.01	0.98	United Kingdom	0.10	0.01	0.89
Israel	0.03	0.00	0.97	United States	0.11	0.03	0.86
Italy	0.05	0.01	0.94				

Source 1: Alternative and Nuclear Energy; Source 2: Combustible Renewables and Waste; Source 3: Fossil Fuel

There are several ways to model environmental externalities of a production process. Here we largely follow Copeland and Taylor (2004), who assume that production requires "dirty" input (pollution) as a Cobb-Douglas share in the cost function. Our approach is to identify a "dirty" input and show that carbon emissions in each country are largely proportional to the total demand for that input. The advantage of that approach is its relatively easier calibration than the dollar value of pollution as such.

Egger and Nigai (2011) showed that CO_2 emissions are proportional to the natural resource reserves as approximated by the output of the *Mining and quarrying industry.* We adopt a similar approach. We argue that while all industries produce some emissions, those which consume a relatively higher share of output of the *Mining and quarrying industry* produce relatively more emissions. For example, in the *Coke, refined petroleum products and nuclear fuel industry* about 75% of all inputs come from the *Mining and quarrying industry.* For comparison, the *Finance and insurance industry* uses only 0.05% of inputs from the *Mining and quarrying industry.* By that token, we classify the former industry as a major source of CO_2 emissions and the latter industry as a minor one.

Recall, that we can calculate total consumption of goods from industry i in country n as $Y_n^i = \delta_n^i(Y_n - T_n)$. Hence, total consumption of *Mining and quarrying industry* output can be easily calculated. There are two major caveats. First, due to the data limitations the *Mining and* *quarrying industry* is a composite of energy and non-energy mining goods. Second, energy can be produced using relatively "clean" inputs such as renewable inputs and/or nuclear energy inputs versus relatively "polluting" inputs such as fossil fuels.

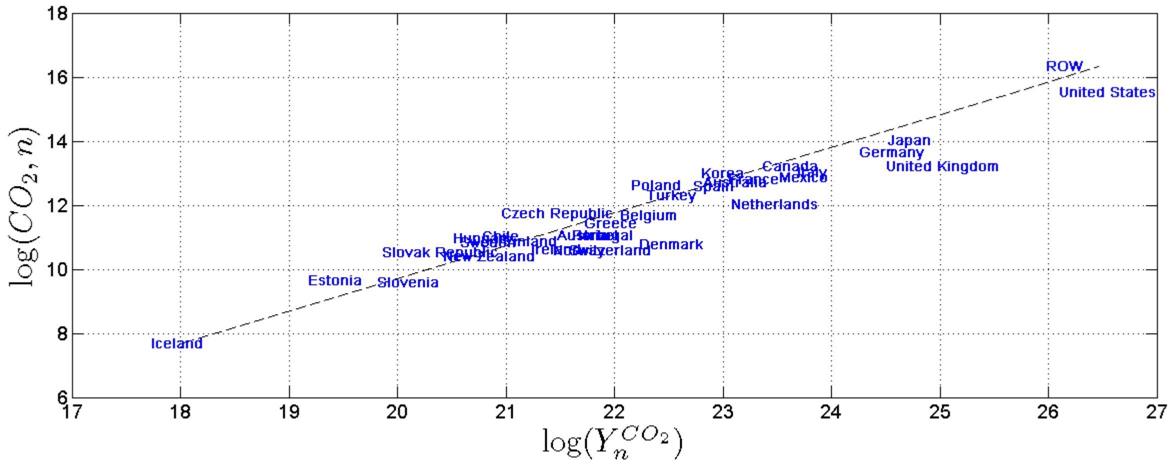

Figure 5: Fit of Calibration: CO_2 emissions

To deal with the former issue, we normalize bilateral exports of the *Mining and quarrying industry*, X_{nj}^{Mining}, by the exporter-specific share of energy related output to the total output of the *Mining and quarrying industry* in country j, ϵ_j. To account for the second problem we note that energy sources can be classified into three main types: alternative and nuclear sources, combustible and renewable waste, and fossil fuels. To account for the heterogeneity across countries in the reliance on energy sources, we normalize each country n's total energy consumption by the share of fossil fuels, μ_n. The share of fossil fuels consumed is directly related to the amount of CO_2 emissions. We list the relative dependence on alternative fuel sources of each of the OECD countries in Table 3. Notice that Finland and Sweden have the lowest share of fossil fuels in total fuel consumption. Perhaps, the reason for this is an aggressive environmental tax policy pursued by these countries. Finland was the first country to introduce a carbon tax in 1990. Sweden introduced its own carbon tax in 1991. Both countries have been successful in reducing the share of "dirty" fuels and increasing the share of "clean" fuels such as biomass fuel. Indirectly, experiences of these countries point to the effectiveness of carbon taxation.

Having obtained μ_n, we can calculate the dollar value of consumption of CO_2-related inputs (in

US dollars) as follows:

$$Y_n^{CO_2} = \sum_i \left(\sum_j \epsilon_j \mu_n X_{nj}^{Mining} \right) Y_n^i. \tag{3.5}$$

Then, it is straightforward to calculate the counterfactual change in CO_2 emissions as $(\widehat{CO_2})_n = \widehat{Y}_n^{CO_2} / \widehat{p}_n^{Mining}$.

In Figure 5, we plot the calculated consumption of CO_2-containing inputs versus the data on real CO_2 emissions. The elasticity between our measure and the data on CO_2 emissions is roughly unity and we are able to predict the level of carbon emissions with a very high accuracy.

The metric that we have developed is very convenient, because it allows directly mapping a 1% change in the model's implied $Y_n^{CO_2}$ into a 1% change in CO_2 emissions produced by country n.

3.4 Copenhagen Accord target reductions in CO_2 emissions

The reduction of global CO_2 emissions has been on the agenda of the international community for a long time. Starting with the Kyoto Protocol in 1997, many countries set certain goals in terms of reducing their carbon emissions. The Kyoto Protocol, however, faced several difficulties. The United States have not ratified the agreement and Canada renounced it in 2011. Despite ambitious goals set in the year when the protocol was signed, most of the countries were not successful in reducing their CO_2 emissions in accordance with the Protocol by 2012.

In 2009, countries announced new targets in carbon emissions as a part of the so-called Copenhagen Accord. This legally non-binding document endorsed continuation of the process initiated by the Kyoto Protocol and included new pledges from the participating countries. For instance, the United States have set a target a reduction of CO_2 emissions of about 17% by the year 2020 relative to 2005. The European Union and Switzerland set a target of a 20-30% reduction in emissions relative to 1990.

Developing countries that emit a considerable share of global pollution such as Brazil, China, and India have also agreed to cut emissions by the target 2020 year. In particular, Brazil, China, and India agreed to reduce their emissions by 20-45% relative to "business as usual" levels through voluntary domestic policies.

Table 4: Emissions and Target Reductions

	CO_2 in 1990	CO_2 in 2000	change in %	target rel. to 2000
Australia	287331.452	329604.628	14.7	25%
Brazil	208886.988	330125.342	58.0	36%
Canada	450076.579	537402.517	19.4	13%
China	2460744.017	3405179.867	38.4	6.5%
Iceland	2071.855	2163.53	4.4	33%
Israel	33534.715	62691.032	86.9	20%
Japan	1094705.843	1219592.862	11.4	37%
Korea	243815.163	432460.311	77.4	30%
Mexico	325603.931	383021.817	17.6	30%
New Zealand	24022.517	32698.639	36.1	41%
Norway	31330.848	38807.861	23.9	52%
Switzerland	42966.239	39093.887	-9.0	23%
United States	4879376.206	5512399.415	13.0	16%
European Union	4134263.66	3888831.498	-5.9	25%

The data on total CO_2 emissions (in ktones) are from the World Bank. The data on target emission according to the Copenhagen Accord are from the Pew Center on Global Climate Change.

To make the results comparable across countries, we normalize all pledges to the year 2000 (the benchmark year of the model) and list the normalized targets in Table 4. On average, the results of the Copenhagen Accord, though not legally binding, suggest that 20% is a relatively sensible lower bound of the pledged target reduction in carbon emissions in the world as a whole. Hence, we use this target for in our counterfactual experiments. This reduction is also implied for the ROW category.

4 Counterfactual experiments

In this section, we conduct a series of counterfactual policy experiments which are aimed at reducing carbon emissions. We analyze the consequences of an inception of such policies in individual countries, in groups of countries, and in the world as a whole. We largely consider two broad measures as well as a combination thereof: a carbon tax placed on production and a carbon border tax.

4.1 Measuring the impact of policy instruments

Any policy instrument aimed at reducing carbon emissions will have an impact on both consumers and producers in each economy. Hence, it is important to examine the effects of either policy not only on the level of carbon emissions but also on economic variables such as GDP and prices. In particular, we focus on changes in the following variables of interest: GDP, industry specific prices and output, change in welfare and change in total carbon emissions on both country-specific and global level. All variables are calculated relative to the benchmark year, 2000.

Levels of all the outcome variables, except welfare, are directly observable in the data. To evaluate welfare of consumers, we calculate real income of consumers in each country n as

$$W_n = \frac{\widehat{Y}_n - T_n}{\Pi_n^i (p_n^i)^{s_n^i}}, \tag{4.1}$$

where $\widehat{Y}_n$ denotes the change in country n's nominal GDP in response to the implementation (or the change of) a carbon tax. In other words, we deflate the change in total nominal income of consumers in n by the aggregate of prices normalized by the consumption share parameters. Since we focus on policy measures that affect welfare and production at a comparable level of reductions in CO_2 emissions, we can measure changes in welfare without having to specify the disutility from CO_2 emissions directly. It suffices to assume that the utility is weakly increasing in real consumption at all levels of CO_2, which appears reasonable.

A carbon tax on CO_2-intensive inputs is the most popular policy measure adopted to reduce carbon emissions. Many countries either have already introduced some form of a carbon tax or are planning its introduction in the near future. The list of countries where a carbon tax is currently in place includes Canada (certain provinces), Costa Rica, Denmark, Finland, India, the Netherlands, Norway, South Africa, Sweden, Switzerland, and the United States (certain states). Many countries, including Australia, China, Japan, and Korea are considering a carbon tax as a major instrument of achieving carbon emission targets under the Copenhagen Accord. Carbon taxes can be implemented through taxing consumption or production. We consider both policies. First, let us consider consumption taxes in the subsequent section.

5 Carbon taxes on CO_2-intensive input consumption

5.1 International policy alignment among OECD countries

One of the major criticisms of the Copenhagen Accord is that the agreement itself is not legally binding. Hence, the reduction in carbon emissions has to be based on voluntary, unilateral measures such as domestic taxation. First, we calculate a tax rate on the consumption (intermediate and final) of the carbon-intensive fossil content of inputs for each country which would be necessary to achieve the targets set in the Copenhagen Accord. The tax rates are reported in Table 5.

Table 5: Unconditional Tax Rates

country	tax rate in %	country	tax rate in %
Australia	30.0	Korea	40.0
Austria	30.5	Mexico	36.0
Belgium	30.5	Netherlands	30.5
Canada	13.3	New Zealand	64.0
Chile	23.0	Norway	88.0
Czech Republic	30.5	Poland	30.5
Denmark	30.5	Portugal	30.5
Estonia	30.5	Slovak Republic	30.5
Finland	30.5	Slovenia	30.5
France	30.5	Spain	30.5
Germany	30.5	Sweden	30.5
Greece	30.5	Switzerland	28.0
Hungary	30.5	Turkey	24.0
Iceland	45.5	United Kingdom	30.5
Ireland	30.5	United States	17.0
Israel	24.0	ROW	22.0
Italy	30.5	**European Union**	30.5
Japan	57.0	-	-

The targets are largely heterogeneous across countries. Consequently, the tax rates necessary to achieve those targets also vary to a considerable degree. For example, Norway, which is a highly resource-dependent country, needs a tax of approximately 88% in order to achieve its ambitious target of a 52% reduction in carbon emissions. On the other hand, Canada only needs to implement a tax rate of 13.3% to reduce its emissions by the announced 13%. The tax brackets are identical across the European Union member countries. This is due to the fact that the members of the European Union will implement a coordinated environmental policy. The European Union has a uniform target of a 25% reduction in CO_2 emissions. In terms of the uniform tax, such a reduction would require a 30.5% tax on the polluting inputs.

Table 6: The European Union

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	0.0310	-0.0215	Korea	0.1763	-0.0958
Austria	-1.9245	-24.5356	Mexico	-0.1443	-0.0148
Belgium	-7.2650	-25.3161	Netherlands	-1.8069	-25.0615
Canada	-0.1503	-0.1399	New Zealand	0.1973	-0.0732
Chile	0.6048	0.3175	Norway	0.9584	0.1920
Czech Republic	-2.8216	-24.9012	Poland	-3.0994	-24.9094
Denmark	-2.7233	-25.9951	Portugal	-3.6722	-24.7294
Estonia	-2.0664	-25.1840	Slovak Republic	-2.1231	-24.9776
Finland	-1.8024	-25.1457	Slovenia	-12.4779	-25.3615
France	-2.1375	-23.8079	Spain	-7.3316	-24.4012
Germany	-1.9219	-25.0217	Sweden	-3.4591	-24.1304
Greece	-1.9948	-24.4501	Switzerland	-0.0343	-0.5043
Hungary	-1.7221	-24.2968	Turkey	0.0268	-0.1661
Iceland	0.2995	-0.2800	United Kingdom	-2.8134	-25.7804
Ireland	-2.1394	-25.0213	United States	-0.0875	-0.0889
Israel	0.0655	-0.0333	ROW	-0.6366	0.0149
Italy	-1.9785	-24.5966	**World**	-0.8481	-6.3927
Japan	0.1629	-0.0427	**European Union**	-2.7830	-25.0098

A 30.5% uniform tax across all the member countries of the European Union would have a substantial effect on the level of carbon emissions in the world. Such a tax would lower the level of emissions by approximately 6.4%. Such a reduction would cost 2.78% of European Union total welfare, according to the model. This may seem little, but at current growth rates it means giving up several year's worth of real income growth. Of course, with heterogeneous economies in the outset, the individual effects vary by country.

International cooperation appears important in reducing the world level of carbon emissions for two reasons. First, without coordinated efforts, it is likely that reductions in energy use in some countries will partially be offset by *carbon leakage*, i.e., uncoordinated policy may lead to a geographical reallocation of polluting industries without much aggregate consequences on pollution. Second, domestic tax policies have a second-order indirect effect on all other countries in the world, so that a joint implementation (or policy alignment) will require less effort of individual countries in comparison to an uncoordinated implementation.

First, let us consider a counterfactual case where *all* OECD members commit to the reduction of CO_2 emissions and implement domestic tax rates as in Table 5.

Table 7: The OECD

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	-3.1709	-24.8694	Korea	-1.8234	-30.2434
Austria	-1.4696	-24.5934	Mexico	-5.0723	-29.5877
Belgium	-9.0445	-25.7620	Netherlands	-1.5168	-25.9251
Canada	-2.3848	-13.7242	New Zealand	-3.1032	-41.6392
Chile	-0.8966	-19.6425	Norway	-5.7856	-52.2315
Czech Republic	-2.7065	-25.2037	Poland	-3.0102	-24.9853
Denmark	-2.6946	-26.3587	Portugal	-3.8212	-25.0262
Estonia	-1.8963	-25.2588	Slovak Republic	-1.6980	-25.0411
Finland	-1.4291	-25.6360	Slovenia	-15.7314	-25.3985
France	-1.7144	-25.0490	Spain	-8.7024	-24.6564
Germany	-1.5173	-25.3635	Sweden	-3.6743	-27.3528
Greece	-1.4658	-24.5245	Switzerland	-1.3635	-23.9354
Hungary	-1.2926	-24.4125	Turkey	-1.4235	-20.3996
Iceland	-2.7055	-34.8200	United Kingdom	-2.6905	-26.4178
Ireland	-2.0664	-27.2009	United States	-2.4862	-16.4789
Israel	-1.1269	-20.5612	ROW	-1.8844	0.0723
Italy	-1.5667	-24.7357	**OECD**	-2.8365	-23.0848
Japan	-3.9156	-36.8990	**World**	-2.6704	-17.3191
-	-	-	**European Union**	-2.6663	-25.5100

If all OECD countries reduce their emissions to the levels specified in the Copenhagen Accord, the world level of emissions will decrease by more than 17%. Hence, even if the rest of the world refuses to cooperate, the OECD alone may induce a significant decrease in the level of CO_2 emissions. Such a reduction in carbon emissions would cost about 3% of the aggregate welfare. The welfare effects across countries are largely heterogeneous. Some countries, such as Norway, Slovenia, and Spain, would lose relatively more than others. Other countries, such as Chile and Israel, would lose relatively less than others. The welfare effects primarily depend on countries' dependence on energy use and resource endowments. Carbon leakage would be present but minor due to the OECD's economic size. The rest of the world's level of carbon emissions would increase only by 0.07%, according to the model.

5.2 Worldwide international policy alignment

Next, let us consider a case where *all* countries in the world implement domestic carbon tax policies and reduce their levels of emissions according to the Copenhagen Accord pledges. We assume that the rest of the world (ROW) reduces its emissions by 20%. This is a reasonable benchmark given the pledges of big developing countries such as Brazil, China, and India.

Table 8: World

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	-3.1799	-25.6480	Korea	-1.9378	-31.2427
Austria	-1.3264	-25.8190	Mexico	-5.1782	-29.6119
Belgium	-9.9873	-26.3269	Netherlands	-1.4802	-26.4957
Canada	-2.5187	-14.0282	New Zealand	-3.0145	-42.3291
Chile	-0.5708	-20.8125	Norway	-5.6650	-52.2630
Czech Republic	-2.8066	-26.0354	Poland	-3.0977	-25.8878
Denmark	-2.7071	-26.4347	Portugal	-3.9675	-25.9671
Estonia	-2.5203	-25.9325	Slovak Republic	-1.6298	-25.8954
Finland	-1.3763	-26.3734	Slovenia	-18.0637	-26.0183
France	-1.6226	-26.4571	Spain	-9.5551	-25.8556
Germany	-1.4001	-26.1426	Sweden	-3.7448	-27.9136
Greece	-1.2235	-25.7470	Switzerland	-1.3067	-24.4524
Hungary	-1.1767	-25.7499	Turkey	-1.3844	-21.6463
Iceland	-2.6400	-34.9180	United Kingdom	-2.6763	-26.5613
Ireland	-2.0307	-27.4118	United States	-2.6061	-16.9737
Israel	-1.1023	-21.6535	ROW	-6.2222	-20.2807
Italy	-1.4847	-25.8789	**OECD**	-2.8948	-23.8011
Japan	-3.8909	-38.4874	**World**	-3.4756	-22.9246
-	-	-	**European Union**	-2.6999	-26.2441

If the ROW agreed to reduce its emissions by 20%, there would be a substantial effect on the level of world carbon emissions. The emissions would decline by approximately 23% versus 17% in the previous subsection (alignment among OECD members alone). Of course the welfare cost of a bigger reduction would also be bigger. A 23% reduction in the level of CO_2 emission would cost the world about 3.5% in welfare. Country-specific changes in welfare also increase. This is due to the fact that higher taxes in the ROW have a second-order price effects on goods exported to OECD countries. Consumers and firms in those countries would face higher prices and accordingly lose in welfare.

Overall, a worldwide carbon consumption tax is an effective instrument that, if implemented in a coordinated manner, may significantly reduce the world's level of carbon emission to meet the targets adopted at the Copenhagen Accord. However, a more likely policy scenario is that individual countries will implement stand-alone policies in an uncoordinated manner. In what follows, we consider four individual cases: a resource-scarce small open economy (Switzerland), a resource-abundant small open economy (Norway), a resource-scarce big economy (Germany), and a resource-abundant big economy (the United States). We analyze the effects of a carbon consumption tax on each individual country's domestic levels of carbon emissions, prices, and demand.

5.3 Switzerland

5.3.1 Policy implementation in Switzerland alone

Firms in Switzerland have two broad options as far as abatement activities and carbon emission are concerned. First, they may choose to participate in Switzerland's cap-and-trade program. This program exempts firms from environmental taxes, currently 36 Swiss Francs per ton of carbon, if they commit to employing "cleaner" environmental technologies. Swiss government distributes annual permits which can be traded during the year. Companies that choose not to participate in the program are subject to the carbon tax. The tax rate is specified in the federal law on the reduction of carbon emissions. From that point of view, Switzerland is an interesting case to analyze because it uses a direct carbon tax identical to the one that we analyze in this study.

Switzerland's unconditional target reduction in CO_2 emissions according to the Copenhagen accord is 23% relative to the year 2000. Switzerland has also agreed to consider further reductions should cooperative effort from other developed countries be present. The most likely instrument to achieve the goal is considered to be an ad-valorem carbon tax. In the benchmark, the carbon tax in Switzerland is 36 Swiss Francs per ton of carbon. We use the calibrated model to infer the size of a carbon tax necessary to achieve a 23% reduction in CO_2 emissions.

We consider a uniform increase in carbon taxes in all industries in Switzerland.[8] The calibrated model suggest that to reduce emissions by 23%, Switzerland would have to implement a 28% carbon tax relative to the benchmark year. This tax would have a distortive effect and would reduce total welfare in Switzerland by around 1.7%. We use the data on the value of total fossil fuel demand in Switzerland as of 2011 and estimate that a 28% carbon tax in 2000 can be translated into a per-ton tax of about 57.2 Swiss Francs (of 2011). To obtain this estimate, we divide the calibrated value

[8]Currently, certain categories of firms in the *Construction industry* are exempt from a carbon tax. Also, firms which manage to undercut the benchmark value of emissions in any industry would be tax exempt. We ignore these matters in the interest of parsimonious modeling. The calibration fit for the aggregate economy appears to be very good so that this approximation does not seem harmful.

Table 9: Unconditional Policy (Switzerland)

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0004	0.0003	Korea	0.0036	0.0004
Austria	-0.0051	-0.0059	Mexico	-0.0029	-0.0004
Belgium	-0.0334	0.0087	Netherlands	0.0070	0.0032
Canada	-0.0030	-0.0002	New Zealand	0.0040	-0.0002
Chile	0.0104	0.0067	Norway	0.0074	0.0013
Czech Republic	-0.0016	-0.0014	Poland	-0.0013	-0.0009
Denmark	-0.0023	-0.0019	Portugal	-0.0041	-0.0015
Estonia	0.0035	0.0006	Slovak Republic	0.0003	-0.0026
Finland	-0.0002	-0.0041	Slovenia	-0.0688	0.0004
France	0.0206	0.0147	Spain	-0.0213	-0.0011
Germany	-0.0057	-0.0071	Sweden	-0.0037	-0.0028
Greece	0.0039	-0.0005	**Switzerland**	-1.7047	-23.4402
Hungary	-0.0017	-0.0048	Turkey	0.0008	-0.0016
Iceland	0.0069	-0.0006	United Kingdom	-0.0013	-0.0019
Ireland	-0.0085	-0.0097	United States	-0.0022	-0.0006
Israel	-0.0019	0.0438	ROW	-0.0114	-0.0006
Italy	-0.0023	-0.0044	**OECD**	-0.0149	-0.1063
Japan	0.0021	-0.0003	**World**	-0.0143	-0.0800

of the total "polluting" input $Y_n^{CO_2}$ per ton of carbon to determine 28% thereof. We express the resulting value in 2011 terms by normalizing it using the real GDP deflators for 2000 and 2011 for the respective years.

$$tax_n = 0.28 \times \frac{Y_n^{CO_2}}{CO_2} \times deflator. \qquad (5.1)$$

Currently, Switzerland imposes a carbon tax of 36 Swiss Francs per ton of carbon.

Of course, domestic environmental policies in Switzerland will have impact on all other countries in the world in terms of their welfare and CO_2 emissions. We report those results in Table 9. The impact is not strong for most countries, since Switzerland is a relatively small economy. For the aggregate categories there are minor reductions in total carbon emissions, 0.11% and 0.08% for the OECD and the world, respectively. This suggests that aggressive environmental policies in Switzerland would not have any significant impact on the world level of emissions, unless they are supported by other countries in the world.

5.3.2 International policy alignment with Switzerland

Non-cooperative environmental policy would be an effective instrument for Switzerland to meet its own targets of the Copenhagen Accord. However, if other countries do not take similar policies Switzerland will not be able to have a significant impact on the level of carbon emissions in the world. Given this, the incentive to implement restrictive environmental policy measures without other countries' responsiveness appears relatively small. From that point of view, it is important to discuss implications of international policy alignment for Switzerland. Switzerland's major trading partner is the European Union. The member countries pledged to reduce the level of carbon emissions by 25%. What would be Switzerland's optimal policy given that the European Union also implements an environmental tax? How would the world's level of carbon emissions change if Switzerland and the European Union implemented carbon taxes together? We give answers to these questions in Table 10.

Table 10: Switzerland and the EU

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0315	-0.0213	Korea	0.1802	-0.0958
Austria	-1.9313	-24.5412	Mexico	-0.1474	-0.0152
Belgium	-7.2977	-25.3107	Netherlands	-1.8009	-25.0603
Canada	-0.1535	-0.1403	New Zealand	0.2018	-0.0735
Chile	0.6190	0.3274	Norway	0.9688	0.1941
Czech Republic	-2.8246	-24.9039	Poland	-3.1011	-24.9106
Denmark	-2.7265	-25.9970	Portugal	-3.6771	-24.7312
Estonia	-2.0615	-25.1832	Slovak Republic	-2.1228	-24.9800
Finland	-1.8027	-25.1493	Slovenia	-12.5368	-25.3620
France	-2.1224	-23.8006	Spain	-7.3527	-24.4029
Germany	-1.9298	-25.0286	Sweden	-3.4638	-24.1335
Greece	-1.9912	-24.4509	**Switzerland**	-1.6622	-22.5700
Hungary	-1.7238	-24.3009	Turkey	0.0277	-0.1681
Iceland	0.3105	-0.2805	United Kingdom	-2.8156	-25.7825
Ireland	-2.1483	-25.0295	United States	-0.0898	-0.0895
Israel	0.0641	0.0087	ROW	-0.6488	0.0143
Italy	-1.9825	-24.6013	**OECD**	-0.9077	-8.6174
Japan	0.1654	-0.0431	**World**	-0.8625	-6.4682
-	-	-	**EU**	-2.7863	-25.0123

Recall that in order to achieve their target reductions, the European Union member countries would have to implement a carbon tax of 30.5%. Given that the Union members comply with this target, what would Switzerland's optimal policy be? As expected, under cooperation with the European

Union, Switzerland may meets its target of carbon emission reductions by using a slightly lower tax than with an implementation in Switzerland alone. In particular, our estimates suggest that a 53.1 Swiss Francs per ton of CO_2 (instead of 57.2 Swiss Francs) in 2011 terms would suffice.

More importantly, if both the European Union members and Switzerland implemented the respective environmental policies, the world as whole would benefit considerably in terms of the reduction of CO_2 emissions. Table 10 suggests that in that case the world level of carbon emissions would fall by 6.5%. The level of CO_2 emissions in OECD would fall by 8.6%. The welfare costs of these policies would be 1.7% and 2.8% for Switzerland and the European Union, respectively. Notice that the welfare costs of Switzerland associated with fulfilling its Copenhagen Accord pledges are higher than those of the European Union not only because it committed to more severe reductions but also because it is a small open economy where the competitive effects of tax policy are more detrimental than for large open economies.

Now let us suppose that all OECD members comply with their pledges made at the Copenhagen Accord. What would be Switzerland's optimal policy in that case? Non-EU OECD members such as Australia, Canada, Japan, and the United States are among the biggest emitters in the world. Accordingly, the policies of these countries have significant effects on the level of the world's CO_2 emissions. Given that each OECD country implemented a carbon consumption tax independently to reach its emission target, the level of carbon emissions would decrease substantially in the whole world. The exact results are given in Table 7. With the rest of the OECD implementing such a policy, Switzerland's tax rate to meet the Copenhagen Accord pledges would be 53.1 Swiss Francs per ton (instead of 57.2 Swiss Francs with a policy implemented in Switzerland alone). We also consider the scenario where all countries in the world reduce their carbon emissions. Under such a commitment, Switzerland's optimal tax would also be about 53 Swiss Francs per ton of carbon (instead of 57.2 Swiss Francs) in 2011 terms. Hence, for Switzerland, the most important incentive device for implementing the projected policy would be that the European Union moves along with it.

5.3.3 Policy effects on prices and demand in Switzerland

Domestic environmental policies such as a carbon tax, either implemented independently or under international policy alignment, will have considerable effects on the output and price of each of the 43 industries considered. Industries differ in their dependence on "polluting" inputs. For example, the *Coke, refined petroleum products and nuclear fuel industry* depends heavily on carbon-intensive fuels. On the other hand, service sectors such as the *Health and social work industry* do not use much of the "polluting" input. Hence, the effect of a uniform tax on the carbon content of inputs will have largely heterogeneous effects across industries. In Table 11, we report changes (in percent) in prices of each industry's output as well as changes in the final demand for the respective output. The numbering of the industries there is the same as the one given in Table 1.

Naturally, industries that employ relatively more energy are affected the most. Besides the *Mining and quarrying industry* which produces output that is directly linked to the level of CO_2 emissions, such industries as *Non-ferrous metals*, *Electricity, gas and water* and *Coke, refined petroleum products and nuclear fuel* would be affected the most. This is not surprising because these industries heavily depend on carbon-containing inputs.

We also report the change in the industry-specific prices and final demand for four scenarios: unconditional tax policy (only Switzerland aims to fulfill the Copenhagen Accord pledges), cooperation with the European Union, cooperation with the OECD, and worldwide cooperation. These changes differ and depend much on the scenario. For example, a 57.1 Swiss Francs per ton of carbon tax would increase the price of "Coke, refined petroleum products and nuclear fuel" output by 14.08% with a corresponding 13.67% decrease in the total demand under scenario 1. However, under scenario 2, which assumes full cooperation of the European Union, the respective changes are 20.44% and 18.13%.

Under cooperation with the European Union, the prices will increase and demand will fall by relatively higher margins. The reason for this is the following. A domestic tax on "polluting" inputs will drive prices up, especially so in the industries that depend heavily on the carbon-containing inputs. If the European Union member countries do not implement a carbon tax, Swiss firms will start substituting away from domestically produced carbon-intensive intermediates and export relatively more "pollution" to the partner countries. Hence, carbon leakage cushions the

Table 11: CHANGE IN INDUSTRY PRICES AND DEMAND (SWITZERLAND)

	In isolation		In cooperation					
			EU		OECD		World	
industry number	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i
1	-1.7079	0.1923	-1.9291	0.5370	-1.9186	1.0355	-1.9526	1.1582
2	-24.0369	29.6433	-23.0218	28.0851	-23.0328	28.7522	-23.1758	29.1038
3	-1.6413	0.1244	-1.8002	0.4051	-1.7787	0.8916	-1.8106	1.0118
4	-1.5526	0.0342	-1.7274	0.3307	-1.7484	0.8605	-1.7933	0.9941
5	-1.6284	0.1113	-1.8149	0.4201	-1.7963	0.9097	-1.8306	1.0324
6	-1.6046	0.0871	-1.7427	0.3464	-1.7240	0.8354	-1.7690	0.9691
7	-13.6724	14.0784	-18.1381	20.4437	-18.3464	21.3628	-18.5690	21.8000
8	-1.8671	0.3548	-3.3177	1.9810	-3.6406	2.8411	-3.8500	3.1544
9	-1.5458	0.0274	-1.7361	0.3395	-1.7549	0.8671	-1.8387	1.0408
10	-1.6424	0.1256	-2.1062	0.7189	-2.1707	1.2959	-2.2585	1.4748
11	-3.6368	2.1978	-4.2297	2.9522	-4.2465	3.4918	-4.3179	3.6588
12	-3.2113	1.7485	-4.3624	3.0950	-4.4610	3.7242	-4.5908	3.9554
13	-1.5326	0.0140	-2.8193	1.4580	-4.9560	4.2644	-6.9721	6.6163
14	-1.7647	0.2502	-2.2085	0.8243	-2.2539	1.3821	-2.3555	1.5755
15	-1.5332	0.0145	-1.7339	0.3373	-1.7621	0.8746	-1.8650	1.0679
16	-1.5116	-0.0074	-1.5822	0.1827	-1.5669	0.6746	-1.6115	0.8074
17	-1.6152	0.0979	-1.9143	0.5218	-1.9648	1.0831	-2.0623	1.2715
18	-1.5132	-0.0058	-1.5917	0.1924	-1.5782	0.6861	-1.6239	0.8202
19	-1.5194	0.0005	-1.6040	0.2049	-1.5963	0.7046	-1.6454	0.8422
20	-1.5924	0.0747	-1.8407	0.4465	-1.8801	0.9959	-1.9654	1.1714
21	-1.6400	0.1231	-1.8632	0.4696	-1.8615	0.9768	-1.9118	1.1161
22	-1.5088	-0.0103	-1.6089	0.2099	-1.6392	0.7486	-1.7383	0.9376
23	-1.7029	0.1872	-1.9628	0.5716	-1.9977	1.1171	-2.0775	1.2872
24	-1.8949	0.3833	-2.3587	0.9794	-2.4496	1.5855	-2.5910	1.8211
25	-4.2986	2.9045	-5.5526	4.3942	-5.5381	4.9069	-5.5945	5.0605
26	-2.1052	0.5989	-2.2833	0.9014	-2.2624	1.3909	-2.2939	1.5115
27	-1.5152	-0.0038	-1.5889	0.1895	-1.5436	0.6507	-1.5511	0.7457
28	-1.5059	-0.0132	-1.5998	0.2006	-1.5579	0.6653	-1.5687	0.7636
29	-2.2538	0.7518	-2.6626	1.2947	-2.6373	1.7813	-2.6612	1.8946
30	-2.4515	0.9560	-2.9455	1.5899	-2.9267	2.0847	-2.9566	2.2048
31	-2.8783	1.3997	-3.5555	2.2324	-3.5484	2.7428	-3.5888	2.8749
32	-1.6812	0.1651	-1.8430	0.4488	-1.8013	0.9149	-1.8119	1.0133
33	-1.3785	-0.1424	-1.4190	0.0168	-1.3705	0.4741	-1.3757	0.5665
34	-1.2524	-0.2699	-1.2432	-0.1612	-1.1863	0.2867	-1.1832	0.3706
35	-1.2831	-0.2389	-1.2712	-0.1329	-1.2145	0.3153	-1.2116	0.3994
36	-1.4988	-0.0204	-1.5938	0.1945	-1.5473	0.6545	-1.5535	0.7481
37	-1.3318	-0.1896	-1.3601	-0.0429	-1.3104	0.4129	-1.3139	0.5034
38	-1.3865	-0.1343	-1.4570	0.0554	-1.4133	0.5177	-1.4206	0.6123
39	-1.3463	-0.1749	-1.3828	-0.0199	-1.3336	0.4365	-1.3374	0.5274
40	-1.4417	-0.0783	-1.5002	0.0993	-1.4521	0.5572	-1.4573	0.6497
41	-1.3086	-0.2131	-1.3215	-0.0820	-1.2660	0.3677	-1.2643	0.4530
42	-1.3530	-0.1682	-1.4230	0.0209	-1.3838	0.4876	-1.3928	0.5839
43	-1.4749	-0.0447	-1.5675	0.1677	-1.5245	0.6311	-1.5331	0.7272

detrimental effect to some extent. However, if the European Union implements a carbon tax along Switzerland, the cushioning effect of carbon leakage is reduced, since the the European Union is relatively closed (as a large trading bloc) and it represents Switzerlan's most important trading partner. This detrimental effect on demand is larger, the more important trading partners of Switzerland implement a carbon tax and, hence, it is larger in case of a policy alignment with the OECD countries or the whole world.

The reported changes in prices in Table 11 are those that would clear the markets under alternative tax instruments. For example, one could use those changes in prices and demand to infer about a potential price of carbon permits in a cap-a-trade framework such as the European Trading Scheme so that permits would have the same effect as the envisaged tax. However, for this to be the case permits would have to be industry-specific.

5.4 Norway

5.4.1 Policy implementation in Norway alone

Norway was one of the first countries to introduce a carbon tax. The first variant of the tax was introduced in Norway in 1991. The tax mainly covered gas, gasoline, and oil inputs that produced CO_2 emissions. Norway pledged to reduce its CO_2 emissions by 52% relative to the emissions level in 2000.

Norway and Switzerland are both small open economies. However, Norway is considerably richer in natural resources. Higher taxes on polluting inputs would therefore bring about relatively stronger negative welfare effects. We conduct a similar policy analysis for Norway as we did for Switzerland to compare the results for a resource-scarce small open economy (Switzerland) and a resource-abundant small open economy (Norway).

First, we identify the domestic carbon consumption tax level required to drive down the level of Norway's carbon emissions to the targeted 52%. This tax rate is 88% and can be translated into an equivalent 143 US dollars per ton of CO_2 in 2011 terms. With an exchange rate of roughly one-to-one between the Swiss Franc and the US dollar, the necessary tax to fulfill the pledges in Norway is obviously much higher than the one discussed in Switzerland.

Table 12: UNCONDITIONAL POLICY (NORWAY)

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	0.0050	-0.0011	Korea	0.0135	-0.0336
Austria	0.0060	-0.0121	Mexico	-0.0149	-0.0018
Belgium	-0.2535	-0.6246	Netherlands	-0.0525	-1.0871
Canada	-0.0540	-0.8726	New Zealand	0.0213	-0.0057
Chile	0.0432	0.0156	**Norway**	-6.8138	-52.2265
Czech Republic	-0.0177	-0.3019	Poland	-0.0038	-0.0206
Denmark	-0.0952	-0.4423	Portugal	-0.0290	-0.1758
Estonia	-0.0270	-0.0201	Slovak Republic	0.0070	-0.0181
Finland	-0.0616	-0.7665	Slovenia	-0.1353	-0.0073
France	0.0051	-1.6203	Spain	-0.0808	-0.1111
Germany	-0.0004	-0.3984	Sweden	-0.1203	-4.2424
Greece	0.0142	-0.0129	Switzerland	0.0084	-0.0231
Hungary	0.0095	-0.0131	Turkey	0.0089	-0.0119
Iceland	-0.1111	-0.2293	United Kingdom	-0.0182	-0.8214
Ireland	-0.0274	-2.7454	United States	-0.0109	-0.0656
Israel	0.0160	-0.0084	ROW	-0.0468	-0.0011
Italy	0.0086	-0.1104	**OECD**	-0.0493	-0.4932
Japan	0.0132	-0.0103	**World**	-0.0488	-0.3707

Second, we look at how a domestic tax in Norway would impact the world level of CO_2 emissions. Norway is a relatively big exporter of carbon-containing goods. Accordingly, a domestic carbon consumption tax implemented in a resource-abundant country such as Norway will have a higher impact on the level of world CO_2 emissions relative to a resource-scarce country such as Switzerland. However, in absolute terms Norway is not big enough to have a significant impact on the level of the world's emissions. A 88% tax would reduce carbon emissions by 52% in Norway and by only 0.04% in the world. Partially, this is due to carbon leakage. Some countries would actually increase their consumption of carbon-containing goods.

5.4.2 International policy alignment with Norway

As in the case of Switzerland, we calculate the optimal level of carbon tax given that the European Union also commits to the reduction pledged at the Copenhagen Accord. In that case, the optimal level of carbon tax is only slightly lower – approximately 140 US dollars per ton of CO_2 (instead of 143 US dollars per ton with isolated implementation). We also analyze the impact of an aligned policy implementation according to the pledges in Norway (associated with an 88% tax) and the

European Union (associated with a 35% tax) on the level of carbon emissions in the world. This would reduce world carbon emissions by about 6.7% at a welfare cost of 0.90%. The welfare costs for Norway alone would be quite substantial, amounting to about 6.2%, though.

Table 13: Norway and the EU

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	0.0368	-0.0231	Korea	0.1924	-0.1297
Austria	-1.9209	-24.5476	Mexico	-0.1607	-0.0167
Belgium	-7.5684	-25.7682	Netherlands	-1.8757	-25.8299
Canada	-0.2020	-0.9593	New Zealand	0.2219	-0.0800
Chile	0.6624	0.3423	**Norway**	-6.2343	-51.6596
Czech Republic	-2.8408	-25.1122	Poland	-3.1065	-24.9273
Denmark	-2.8715	-26.3413	Portugal	-3.7157	-24.8622
Estonia	-2.0863	-25.1982	Slovak Republic	-2.1157	-24.9944
Finland	-1.8814	-25.7023	Slovenia	-12.6156	-25.3676
France	-2.1349	-24.9871	Spain	-7.4293	-24.4845
Germany	-1.9252	-25.3103	Sweden	-3.6264	-27.2447
Greece	-1.9806	-24.4626	Switzerland	-0.0218	-0.5260
Hungary	-1.7109	-24.3089	Turkey	0.0376	-0.1800
Iceland	0.1932	-0.5252	United Kingdom	-2.8391	-26.3669
Ireland	-2.1809	-27.0376	United States	-0.0988	-0.1516
Israel	0.0835	-0.0477	ROW	-0.6898	0.0142
Italy	-1.9702	-24.6785	**OECD**	-0.9466	-8.9496
Japan	0.1785	-0.0541	**World**	-0.9018	-6.7178
-	-	-	**European Union**	-2.8155	-25.4445

The effects of Norway's potential policy alignment with the OECD and the world as a whole had been summarized in Table 7 and 8. In case of a cooperation with the OECD, Norway's welfare cost would be lower relative to the case when only the European Union cooperated. The welfare cost would be 5.79%. This cost is even lower in case that all country in the world economy cooperated and would amount to 5.67%, then. The reason for these differences is international competition. Under a common tax, all countries lose in competitiveness, so that the relative welfare losses in Norway are lower and shared internationally.

5.4.3 Policy effects on prices and demand in Norway

A 88% is a relatively aggressive tax and would have major effects on industry-specific prices and demand. We report those in Table 15. Again as in the case of Switzerland, industries that rely heavily on carbon containing inputs are the ones affected the most. For example, in case of an

Table 14: Change in industry prices and demand (Norway)

	In isolation		In cooperation					
			EU		OECD		World	
industry number	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i
1	-6.244	-1.1429	-6.3768	-0.333	-6.2908	0.2335	-6.3006	0.3862
2	-52.0426	93.2643	-51.5542	92.6098	-51.5116	93.7122	-51.5387	94.0958
3	-6.1221	-1.2713	-6.1406	-0.5839	-6.0464	-0.0274	-6.0525	0.1211
4	-6.2763	-1.1088	-6.2326	-0.4863	-6.146	0.0787	-6.1457	0.2206
5	-6.1916	-1.1981	-6.1955	-0.5257	-6.0994	0.0291	-6.1117	0.1843
6	-6.2603	-1.1257	-6.1961	-0.525	-6.0908	0.0199	-6.1007	0.1725
7	-32.7866	37.8959	-37.9292	50.3305	-38.0018	51.501	-38.1863	52.1691
8	-9.2636	2.147	-10.0622	3.7511	-10.033	4.4026	-10.152	4.6894
9	-6.2855	-1.0991	-6.2891	-0.4264	-6.1949	0.1309	-6.2177	0.2975
10	-6.8313	-0.5197	-6.9951	0.3295	-6.9229	0.9141	-6.9666	1.1048
11	-12.3406	5.7326	-12.6048	6.7695	-12.534	7.3879	-12.5801	7.597
12	-11.4033	4.6139	-12.094	6.1491	-12.2813	7.0786	-12.382	7.3538
13	-10.0985	3.0956	-10.6703	4.4573	-11.42	6.0373	-13.8298	9.1575
14	-7.0838	-0.2494	-7.2068	0.5584	-7.1639	1.176	-7.2329	1.395
15	-7.1392	-0.1899	-6.8805	0.2061	-6.7596	0.7374	-6.802	0.9263
16	-6.3346	-1.0472	-6.1359	-0.5888	-6.0231	-0.0522	-6.0224	0.089
17	-6.7147	-0.6441	-6.7117	0.0247	-6.6435	0.612	-6.7023	0.8185
18	-6.3051	-1.0784	-6.1107	-0.6155	-5.9972	-0.0796	-6.008	0.0737
19	-6.0868	-1.3083	-5.9472	-0.7883	-5.8438	-0.2424	-5.8653	-0.078
20	-6.6578	-0.7047	-6.6055	-0.0889	-6.5347	0.495	-6.5717	0.6774
21	-6.9968	-0.3426	-6.7637	0.0805	-6.7184	0.6929	-6.7463	0.8659
22	-6.3379	-1.0438	-6.147	-0.5771	-6.0438	-0.0301	-6.124	0.1974
23	-6.5754	-0.7922	-6.6158	-0.078	-6.5626	0.525	-6.6215	0.7312
24	-8.0433	0.7915	-8.1293	1.5682	-8.0604	2.1627	-8.1144	2.3678
25	-16.1931	10.5929	-16.211	11.3647	-16.1379	12.0028	-16.2158	12.2661
26	-7.3597	0.0477	-7.414	0.7835	-7.335	1.3629	-7.3488	1.5219
27	-5.335	-2.0922	-5.3335	-1.4315	-5.2423	-0.8756	-5.2376	-0.7399
28	-5.4133	-2.0111	-5.3993	-1.3629	-5.3066	-0.8084	-5.3034	-0.671
29	-7.3362	0.0223	-7.9036	1.3193	-7.831	1.9084	-7.8486	2.0726
30	-7.9434	0.6821	-8.6464	2.1432	-8.58	2.7433	-8.6046	2.9168
31	-9.0871	1.9487	-10.0797	3.7712	-10.0227	4.3907	-10.0597	4.5818
32	-5.7905	-1.6187	-5.9357	-0.8004	-5.8492	-0.2367	-5.8501	-0.0941
33	-4.9287	-2.5105	-4.8771	-1.9044	-4.7824	-1.3545	-4.7749	-1.2222
34	-4.4307	-3.0186	-4.3352	-2.46	-4.2386	-1.9147	-4.2245	-1.7898
35	-4.5324	-2.9152	-4.4244	-2.369	-4.3284	-1.8226	-4.3147	-1.6973
36	-5.2162	-2.2148	-5.2752	-1.4921	-5.185	-0.9356	-5.1805	-0.7997
37	-4.7649	-2.6782	-4.7004	-2.0862	-4.6053	-1.5376	-4.5959	-1.4075
38	-4.9965	-2.441	-4.9606	-1.8182	-4.8681	-1.2656	-4.8626	-1.1312
39	-4.8084	-2.6337	-4.7531	-2.0321	-4.6583	-1.4828	-4.6495	-1.3522
40	-5.1238	-2.3101	-5.0875	-1.6869	-4.9948	-1.1339	-4.9883	-1.0003
41	-4.6337	-2.8121	-4.5523	-2.2382	-4.4566	-1.6909	-4.4443	-1.5639
42	-4.8943	-2.5459	-4.8583	-1.9237	-4.7658	-1.3716	-4.7611	-1.2365
43	-5.2755	-2.1536	-5.2701	-1.4974	-5.1783	-0.9426	-5.1746	-0.8058

unconditional implementation of the advocated tax policy, the *Coke, refined petroleum products and nuclear fuel industry* would experience a a 37.89% increase in the price of its output and a comparable 32.79% decline in its total demand. In the presence of international cooperation, the corresponding effects are even larger. The same industry would experience a price increase of 50.33%, 51.50%, and 52.17% in case of cooperation with the European Union, the OECD, and the whole world, respectively.

The price increase in the *Electricity, gas and water industry* would be much smaller and amount to "only" 10.59%, 11.36%, 12.00%, and 12.2% in case of unconditional tax implementation, cooperation with the European Union, cooperation with the OECD, and cooperation with all countries in the world economy, respectively.

So far, we have considered two small open economies. Such economies, as we have seen, can reduce their domestic consumption of the polluting inputs, but these measures will have only minor effects on the level of the world's CO_2 emissions as a whole. Next, we consider counterfactual reductions in emissions in two large countries: one natural resource-scarce (Germany) and one natural resource-abundant (the United States).

5.5 Germany

5.5.1 Policy implementation in Germany alone

As a part of the European Union, Germany is not likely to pursue an independent energy tax policy per se. On the other hand, analyzing a big economy, such as Germany, would be very instructive for a comparison with Switzerland (also resource-scarce but small) and the United States (also large but resource-abundant). So far, we have assumed that the European Union member countries would uniformly implement a 30.5% tax. Here, we can discuss what would happen if Germany implemented an independent tax policy.

It turns out that in order to decrease domestic consumption by the targeted 25 %, Germany would have to introduce a 31% tax on carbon containing input across all industries. The domestic costs of such a tax would be 1.85% in terms of total welfare. A 25% reduction in Germany alone would mean a 5.93% and 1.51% reduction in the level of carbon emissions of the European Union and the

Table 15: Unconditional Policy (Germany)

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	0.0064	-0.0009	Korea	0.0358	-0.0139
Austria	-0.0565	-0.1392	Mexico	-0.0319	-0.0039
Belgium	-0.3868	-0.0669	Netherlands	0.1144	0.0685
Canada	-0.0295	-0.0130	New Zealand	0.0440	-0.0094
Chile	0.0980	0.0452	Norway	0.1367	0.0239
Czech Republic	-0.2091	-0.1792	Poland	-0.0708	-0.0477
Denmark	-0.0290	-0.0284	Portugal	-0.0565	-0.0484
Estonia	-0.0370	-0.0286	Slovak Republic	-0.0406	-0.0789
Finland	0.0012	-0.0564	Slovenia	-0.4421	-0.0662
France	0.0065	-0.0523	Spain	-0.1619	-0.0441
Germany	-1.8547	-24.9727	Sweden	-0.0709	-0.0747
Greece	0.0251	-0.0261	Switzerland	-0.0903	-0.1025
Hungary	-0.1328	-0.1437	Turkey	-0.0096	-0.0442
Iceland	0.1508	-0.0333	United Kingdom	-0.0064	-0.0305
Ireland	-0.0278	-0.0710	United States	-0.0167	-0.0055
Israel	0.0217	-0.0188	ROW	-0.1359	-0.0062
Italy	-0.0079	-0.0452	**OECD**	-0.1460	-2.0127
Japan	0.0339	-0.0031	**World**	-0.1442	-1.5131
-	-	-	**European Union**	-0.4530	-5.9333

whole world, respectively.

5.5.2 International policy alignment with Germany

In terms of international cooperation, Germany's environmental policy is an integral part of the European Union's common approach. In cooperation with the other members of the European Union Germany may introduce a 30.5% tax on carbon emissions to have a 25% reduction in the domestic and the European Union carbon emissions. The exact results are given in Table 6. The welfare domestic costs of such common policy for Germany would be 1.92%. This illustrates the enormous relevance of environmental policy coordination at the level of supranational organizations such as the European Union.

Cooperation with the OECD would have even larger effects on the level of carbon emissions in the world. In addition, it would also cost less in terms of welfare. German domestic welfare costs would be only 1.57%. The exact results are summarized in Table 7. International cooperation should be an important aspect in the agenda of the reduction of carbon emissions in Germany. This is further confirmed by the results in Table 8. If *all* countries in the world would agree to cooperate, the economic costs for Germany would be as small as 1.40% in terms of welfare.

5.5.3 Policy effects on prices and demand in Germany

Relative to small open economies such as Switzerland or Norway, Germany's domestic tax policy would have similar effects effects on domestic prices and relative demand. The effects are the largest under full cooperation with all other countries in the sample. For instance, a heavily carbon-dependent industry such as *Electricity, gas and water* would experience an increase in domestic prices of 5.93%, 6.19%, 6.27%, and 6.39% in case of an unconditional tax, cooperation with the rest of the European Union, cooperation with the OECD, and cooperation with the whole world, respectively.

Table 16: CHANGE IN INDUSTRY PRICES AND DEMAND (GERMANY)

	In isolation		In cooperation					
			EU		OECD		World	
industry number	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i
1	-1.9549	0.2111	-2.1709	0.3921	-2.2259	0.9161	-2.2721	1.1083
2	-25.6651	32.1749	-25.6709	32.1322	-25.8595	33.0849	-26.1936	33.8787
3	-1.8733	0.1278	-2.0401	0.2580	-2.0856	0.7715	-2.1218	0.9530
4	-1.8186	0.0720	-2.0236	0.2412	-2.1041	0.7906	-2.1236	0.9549
5	-1.8724	0.1268	-2.0522	0.2704	-2.1013	0.7877	-2.1399	0.9717
6	-1.8601	0.1142	-2.0171	0.2345	-2.0553	0.7404	-2.0895	0.9198
7	-16.1091	17.1189	-19.5128	22.0227	-19.8588	23.1201	-20.4884	24.2725
8	-2.7938	1.0759	-3.8024	2.0947	-4.1145	2.9038	-4.2915	3.2416
9	-1.8641	0.1184	-2.0801	0.2990	-2.1500	0.8379	-2.1955	1.0291
10	-2.0316	0.2895	-2.4062	0.6341	-2.5286	1.2295	-2.6024	1.4511
11	-4.2366	2.5987	-4.6937	3.0495	-4.8126	3.6586	-4.9315	3.9366
12	-3.8696	2.2071	-4.8268	3.1936	-5.0041	3.8674	-5.1774	4.2062
13	-5.3452	3.8004	-6.9357	5.5320	-7.8575	7.0840	-8.8612	8.4182
14	-2.1530	0.4140	-2.5330	0.7650	-2.6385	1.3438	-2.7247	1.5787
15	-1.8468	0.1007	-2.1009	0.3203	-2.1882	0.8773	-2.2350	1.0700
16	-1.7601	0.0124	-1.9309	0.1463	-1.9660	0.6485	-1.9536	0.7799
17	-1.9328	0.1885	-2.2387	0.4617	-2.3560	1.0506	-2.4245	1.2662
18	-1.7680	0.0204	-1.9342	0.1497	-1.9678	0.6505	-1.9659	0.7925
19	-1.7483	0.0003	-1.9074	0.1224	-1.9474	0.6295	-1.9743	0.8011
20	-1.8858	0.1405	-2.1640	0.3850	-2.2510	0.9421	-2.3080	1.1454
21	-1.9001	0.1551	-2.1179	0.3377	-2.1848	0.8737	-2.2341	1.0690
22	-1.7773	0.0299	-1.9586	0.1747	-2.0291	0.7134	-2.0904	0.9207
23	-2.0189	0.2765	-2.2756	0.4997	-2.3648	1.0597	-2.4316	1.2736
24	-2.5324	0.8048	-2.8320	1.0751	-2.9275	1.6455	-3.0165	1.8844
25	-5.9284	4.4439	-6.1957	4.6995	-6.2684	5.2685	-6.3963	5.5632
26	-2.3774	0.6448	-2.5599	0.7929	-2.6138	1.3181	-2.6661	1.5176
27	-1.6732	-0.0760	-1.7622	-0.0256	-1.7897	0.4679	-1.8160	0.6386
28	-1.6856	-0.0634	-1.7802	-0.0073	-1.8099	0.4886	-1.8367	0.6598
29	-2.5817	0.8559	-2.9281	1.1752	-2.9814	1.7020	-3.0567	1.9266
30	-2.8247	1.1081	-3.2407	1.5020	-3.3019	2.0390	-3.3903	2.2785
31	-3.3479	1.6553	-3.9056	2.2043	-3.9811	2.7609	-4.0966	3.0318
32	-1.8841	0.1388	-2.0357	0.2536	-2.0687	0.7541	-2.1069	0.9377
33	-1.5103	-0.2413	-1.5767	-0.2140	-1.6000	0.2742	-1.6187	0.4368
34	-1.3424	-0.4111	-1.3685	-0.4246	-1.3844	0.0549	-1.3965	0.2104
35	-1.3765	-0.3766	-1.3996	-0.3933	-1.4161	0.0872	-1.4289	0.2434
36	-1.6526	-0.0970	-1.7598	-0.0281	-1.7869	0.4650	-1.8151	0.6377
37	-1.4517	-0.3006	-1.5081	-0.2835	-1.5301	0.2030	-1.5470	0.3636
38	-1.5380	-0.2132	-1.6157	-0.1744	-1.6430	0.3180	-1.6654	0.4845
39	-1.4722	-0.2798	-1.5315	-0.2598	-1.5539	0.2273	-1.5725	0.3896
40	-1.5902	-0.1603	-1.6618	-0.1276	-1.6864	0.3624	-1.7090	0.5291
41	-1.4202	-0.3324	-1.4555	-0.3368	-1.4730	0.1450	-1.4880	0.3035
42	-1.4996	-0.2521	-1.5797	-0.2110	-1.6097	0.2842	-1.6324	0.4508
43	-1.6481	-0.1015	-1.7391	-0.0491	-1.7678	0.4455	-1.7939	0.6160

5.6 United States

5.6.1 Policy implementation in the United States alone

The United States is a large country that differs from Germany in two major ways. First, the United States will implement the environmental policy independent from other countries. Second, energy resources are relatively abundant there. According to the Copenhagen Accord, The United States targets reduction of 16%. In order to achieve this target, it would have to implement a carbon consumption tax of 17%. This tax would cost approximately 2.24% in terms of welfare.

The policy implemented by the United States alone would have a major impact on the level of world emissions of CO_2. If the United States implemented that type of carbon tax to the mentioned extent, the world level of carbon emissions would decrease by approximately 5%. This is substantially more than the corresponding numbers for Switzerland, Norway, and even Germany are – a reflection of the size of the US economy.

Table 17: UNCONDITIONAL POLICY (THE UNITED STATES)

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0164	-0.0166	Korea	0.1043	-0.0540
Austria	0.1597	-0.0086	Mexico	-0.2792	-0.0853
Belgium	-0.5250	-0.0112	Netherlands	0.1298	-0.0496
Canada	-0.2335	-0.0112	New Zealand	0.1422	-0.0319
Chile	0.2593	0.0861	Norway	0.2737	0.0550
Czech Republic	0.0486	-0.0318	Poland	0.0358	-0.0172
Denmark	0.0694	-0.0066	Portugal	-0.0274	-0.0216
Estonia	0.0706	-0.0206	Slovak Republic	0.1373	-0.0141
Finland	0.1783	0.0145	Slovenia	-1.1554	-0.0090
France	0.1419	-0.0223	Spain	-0.4453	-0.0092
Germany	0.1455	-0.0179	Sweden	-0.0059	-0.0457
Greece	0.1699	-0.0206	Switzerland	0.1006	-0.0193
Hungary	0.1404	-0.0367	Turkey	0.1142	-0.0233
Iceland	0.1441	-0.0339	United Kingdom	0.0612	-0.0215
Ireland	0.0605	-0.0605	**United States**	-2.2443	-16.1371
Israel	0.0789	-0.0753	ROW	-0.3161	0.0070
Italy	0.1430	-0.0150	**OECD**	-0.8343	-6.6259
Japan	0.0934	-0.0412	**World**	-0.7438	-4.9744
-	-	-	**European Union**	0.0547	-0.0202

5.6.2 International policy alignment with the United States

The United States and the European Union are the largest polluters in the world. If they agreed to reduce their emissions jointly to the levels in Table 4, the world's level of CO_2 emissions would fall by more than 11%.

Table 18: The United States and the EU

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	0.0485	-0.0377	Korea	0.2837	-0.1506
Austria	-1.7718	-24.5450	Mexico	-0.4261	-0.1004
Belgium	-7.7609	-25.3352	Netherlands	-1.6899	-25.1066
Canada	-0.3870	-0.1498	New Zealand	0.3428	-0.1058
Chile	0.8834	0.4175	Norway	1.2351	0.2466
Czech Republic	-2.7756	-24.9288	Poland	-3.0657	-24.9253
Denmark	-2.6576	-26.0009	Portugal	-3.7005	-24.7499
Estonia	-1.9979	-25.2008	Slovak Republic	-1.9893	-24.9915
Finland	-1.6362	-25.1433	Slovenia	-13.5000	-25.3701
France	-2.0028	-23.8286	Spain	-7.7463	-24.4131
Germany	-1.7831	-25.0384	Sweden	-3.4694	-24.1694
Greece	-1.8324	-24.4703	Switzerland	0.0410	-0.5360
Hungary	-1.5857	-24.3277	Turkey	0.1417	-0.1917
Iceland	0.4566	-0.3131	United Kingdom	-2.7620	-25.7995
Ireland	-2.0882	-25.0708	**United States**	-2.3388	-16.2150
Israel	0.1462	-0.1059	ROW	-0.9574	0.0223
Italy	-1.8420	-24.6116	**OECD**	-1.7306	-15.1381
Japan	0.2588	-0.0845	**World**	-1.5956	-11.3634
-	-	-	**European Union**	-2.7317	-25.0289

In terms of the welfare effects, the United States would lose more in case of a policy alignment with the European Union. The same tendencies are true for the case of cooperation with the OECD and the world. The exact numbers are in Tables 7 and 8.

5.6.3 Policy effects on prices and demand (the United States)

The effect of a domestic environmental policy in the United States are largely consistent with the previous results. The industries that use a relatively higher share of ”polluting” inputs are affected relatively more. In case of international cooperation both prices and demand are also affected to a relatively larger extent. The detailed results are provided in Table 19.

Table 19: Change in industry total demand in prices (the United States)

	In isolation		In cooperation					
			EU		OECD		World	
industry number	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i
1	-1.1937	0.2506	-1.2272	0.5163	-1.2770	0.8532	-1.3241	1.0451
2	-16.0456	17.9853	-16.1034	18.3395	-16.2726	18.9161	-16.4625	19.3563
3	-1.1234	0.1793	-1.1523	0.4402	-1.1952	0.7697	-1.2321	0.9510
4	-1.1133	0.1690	-1.1552	0.4432	-1.2280	0.8032	-1.2423	0.9615
5	-1.1329	0.1889	-1.1647	0.4528	-1.2086	0.7834	-1.2476	0.9669
6	-1.1147	0.1704	-1.1427	0.4304	-1.1819	0.7562	-1.2149	0.9335
7	-11.2695	11.6345	-11.5777	12.2825	-12.0120	13.1578	-12.8793	14.4472
8	-2.1222	1.2015	-2.2857	1.6052	-2.5021	2.1204	-2.6340	2.4046
9	-1.1478	0.2040	-1.1871	0.4756	-1.2435	0.8190	-1.2846	1.0048
10	-1.3303	0.3893	-1.3947	0.6871	-1.4932	1.0746	-1.5540	1.2811
11	-2.6230	1.7221	-2.6964	2.0340	-2.8112	2.4453	-2.9071	2.6926
12	-2.6658	1.7668	-2.7693	2.1105	-2.9547	2.5968	-3.1015	2.8986
13	-4.3096	3.5149	-4.5003	3.9614	-4.9892	4.7937	-5.4402	5.4436
14	-1.3981	0.4584	-1.4506	0.7442	-1.5524	1.1354	-1.6208	1.3499
15	-1.1547	0.2110	-1.1950	0.4835	-1.2798	0.8561	-1.3228	1.0439
16	-1.0499	0.1049	-1.0788	0.3655	-1.1298	0.7030	-1.1165	0.8330
17	-1.2269	0.2843	-1.2759	0.5659	-1.4025	0.9816	-1.4552	1.1796
18	-1.0606	0.1157	-1.0876	0.3745	-1.1306	0.7039	-1.1238	0.8405
19	-1.0459	0.1008	-1.0696	0.3562	-1.1147	0.6877	-1.1405	0.8575
20	-1.1804	0.2371	-1.2246	0.5137	-1.3403	0.9179	-1.3894	1.1121
21	-1.1686	0.2251	-1.2035	0.4922	-1.2642	0.8402	-1.3073	1.0279
22	-1.0937	0.1492	-1.1105	0.3977	-1.1683	0.7423	-1.2163	0.9349
23	-1.2589	0.3168	-1.2980	0.5885	-1.3791	0.9576	-1.4318	1.1556
24	-1.5382	0.6013	-1.5942	0.8912	-1.7028	1.2901	-1.7930	1.5276
25	-3.5149	2.6623	-3.5503	2.9374	-3.6451	3.3318	-3.7246	3.5646
26	-1.4169	0.4776	-1.4493	0.7428	-1.5024	1.0840	-1.5480	1.2750
27	-0.9701	0.0242	-0.9903	0.2758	-1.0209	0.5922	-1.0483	0.7636
28	-0.9812	0.0354	-1.0023	0.2879	-1.0338	0.6053	-1.0611	0.7766
29	-1.5944	0.6588	-1.6345	0.9325	-1.6932	1.2802	-1.7797	1.5138
30	-1.7608	0.8293	-1.8064	1.1092	-1.8727	1.4654	-1.9742	1.7153
31	-2.1212	1.2006	-2.1778	1.4931	-2.2599	1.8675	-2.3945	2.1533
32	-1.1153	0.1711	-1.1400	0.4277	-1.1766	0.7508	-1.2185	0.9372
33	-0.8681	-0.0787	-0.8861	0.1704	-0.9130	0.4827	-0.9332	0.6465
34	-0.7551	-0.1925	-0.7690	0.0522	-0.7885	0.3566	-0.8031	0.5144
35	-0.7736	-0.1739	-0.7876	0.0710	-0.8075	0.3759	-0.8218	0.5334
36	-0.9649	0.0189	-0.9858	0.2713	-1.0166	0.5879	-1.0483	0.7636
37	-0.8308	-0.1163	-0.8479	0.1319	-0.8731	0.4423	-0.8918	0.6044
38	-0.8905	-0.0561	-0.9103	0.1949	-0.9395	0.5096	-0.9626	0.6763
39	-0.8440	-0.1030	-0.8615	0.1455	-0.8867	0.4561	-0.9070	0.6198
40	-0.9158	-0.0306	-0.9343	0.2191	-0.9620	0.5324	-0.9857	0.6999
41	-0.8034	-0.1439	-0.8182	0.1019	-0.8394	0.4082	-0.8563	0.5684
42	-0.8715	-0.0753	-0.8924	0.1768	-0.9222	0.4921	-0.9450	0.6585
43	-0.9577	0.0117	-0.9785	0.2639	-1.0097	0.5808	-1.0365	0.7515

6 Carbon taxes on CO_2-intensive input production

An alternative viable policy option to taxing energy consumption is taxing the production of the carbon-containing output directly. In terms of our model, this means placing a production tax on the *Mining and quarrying industry* in each country. Some countries, however, have a very low endowment of fossil fuels (e.g., Japan) and import a large share of the consumed energy sources. Hence, a production tax in those countries will be relatively ineffective.

We analyze the effects of a production tax in terms of changes in carbon emissions, welfare, and industry prices and demand. This permits comparing reductions in CO_2 emissions from a production versus a consumption tax at the same welfare cost.

Table 20: UNCONDITIONAL TAX RATES

country	tax rate in %	country	tax rate in %
Australia	56	Korea	-
Austria	87	Mexico	20
Belgium	87	Netherlands	87
Canada	24	New Zealand	-
Chile	-	Norway	99
Czech Republic	87	Poland	87
Denmark	87	Portugal	87
Estonia	87	Slovak Republic	87
Finland	87	Slovenia	87
France	87	Spain	87
Germany	87	Sweden	87
Greece	87	Switzerland	44.5
Hungary	87	Turkey	-
Iceland	47	United Kingdom	87
Ireland	87	United States	28.5
Israel	-	ROW	23.5
Italy	87	**European Union**	87
Japan	-	-	-

We use "-" for countries that are unable to reduce carbon emissions with the production tax.

In Table 20 we report the results for the implementation of an unconditional (isolated) implementation of a carbon production tax rate for each country at a time. In absolute terms, production tax rates are higher than the respective consumption tax rates. This is due to the fact that consumption taxes affect both domestically produced and imported carbon-intensive inputs while the production tax does not. A production tax only covers domestic production for domestic sales or exporting.

This immediately suggests two insights. First, domestic production-based environmental policies are likely to have larger second-order effects on others, especially, for resource-abundant countries. Second, international coordination is relatively more important in case of taxes on production relative to ones on consumption.

6.1 International policy alignment

In terms of the aggregate welfare of the European Union, a 25% reduction in CO_2 emissions would be more costly in comparison, if a production tax were implemented. While the consumption tax would reduce total welfare by about 2.78%, the production tax would cause a 3.17% loss in welfare. Another important dimension where the effects of the production versus consumption tax are different is in the heterogeneous country-specific effects. In case of a uniform production tax, the European Union member countries would experience largely different effects in terms of both the reduction in the carbon emissions and welfare relative to the case of a consumption tax. While some countries, such as the United Kingdom, would experience a large decrease in the level of carbon emissions, other countries, such as Greece, would experience only a moderate effect of a uniform carbon tax on production. These results are reported in Table 21.

Next, we consider the case where all the OECD member countries implement the unconditional production tax (unaligned with and isolated from other economies) as in Table 20. Recall, that cooperation within the OECD was projected to reduce world level of carbon emissions by approximately 17.32% in case of the carbon consumption tax. The effects are much stronger in case of the production tax. In Table 22, we report the detailed results. Production taxes would reduce the level of world carbon emissions by 21.67%. Naturally, such a reduction would also be more costly. The aggregate welfare loss of the OECD in case of the production tax would be about 3.31%. In contrast to the counterfactual experiment with a consumption tax, the corresponding individual country effects are largely heterogenous.

Finally, we consider the effects of a worldwide concerted implementation of carbon production taxes. The differences between the consumption and the production taxes documented in the previous two tables are carried through. The need for a better international coordination is apparent from the results in Table 22. If all countries in the world economy implemented the tax rates specified

Table 21: THE EUROPEAN UNION

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	0.0627	-0.1838	Korea	0.2375	-0.4017
Austria	-3.4532	-30.2518	Mexico	-0.2179	-0.0457
Belgium	-5.2863	-20.6521	Netherlands	-0.5477	-13.1598
Canada	-0.3200	-1.3105	New Zealand	0.2958	-0.2958
Chile	0.8818	0.1833	Norway	3.1991	-1.4922
Czech Republic	-0.6960	-2.7561	Poland	-2.4372	-17.0409
Denmark	-5.5212	-44.9984	Portugal	-4.1599	-23.3515
Estonia	-3.3197	-35.5979	Slovak Republic	-0.0494	-3.6445
Finland	-0.3563	-12.4604	Slovenia	-17.6395	-36.2701
France	-2.7806	-18.4504	Spain	-5.2289	-11.9935
Germany	-2.2588	-25.5716	Sweden	-4.3166	-20.9951
Greece	-1.8774	-15.1698	Switzerland	-0.1967	-6.1252
Hungary	-1.7844	-18.0307	Turkey	0.0173	-0.6717
Iceland	0.2909	-2.0053	United Kingdom	-4.7448	-37.3733
Ireland	-3.1897	-31.2895	United States	-0.2074	-1.1566
Israel	-0.4292	-13.2768	ROW	-1.2602	-1.5160
Italy	-2.2995	-21.1633	**World**	-1.0843	-7.2230
Japan	0.2303	-0.3966	**European Union**	-3.1737	-24.8498

in Table 20 simultaneously, many of them would experience a reduction in the use of carbon-containing inputs that is much larger than the targeted level. This is due to the bigger second-order effects relative to a carbon consumption tax. A carbon-related production tax raises prices of carbon-containing inputs that are consumed domestically or abroad. Importers of those inputs face higher prices and are projected to substitute away from those products, thereby reducing world emissions even further than with a consumption tax. Under a world-wide production tax, the second-order (general equilibrium spillover) effects are found to bring about larger reductions in CO_2 than initially targeted at the implicit production tax rates associated with isolated policy implementation. For example, as indicated in Table 23, the European Union would experience a 49.87% reduction in carbon emissions with a carbon-related production tax, which is twice as large as the pledged target. Hence, a concerted carbon-related taxation of production could rely on relatively lower tax rates to meet the targets.

In what follows, we omit the discussion of a German carbon production tax for two reasons. First, Germany is very scarce in natural resources and a carbon production tax would be ineffective in reducing the level of CO_2 emissions to the targeted level. Second, we have discussed the case of a uniform carbon production tax in the European Union which implicitly covers the case of Germany.

Table 22: The OECD

country	% change in W_n	$CO_{2,n}$	country	% change in W_n	$CO_{2,n}$
Australia	-5.0411	-38.2746	Korea	0.7354	-0.2497
Austria	-4.0368	-48.6554	Mexico	-3.4629	-18.7549
Belgium	-15.7280	-49.0388	Netherlands	-1.7942	-48.8883
Canada	-3.6774	-21.9352	New Zealand	0.7587	-0.3237
Chile	2.3676	1.1605	Norway	-5.3572	-55.2866
Czech Republic	-4.3378	-48.1668	Poland	-5.8439	-48.5497
Denmark	-6.7299	-51.4640	Portugal	-7.8562	-48.6760
Estonia	-4.1483	-49.5205	Slovak Republic	-2.4778	-48.1034
Finland	-1.7604	-48.6941	Slovenia	-28.4601	-49.7990
France	-3.9525	-48.0195	Spain	-16.2832	-47.8046
Germany	-3.3323	-49.1913	Sweden	-7.6527	-50.0480
Greece	-3.0383	-47.8952	Switzerland	-2.1982	-33.7664
Hungary	-2.3943	-47.6207	Turkey	0.3679	-0.5152
Iceland	-2.5872	-35.8511	United Kingdom	-6.3566	-51.0344
Ireland	-4.4746	-50.7663	United States	-3.5753	-24.1885
Israel	0.4274	-0.3980	ROW	-2.3803	0.1045
Italy	-3.4288	-48.3385	**OECD**	-3.3101	-28.8691
Japan	0.6719	-0.3419	**World**	-3.1478	-21.6553
-	-	-	**European Union**	-5.5231	-49.2871

Table 23: The World

country	% change in W_n	$CO_{2,n}$	country	% change in W_n	$CO_{2,n}$
Australia	-5.1314	-39.0079	Korea	0.7691	-1.6181
Austria	-3.9327	-49.5909	Mexico	-3.5820	-18.7837
Belgium	-17.0050	-49.5079	Netherlands	-1.8432	-49.3525
Canada	-3.8402	-22.2350	New Zealand	0.9005	-1.5230
Chile	2.9833	-0.1873	Norway	-5.2404	-55.3285
Czech Republic	-4.5410	-48.8043	Poland	-6.1048	-49.2586
Denmark	-6.8173	-51.5521	Portugal	-8.1462	-49.4022
Estonia	-4.9504	-50.0557	Slovak Republic	-2.4994	-48.7729
Finland	-1.8432	-49.3117	Slovenia	-31.5966	-50.3471
France	-3.9365	-49.0986	Spain	-17.4374	-48.7162
Germany	-3.2878	-49.8046	Sweden	-7.8148	-50.4880
Greece	-2.9417	-48.8560	Switzerland	-2.1702	-34.2737
Hungary	-2.4788	-48.7046	Turkey	0.4484	-2.1593
Iceland	-2.4589	-35.9719	United Kingdom	-6.4176	-51.1689
Ireland	-4.4671	-50.9386	United States	-3.7275	-24.6789
Israel	0.5039	-1.8079	ROW	-6.9025	-21.3158
Italy	-3.4515	-49.2310	**OECD**	-3.4023	-29.6732
Japan	0.7618	-2.9924	**World**	-4.0132	-27.5924
-	-	-	**European Union**	-5.6655	-49.8668

6.2 Switzerland

6.2.1 Policy implementation in Switzerland alone

A CO_2 production tax in a resource-scarce country like Switzerland is unlikely to be as efficient as a CO_2 consumption tax, simply because Switzerland does not primarily produce or export carbon-containing goods. Nevertheless, let us investigate the effects of a carbon-related production tax for reasons of comparison.

We report the results of the counterfactual exercise where Switzerland alone implements a carbon production tax of 44.5%. This policy achieves the targeted 23% reduction in carbon emissions but at higher welfare costs than the consumption tax. While the consumption tax would cost 1.70% of welfare, the production tax would entail a welfare loss of 1.93%. At the same time, the production tax would have an only marginally larger effect on the level of world emissions than the consumption tax. Hence, the consumption tax would be more advisable for Switzerland, if no strong commitment to a concerted implementation of production taxes could be expected.

Table 24: Unconditional Policy (Switzerland)

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0006	-0.0003	Korea	0.00448	-0.00113
Austria	-0.0065	-0.0112	Mexico	-0.00339	-0.00046
Belgium	-0.0411	0.0025	Netherlands	0.00788	0.00211
Canada	-0.0035	-0.0004	New Zealand	0.00519	-0.00105
Chile	0.0121	0.0060	Norway	0.00862	0.00142
Czech Republic	-0.0023	-0.0047	Poland	-0.00156	-0.00282
Denmark	-0.0026	-0.0025	Portugal	-0.00458	-0.00447
Estonia	0.0033	-0.0003	Slovak Republic	-0.00062	-0.00662
Finland	-0.0006	-0.0065	Slovenia	-0.07104	-0.00116
France	0.0210	0.0119	Spain	-0.02287	-0.00313
Germany	-0.0069	-0.0118	Sweden	-0.00400	-0.00382
Greece	0.0046	-0.0020	**Switzerland**	-1.93339	-22.93786
Hungary	-0.0024	-0.0074	Turkey	0.00090	-0.00353
Iceland	0.0077	-0.0008	United Kingdom	0.00009	-0.00153
Ireland	-0.0100	-0.0123	United States	-0.00259	-0.00121
Israel	-0.0510	-1.1403	ROW	-0.01523	-0.00052
Italy	-0.0033	-0.0137	**OECD**	-0.01725	-0.11371
Japan	0.0027	-0.0025	**World**	-0.01690	-0.08553
-	-	-	**European Union**	-0.00185	-0.00507

6.2.2 International policy alignment with Switzerland

We have already mentioned that taxing the production of carbon-containing inputs requires much better international coordination than a carbon-related consumption tax. If such coordination were possible, a production tax would be much more desirable than a consumption tax. For example, let us suppose that the European Union members committed to the production taxes specified in Table 20. Given the second-order effects of European Union policy, what would be Switzerland's best response be?

Our estimates suggest that under full commitment from the European Union, Switzerland would achieve the targeted reduction in carbon emissions by implementing a 30% carbon production tax. Such a tax would be desirable in terms of welfare effects compared to the consumption tax. The detailed results are reported in Table 25. Notice that a 30% production tax entails lower welfare losses relative to both a consumption tax and an unaligned production tax (implemented in isolation by Switzerland). Hence, it would be preferable for a small open economy to formulate an environmental policy subject to other countries. However, for the latter a strong enforcement mechanism and binding international agreements would be required.

Table 25: Switzerland and the EU

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0634	-0.1841	Korea	0.2415	-0.4029
Austria	-3.4623	-30.2613	Mexico	-0.2210	-0.0461
Belgium	-5.3194	-20.6519	Netherlands	-0.5415	-13.1592
Canada	-0.3231	-1.3110	New Zealand	0.3005	-0.2968
Chile	0.8958	0.1915	Norway	3.2088	-1.4904
Czech Republic	-0.6946	-2.7551	Poland	-2.4387	-17.0432
Denmark	-5.5254	-45.0004	Portugal	-4.1644	-23.3553
Estonia	-3.3159	-35.5977	Slovak Republic	-0.0486	-3.6489
Finland	-0.3562	-12.4653	Slovenia	-17.6815	-36.2722
France	-2.7694	-18.4465	Spain	-5.2472	-11.9968
Germany	-2.2667	-25.5813	Sweden	-4.3211	-20.9990
Greece	-1.8738	-15.1717	**Switzerland**	-1.6655	-23.0046
Hungary	-1.7863	-18.0365	Turkey	0.0181	-0.6749
Iceland	0.3011	-2.0059	United Kingdom	-4.7469	-37.3754
Ireland	-3.1985	-31.2980	United States	-0.2096	-1.1576
Israel	-0.4750	-14.0826	ROW	-1.2734	-1.5164
Italy	-2.3040	-21.1743	**OECD**	-1.0609	-9.1989
Japan	0.2329	-0.3986	**World**	-1.0980	-7.2861
-	-	-	**European Union**	-3.1773	-24.8546

Table 26: Switzerland and the OECD

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	-5.0411	-38.2743	Korea	0.7320	-0.2490
Austria	-4.0289	-48.6484	Mexico	-3.4604	-18.7546
Belgium	-15.7031	-49.0288	Netherlands	-1.7977	-48.8879
Canada	-3.6748	-21.9348	New Zealand	0.7550	-0.3230
Chile	2.3539	1.1514	Norway	-5.3657	-55.2874
Czech Republic	-4.3341	-48.1636	Poland	-5.8421	-48.5485
Denmark	-6.7257	-51.4625	Portugal	-7.8513	-48.6731
Estonia	-4.1536	-49.5212	Slovak Republic	-2.4771	-48.1006
Finland	-1.7597	-48.6914	Slovenia	-28.4256	-49.7980
France	-3.9565	-48.0184	Spain	-16.2687	-47.8026
Germany	-3.3240	-49.1844	Sweden	-7.6480	-50.0457
Greece	-3.0403	-47.8941	**Switzerland**	-1.0208	-22.9617
Hungary	-2.3923	-47.6177	Turkey	0.3672	-0.5130
Iceland	-2.5951	-35.8508	United Kingdom	-6.3545	-51.0331
Ireland	-4.4670	-50.7614	United States	-3.5734	-24.1879
Israel	0.3999	-1.0051	ROW	-2.3706	0.1046
Italy	-3.4240	-48.3289	**OECD**	-3.2988	-28.8228
Japan	0.6694	-0.3419	**World**	-3.1368	-21.6204
-	-	-	**European Union**	-5.5186	-49.2828

Similar results apply for a concerted implementation of a carbon-related production tax with the OECD. If all *other* OECD countries committed to the unconditional (isolated) production tax rates as in Table 22, the optimal production tax for Switzerland would be only 18.9%. Such a tax would entail an approximate welfare loss of 1.02% which is considerably lower than the one under independent policy implementation by Switzerland as well as under cooperation with the European Union members only. The reason for this is twofold. First, production taxes elsewhere raise Swiss import prices of carbon-containing inputs which lowers demand for such inputs. In that case, the welfare loss is borne partially by the exporters, so that Switzerland might reduce carbon emissions at a relatively lower cost. Second, a relatively lower domestic carbon production tax would make Swiss firms more competitive and raise their demand relative to the rest of the world.

Although it is possible for Switzerland to reduce carbon emissions subject to the lower welfare loss under international cooperation, as Kyoto Protocol process demonstrated, it is hard to enforce the pledges made. On the one hand, the larger the number of committed countries is, the less costly it is for Switzerland (and each other individual country) to achieve the targeted reduction in CO_2 emissions. On the other hand, multilateral agreements that involve large numbers of countries is generally harder to sustain than smaller ones.

In case when all countries in the world economy committed to a legally binding agreement, Switzerland might implement a 18% carbon production tax to meet the targeted emission levels as pledged in the Copenhagen Accord, coming at a welfare loss of only 0.94%.

6.2.3 Policy effects on prices and demand in Switzerland

An unconditionally (in isolation) implemented carbon production tax would have larger effects on industry-level prices and demand relative to the consumption tax. For instance, the unconditional consumption tax would raise the price of *Electricity, gas and water* by 2.90% while the production tax would increase it by approximately 8.29%. However, the effects are quite similar under international cooperation.

Table 27: Change in industry prices and demand (Switzerland)

	In isolation		In cooperation					
			EU		OECD		World	
industry number	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i
1	-3.1343	1.5135	-1.9205	0.5419	-1.8771	1.2827	-1.8855	1.3976
2	-34.2959	49.6583	-24.5690	30.7301	-22.0246	27.4525	-21.6498	26.9756
3	-2.8630	1.2299	-1.7738	0.3917	-1.6723	1.0718	-1.6808	1.1864
4	-2.8196	1.1847	-1.7029	0.3193	-1.7242	1.1252	-1.7597	1.2677
5	-2.9133	1.2824	-1.7907	0.4090	-1.7291	1.1302	-1.7408	1.2482
6	-2.7734	1.1367	-1.7013	0.3177	-1.6294	1.0277	-1.6582	1.1631
7	-30.0733	40.6210	-19.1724	22.0017	-21.5966	26.7568	-21.4490	26.6510
8	-6.9016	5.6212	-3.6214	2.3163	-5.5952	5.2717	-5.8546	5.6723
9	-2.8860	1.2538	-1.7002	0.3166	-1.8152	1.2189	-1.9027	1.4153
10	-3.7489	2.1616	-2.1394	0.7668	-2.5799	2.0134	-2.6705	2.2154
11	-7.4052	6.1957	-4.4963	3.2536	-4.8214	4.4159	-4.8164	4.5198
12	-8.1263	7.0291	-4.6781	3.4505	-5.7601	5.4559	-5.8371	5.6527
13	-7.3726	6.1583	-3.4328	2.1164	-6.3737	6.1471	-8.9029	9.2084
14	-3.8952	2.3172	-2.2506	0.8815	-2.6344	2.0705	-2.7320	2.2800
15	-2.8949	1.2631	-1.6812	0.2972	-1.8437	1.2483	-1.9549	1.4693
16	-2.4571	0.8087	-1.5284	0.1415	-1.4046	0.7973	-1.4420	0.9413
17	-3.2747	1.6608	-1.9204	0.5418	-2.1383	1.5531	-2.2398	1.7650
18	-2.4849	0.8374	-1.5594	0.1731	-1.4300	0.8234	-1.4681	0.9680
19	-2.5132	0.8667	-1.5684	0.1822	-1.4537	0.8476	-1.4946	0.9951
20	-3.0857	1.4625	-1.8126	0.4314	-1.9694	1.3781	-2.0515	1.5693
21	-3.0570	1.4325	-1.8535	0.4733	-1.8751	1.2807	-1.9067	1.4194
22	-2.5552	0.9102	-1.5703	0.1842	-1.5116	0.9069	-1.6296	1.1337
23	-3.2882	1.6750	-1.9684	0.5910	-2.0636	1.4757	-2.1322	1.6532
24	-4.2531	2.6996	-2.4688	1.1071	-2.9104	2.3606	-3.0450	2.6102
25	-9.1986	8.2931	-5.9142	4.8097	-5.4891	5.1535	-5.3980	5.1623
26	-3.7226	2.1337	-2.3061	0.9388	-2.1990	1.6161	-2.1905	1.7137
27	-2.4033	0.7530	-1.5325	0.1457	-1.3071	0.6978	-1.2840	0.7797
28	-2.4324	0.7831	-1.5481	0.1616	-1.3373	0.7286	-1.3190	0.8155
29	-4.4487	2.9098	-2.6902	1.3372	-2.6873	2.1260	-2.6537	2.1977
30	-4.9989	3.5059	-2.9968	1.6575	-3.0581	2.5166	-3.0241	2.5880
31	-6.1377	4.7617	-3.6537	2.3506	-3.8357	3.3456	-3.7978	3.4131
32	-2.8913	1.2594	-1.8065	0.4252	-1.6333	1.0317	-1.6063	1.1098
33	-2.0863	0.4269	-1.3471	-0.0425	-1.1043	0.4913	-1.0834	0.5753
34	-1.7386	0.0715	-1.1528	-0.2390	-0.8637	0.2474	-0.8359	0.3243
35	-1.7858	0.1196	-1.1848	-0.2066	-0.8913	0.2753	-0.8630	0.3517
36	-2.4233	0.7737	-1.5345	0.1478	-1.3266	0.7177	-1.3012	0.7973
37	-1.9767	0.3146	-1.2824	-0.1080	-1.0348	0.4207	-1.0133	0.5041
38	-2.1745	0.5175	-1.3918	0.0029	-1.1801	0.5683	-1.1616	0.6548
39	-2.0205	0.3595	-1.3076	-0.0825	-1.0645	0.4509	-1.0428	0.5340
40	-2.2322	0.5767	-1.4359	0.0476	-1.1938	0.5823	-1.1701	0.6635
41	-1.8827	0.2185	-1.2392	-0.1516	-0.9560	0.3408	-0.9276	0.4171
42	-2.1279	0.4695	-1.3574	-0.0321	-1.1675	0.5555	-1.1534	0.6465
43	-2.3747	0.7236	-1.5117	0.1246	-1.3015	0.6920	-1.2810	0.7766

6.3 Norway

6.3.1 Policy implementation in Norway alone

The major differences between a consumption and the production tax for Norway would be in the second-order effects, as importers of carbon-containing inputs produced in Norway would face higher prices. Hence, even as a small open economy, Norway might be able to drive down the world level of CO_2 emissions by a considerable amount.

However, the consumption tax is still preferable in terms of the reduction in domestic emissions. In order to achieve a 52% reduction of emissions as pledged, Norway would have to introduce a prohibitive 99% carbon production tax. The welfare costs of this tax rate are higher than those under the consumption tax by almost 3%.

Table 28: Unconditional Policy (Norway)

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0169	-0.0115	Korea	0.0449	-0.3993
Austria	0.0237	-0.0776	Mexico	-0.0576	-0.0075
Belgium	-1.8836	-7.3045	Netherlands	-0.4954	-15.0850
Canada	-0.7843	-8.6414	New Zealand	0.0751	-0.0350
Chile	0.1917	0.0764	**Norway**	-9.3213	-51.5075
Czech Republic	-0.2664	-5.0232	Poland	-0.0306	-0.1688
Denmark	-0.4277	-5.7703	Portugal	-0.1627	-1.4054
Estonia	-0.1457	-0.0930	Slovak Republic	0.0202	-0.0802
Finland	-0.3362	-8.9489	Slovenia	-0.6832	-0.0635
France	-0.1559	-8.9807	Spain	-0.3989	-0.9386
Germany	-0.0785	-3.6325	Sweden	-1.1755	-22.4237
Greece	0.0475	-0.0700	Switzerland	0.0262	-0.2200
Hungary	0.0092	-0.0672	Turkey	0.0265	-0.0621
Iceland	-0.1425	-0.8613	United Kingdom	-0.5432	-10.4451
Ireland	-0.4718	-18.4030	United States	-0.0748	-0.5472
Israel	0.0451	-0.0266	ROW	-0.2073	-0.0286
Italy	0.0083	-0.8779	**OECD**	-0.1887	-2.7516
Japan	0.0513	-0.0573	**World**	-0.1919	-2.0736
-	-	-	**European Union**	-0.2987	-6.0154

On the other hand, because Norway is a big exporter of carbon-containing inputs a domestic carbon production tax would have large second-order effects. Large importers of energy-related goods such as Ireland would experience a dramatic increase in import prices in response. This would drive down carbon emissions in both Europe and the world. The carbon production tax in Norway would entail 6.02% and 2.07% of reductions in carbon emissions in the European Union and the world, respectively.

6.3.2 International policy alignment with Norway

Similar to the case of Switzerland, Norway would take advantage of international cooperation in environmental tax policy. Would the European Union members commit to the pledged target reductions, Norway's optimal carbon production tax rate would be 94.5%. In that case, Norway might reduce its carbon emissions with relatively lower welfare costs than with an isolated implementation of the production tax. The difference in welfare costs would be substantial and amounts to about 2% of aggregate welfare.

Table 29: NORWAY AND THE EU

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0856	-0.1985	Korea	0.3052	-0.8001
Austria	-3.4482	-30.3376	Mexico	-0.2895	-0.0541
Belgium	-7.4552	-27.1864	Netherlands	-1.1237	-26.9387
Canada	-1.0876	-9.4942	New Zealand	0.3991	-0.3412
Chile	1.1403	0.2825	**Norway**	-7.4029	-51.9969
Czech Republic	-0.9874	-7.5177	Poland	-2.4802	-17.2184
Denmark	-6.4783	-49.8159	Portugal	-4.3933	-24.6137
Estonia	-3.4951	-35.6936	Slovak Republic	-0.0124	-3.7431
Finland	-0.7403	-20.7070	Slovenia	-18.3672	-36.3346
France	-3.0889	-26.3318	Spain	-5.6981	-12.8809
Germany	-2.4205	-28.7530	Sweden	-6.1242	-40.7299
Greece	-1.8225	-15.2590	Switzerland	-0.1711	-6.3353
Hungary	-1.7792	-18.1244	Turkey	0.0544	-0.7560
Iceland	0.1684	-2.8345	United Kingdom	-5.7818	-46.1573
Ireland	-4.1360	-47.0361	United States	-0.2874	-1.6813
Israel	-0.3712	-13.3515	ROW	-1.5265	-1.5456
Italy	-2.3045	-21.9507	**OECD**	-1.2995	-11.5780
Japan	0.3026	-0.4614	**World**	-1.3392	-9.0801
-	-	-	**European Union**	-3.6575	-30.0864

The European Union and Norway together could drive down the world level of carbon emissions by 9.08% when implementing a carbon production tax that is consistent with their pledges in the Copenhagen Accord. This is substantially larger than the respective reduction of 6.72% in case of the consumption tax.

Under commitment from all members of the OECD, Norway's optimal rate of carbon production tax would be 86% which in absolute terms is lower than the isolated required consumption and production tax rates. The welfare cost would be as low as 4.91% in comparison. The OECD alone could achieve more than a 20% reduction in the world level of carbon emissions. This reduction, however, would be relatively more costly for big exporters and importers of natural resources than with a consumption tax. This suggests that better coordination of environmental policy within the OECD alone might contribute substantially to the reduction in the worldwide CO_2 emissions.

We also consider the case of full world cooperation and find that Norway's optimal tax rate under such scenario would also be 86% but the welfare costs of the reduction would be slightly lower – at 4.78% – than with less cooperation on a worldwide level (in smaller blocs of economies with policy alignment).

Table 30: Norway and the OECD

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	-5.0412	-38.2773	Korea	0.7289	-0.5581
Austria	-4.0329	-48.6567	Mexico	-3.4702	-18.7565
Belgium	-15.6928	-48.9446	Netherlands	-1.7784	-48.6963
Canada	-4.1715	-26.0138	New Zealand	0.7630	-0.3312
Chile	2.3799	1.1619	**Norway**	-4.9145	-51.8605
Czech Republic	-4.3301	-48.1087	Poland	-5.8424	-48.5508
Denmark	-6.7090	-51.3859	Portugal	-7.8493	-48.6583
Estonia	-4.1527	-49.5232	Slovak Republic	-2.4759	-48.1061
Finland	-1.7495	-48.5792	Slovenia	-28.4753	-49.7998
France	-3.9418	-47.8723	Spain	-16.2823	-47.7946
Germany	-3.3246	-49.1417	Sweden	-7.6109	-49.6704
Greece	-3.0350	-47.8976	Switzerland	-2.1957	-33.7785
Hungary	-2.3906	-47.6230	Turkey	0.3707	-0.5263
Iceland	-2.5839	-35.9889	United Kingdom	-6.3339	-50.8945
Ireland	-4.4504	-50.4701	United States	-3.6064	-24.4046
Israel	0.4316	-0.3982	ROW	-2.3954	0.0714
Italy	-3.4250	-48.3291	**OECD**	-3.3288	-29.0384
Japan	0.6745	-0.3656	**World**	-3.1659	-21.7906
-	-	-	**European Union**	-5.5110	-49.2049

6.3.3 Policy effects on prices and demand in Norway

Table 31: Change in industry prices and demand (Norway)

	In isolation		In cooperation					
			EU		OECD		World	
industry number	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i
1	-6.9660	-3.2818	-6.9007	-1.1240	-6.3050	1.1125	-6.3292	1.2923
2	-50.6772	82.4325	-51.8772	91.2873	-51.9063	96.9852	-51.9397	97.4215
3	-6.8620	-3.3898	-6.6222	-1.4190	-5.9353	0.7151	-5.9552	0.8895
4	-7.3113	-2.9215	-6.8767	-1.1495	-5.9784	0.7613	-5.9915	0.9284
5	-7.0893	-3.1534	-6.7435	-1.2907	-5.9765	0.7593	-6.0049	0.9428
6	-7.1406	-3.1000	-6.7243	-1.3111	-5.8962	0.6734	-5.9205	0.8522
7	-34.9037	38.2273	-41.2036	56.5621	-42.9056	65.9313	-43.1091	66.7777
8	-10.8632	0.9468	-11.4902	4.0030	-11.1794	6.6616	-11.3541	7.0340
9	-7.2790	-2.9553	-6.8908	-1.1346	-6.1004	0.8922	-6.1417	1.0899
10	-8.0074	-2.1869	-7.8055	-0.1537	-7.0815	1.9576	-7.1536	2.1916
11	-12.8368	3.2325	-13.3405	6.2236	-13.0542	8.9615	-13.1185	9.2077
12	-12.7019	3.0731	-13.3228	6.2019	-13.1238	9.0487	-13.2570	9.3821
13	-13.0631	3.5012	-12.9513	5.7487	-12.1194	7.8024	-15.1627	11.8390
14	-8.4192	-1.7470	-8.0844	0.1493	-7.2867	2.1832	-7.3864	2.4486
15	-9.5472	-0.5218	-8.0691	0.1327	-6.3902	1.2046	-6.4521	1.4253
16	-7.7249	-2.4863	-6.8824	-1.1434	-5.6365	0.3963	-5.6464	0.5592
17	-8.0708	-2.1195	-7.5268	-0.4546	-6.5637	1.3925	-6.6511	1.6416
18	-7.6546	-2.5606	-6.8353	-1.1935	-5.6180	0.3765	-5.6414	0.5539
19	-7.2351	-3.0013	-6.5544	-1.4904	-5.5419	0.2957	-5.5789	0.4873
20	-8.0091	-2.1851	-7.3937	-0.5977	-6.3689	1.1815	-6.4251	1.3961
21	-9.1281	-0.9806	-7.9085	-0.0420	-6.2957	1.1025	-6.3390	1.3029
22	-7.9655	-2.2315	-6.9601	-1.0609	-5.6793	0.4418	-5.7972	0.7202
23	-7.5826	-2.6365	-7.2603	-0.7407	-6.5063	1.3303	-6.5917	1.5769
24	-8.9348	-1.1908	-8.8384	0.9777	-8.1752	3.1719	-8.2529	3.4160
25	-16.1533	7.3159	-16.6654	10.4618	-16.3180	13.2113	-16.4355	13.5425
26	-7.8657	-2.3374	-7.8404	-0.1159	-7.3315	2.2326	-7.3592	2.4185
27	-5.7386	-4.5411	-5.5932	-2.4935	-5.0765	-0.1961	-5.0812	-0.0396
28	-5.8573	-4.4209	-5.6805	-2.4032	-5.1316	-0.1380	-5.1388	0.0211
29	-7.9280	-2.2713	-8.5357	0.6434	-8.3043	3.3172	-8.3362	3.5100
30	-8.6584	-1.4897	-9.4144	1.6197	-9.2105	4.3484	-9.2509	4.5534
31	-9.9148	-0.1159	-11.0431	3.4803	-10.9714	6.4123	-11.0265	6.6399
32	-6.2411	-4.0296	-6.2891	-1.7693	-5.8472	0.6209	-5.8588	0.7862
33	-5.3613	-4.9217	-5.1147	-2.9852	-4.5455	-0.7513	-4.5465	-0.5995
34	-4.7581	-5.5240	-4.4811	-3.6287	-3.9368	-1.3801	-3.9296	-1.2378
35	-4.8415	-5.4411	-4.5613	-3.5477	-4.0201	-1.2946	-4.0132	-1.1518
36	-5.6452	-4.6357	-5.5620	-2.5256	-5.0738	-0.1989	-5.0785	-0.0423
37	-5.1734	-5.1101	-4.9143	-3.1896	-4.3504	-0.9537	-4.3492	-0.8045
38	-5.4108	-4.8720	-5.1997	-2.8981	-4.6572	-0.6349	-4.6613	-0.4798
39	-5.2000	-5.0835	-4.9642	-3.1388	-4.4162	-0.8855	-4.4157	-0.7355
40	-5.5316	-4.7504	-5.3261	-2.7685	-4.7825	-0.5042	-4.7850	-0.3505
41	-4.9558	-5.3275	-4.7094	-3.3978	-4.1775	-1.1324	-4.1727	-0.9872
42	-5.3003	-4.9830	-5.0906	-3.0098	-4.5571	-0.7391	-4.5625	-0.5829
43	-5.6885	-4.5919	-5.5313	-2.5573	-5.0080	-0.2680	-5.0144	-0.1099

A counterfactual carbon production tax in Norway would have the effects that are consistent with the our previous analysis. As far as the changes in industry-specific prices and demand are concerned, a carbon production tax would have the biggest effects on industries that use carbon-containing inputs relatively more intensively. For example, the policy would increase the price of *Gas, electricity and water* by 7.32%, 10.46%, 13.21%, and 13.54% for the unconditional (isolated) policy implementation, cooperation with the European Union, cooperation with the OECD, and cooperation with the world as a whole, respectively.

6.4 United States

6.4.1 Policy implementation in the United States alone

An unconditional carbon production tax rate (implemented in isolation) of 28.5% would be sufficient for the United States to meet the pledge of the Copenhagen Accord. Since the United States are a much larger economy than Switzerland and Norway that is relatively rich in natural resources, its domestic environmental policies would have a major impact on the level of carbon emissions in the world.

We report the results of the counterfactual exercise of implementing a carbon-related production tax in Table 32. One striking feature of the United States is that there is some degree of indifference between a carbon consumption versus a carbon production tax. Both taxes reduce the level of carbon emissions in the world by approximately 5%. The carbon production tax is slightly less preferable because of relatively higher welfare costs, but the difference is minor.

6.4.2 International policy alignment with the United States

Let us take the implementation of the required carbon-related production tax in the European Union as given and calculate the optimal carbon production tax rate for the United States. In contrast to the small open economies, cooperation with the European Union does not allow the United States to achieve their target levels of carbon emissions at relatively lower welfare costs. While the unconditional implementation of a carbon production tax would cost 2.24% in welfare, the carbon production tax under cooperation with the European Union would lead to a welfare

Table 32: Unconditional Policy (the United States)

country	% change in W_n	$CO_{2,n}$	country	% change in W_n	$CO_{2,n}$
Australia	0.0228	-0.0885	Korea	0.1201	-0.2673
Austria	0.1959	-0.0422	Mexico	-0.3313	-0.3914
Belgium	-0.7562	-0.6346	Netherlands	0.1535	-0.3004
Canada	-0.3984	-1.4184	New Zealand	0.1770	-0.1028
Chile	0.3010	-0.0313	Norway	0.4385	0.0674
Czech Republic	0.0564	-0.0859	Poland	0.0419	-0.0532
Denmark	0.0871	-0.0356	Portugal	-0.0435	-0.1279
Estonia	0.0747	-0.0448	Slovak Republic	0.1688	-0.0565
Finland	0.1982	-0.4707	Slovenia	-1.4605	-0.0293
France	0.1714	-0.1413	Spain	-0.5786	-0.1377
Germany	0.1743	-0.0934	Sweden	-0.0251	-0.3105
Greece	0.2122	-0.0661	Switzerland	0.1266	-0.1526
Hungary	0.1705	-0.1112	Turkey	0.1368	-0.1773
Iceland	0.1706	-0.2734	United Kingdom	0.0799	-0.1172
Ireland	0.0671	-0.2372	**United States**	-2.4244	-15.9903
Israel	0.0821	-0.3777	ROW	-0.4359	-0.0714
Italy	0.1703	-0.1775	**OECD**	-0.9039	-6.6921
Japan	0.1038	-0.2281	**World**	-0.8222	-5.0437
-	-	-	**European Union**	0.0591	-0.1518

loss of 2.47%. The European Union is one of the largest trading partners of the United States. Aggressive tax policies in both countries would raise the prices in the United States to a level where an independent implementation of a carbon-related production tax would be less costly. This may be seen as a serious obstacle to an international policy alignment of carbon-related production taxes which the United States should be part of.

Yet, if carbon production taxes as in Table 33 were implemented in both the United States and the European Union, the world level of carbon emission would be reduced by slightly more than in the case of carbon consumption taxes.

The effects are even stronger in case of a cooperation with the OECD. The world level of emissions would then drop by 19.09%, which is considerably higher than the 16.48% that could be achieved in case of the carbon consumption tax. In the United States, the welfare costs of the reduction brought about by a carbon-related production tax would be 2.11%.

We obtain similar results when considering the cooperation of the United States with the world. In that case, total world emissions of carbon would decrease by 24.17%. In terms of the welfare

Table 33: THE UNITED STATES AND THE EU

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0861	-0.2652	Korea	0.3543	-0.6510
Austria	-3.2851	-30.2919	Mexico	-0.5303	-0.4095
Belgium	-5.9892	-21.2093	Netherlands	-0.4165	-13.4323
Canada	-0.6992	-2.6239	New Zealand	0.4661	-0.3927
Chile	1.1946	0.1769	Norway	3.6255	-1.4343
Czech Republic	-0.6450	-2.8416	Poland	-2.4009	-17.0906
Denmark	-5.4545	-45.0302	Portugal	-4.2068	-23.4652
Estonia	-3.2553	-35.6328	Slovak Republic	0.1090	-3.7012
Finland	-0.1795	-12.8879	Slovenia	-18.7891	-36.2954
France	-2.6350	-18.5782	Spain	-5.7485	-12.1228
Germany	-2.1079	-25.6553	Sweden	-4.3574	-21.2713
Greece	-1.6874	-15.2328	Switzerland	-0.1110	-6.2773
Hungary	-1.6324	-18.1307	Turkey	0.1451	-0.8403
Iceland	0.4662	-2.2580	United Kingdom	-4.6999	-37.4763
Ireland	-3.1479	-31.4878	**United States**	-2.4732	-15.9785
Israel	-0.3575	-13.6090	ROW	-1.6732	-1.5828
Italy	-2.1536	-21.3222	**OECD**	-1.8953	-15.3167
Japan	0.3312	-0.6094	**World**	-1.8566	-11.8972
-	-	-	**European Union**	-3.1308	-24.9858

costs, the United States would lose 2.17%. The welfare costs for other countries are heterogenous and vary between 1% to 30% of country's welfare.

Table 34: THE UNITED STATES AND THE OECD

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	-5.0428	-38.2016	Korea	0.6429	-0.2604
Austria	-4.1468	-48.6324	Mexico	-3.2531	-18.6227
Belgium	-15.0818	-48.1837	Netherlands	-1.8524	-48.5740
Canada	-3.4317	-21.3802	New Zealand	0.6394	-0.3063
Chile	2.1213	1.0436	Norway	-5.5960	-55.2645
Czech Republic	-4.3658	-48.1339	Poland	-5.8638	-48.5284
Denmark	-6.7700	-51.4310	Portugal	-7.8050	-48.5511
Estonia	-4.1914	-49.5052	Slovak Republic	-2.5788	-48.0823
Finland	-1.8339	-48.0552	Slovenia	-27.7592	-49.7851
France	-4.0388	-47.8894	Spain	-15.9215	-47.6585
Germany	-3.4239	-49.1115	Sweden	-7.5800	-49.7006
Greece	-3.1594	-47.8624	Switzerland	-2.2527	-33.6414
Hungary	-2.4921	-47.5471	Turkey	0.2739	-0.5342
Iceland	-2.6863	-35.6208	United Kingdom	-6.3703	-50.9099
Ireland	-4.4824	-50.5421	**United States**	-2.1132	-15.9786
Israel	0.3604	-0.4436	ROW	-2.1191	0.0500
Italy	-3.5104	-48.1338	**OECD**	-2.7592	-25.4345
Japan	0.5945	-0.3613	**World**	-2.6475	-19.0893
-	-	-	**European Union**	-5.5328	-49.1262

6.4.3 Policy effects on prices and demand in the United States

A carbon production tax under various scenarios of policy alignment increases the prices in those industries that depend on "polluting" inputs and decreases demand for their outputs. For example, the *Coke, refined petroleum products, and nuclear fuel industry* would experience increases in prices by 38.23%, 56.56%, 65.93%, and 66.78% in case of the isolated carbon-related production tax implementation, cooperation with the European Union, cooperation with the OECD, and cooperation with the world as a whole, respectively.

Table 35: CHANGE IN INDUSTRY PRICES AND DEMAND (THE UNITED STATES)

	Non-cooperative		Cooperative					
			EU		OECD		World	
industry number	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i
1	-1.3330	0.2140	-1.4277	0.6149	-1.5949	0.8865	-1.6525	1.0765
2	-17.5992	19.9967	-18.5551	21.7736	-21.0506	25.7482	-21.2612	26.2480
3	-1.2555	0.1354	-1.3376	0.5230	-1.4810	0.7699	-1.5278	0.9485
4	-1.2638	0.1438	-1.3697	0.5557	-1.5261	0.8160	-1.5504	0.9717
5	-1.2701	0.1502	-1.3579	0.5437	-1.4978	0.7870	-1.5464	0.9676
6	-1.2483	0.1281	-1.3281	0.5133	-1.4596	0.7479	-1.5020	0.9220
7	-12.4368	12.9220	-13.5285	14.6949	-15.7616	17.8530	-16.6382	19.2466
8	-2.3825	1.2915	-2.7129	1.9441	-3.1931	2.5520	-3.3373	2.8382
9	-1.2846	0.1649	-1.3749	0.5610	-1.5346	0.8247	-1.5852	1.0073
10	-1.4946	0.3784	-1.6379	0.8299	-1.8591	1.1580	-1.9295	1.3619
11	-2.9242	1.8566	-3.1624	2.4172	-3.6421	3.0299	-3.7509	3.2801
12	-2.9810	1.9163	-3.2650	2.5259	-3.7972	3.1960	-3.9568	3.5015
13	-4.8266	3.8926	-5.3806	4.8183	-6.5742	6.2634	-7.0538	6.9502
14	-1.5701	0.4554	-1.7031	0.8967	-1.9333	1.2346	-2.0111	1.4464
15	-1.3125	0.1932	-1.3983	0.5849	-1.5501	0.8406	-1.6009	1.0235
16	-1.2107	0.0899	-1.2920	0.4766	-1.4148	0.7022	-1.4109	0.8288
17	-1.3956	0.2776	-1.5118	0.7009	-1.7069	1.0014	-1.7677	1.1950
18	-1.2294	0.1089	-1.3069	0.4918	-1.4173	0.7047	-1.4196	0.8376
19	-1.1811	0.0599	-1.2453	0.4290	-1.3676	0.6540	-1.4020	0.8196
20	-1.3520	0.2334	-1.4476	0.6352	-1.5959	0.8875	-1.6519	1.0759
21	-1.3078	0.1884	-1.3994	0.5860	-1.5607	0.8515	-1.6132	1.0360
22	-1.2402	0.1198	-1.2753	0.4595	-1.4087	0.6960	-1.4662	0.8853
23	-1.4130	0.2954	-1.5175	0.7066	-1.7054	0.9999	-1.7673	1.1946
24	-1.7338	0.6228	-1.8902	1.0892	-2.1523	1.4612	-2.2518	1.6962
25	-3.9090	2.9006	-4.1592	3.4825	-4.8013	4.2844	-4.8956	4.5233
26	-1.5792	0.4647	-1.6853	0.8786	-1.8952	1.1953	-1.9511	1.3843
27	-1.0779	-0.0444	-1.1373	0.3193	-1.2460	0.5300	-1.2825	0.6977
28	-1.0910	-0.0312	-1.1525	0.3347	-1.2638	0.5482	-1.3003	0.7158
29	-1.7735	0.6634	-1.9048	1.1043	-2.1659	1.4753	-2.2659	1.7108
30	-1.9595	0.8544	-2.1104	1.3166	-2.4125	1.7317	-2.5288	1.9852
31	-2.3609	1.2690	-2.5520	1.7757	-2.9397	2.2843	-3.0911	2.5769
32	-1.2394	0.1191	-1.3156	0.5005	-1.4604	0.7488	-1.5126	0.9329
33	-0.9658	-0.1576	-1.0151	0.1955	-1.0998	0.3814	-1.1287	0.5410
34	-0.8362	-0.2880	-0.8721	0.0510	-0.9304	0.2098	-0.9530	0.3627
35	-0.8566	-0.2675	-0.8937	0.0728	-0.9557	0.2355	-0.9781	0.3880
36	-1.0716	-0.0508	-1.1319	0.3139	-1.2414	0.5254	-1.2826	0.6977
37	-0.9229	-0.2008	-0.9685	0.1483	-1.0451	0.3260	-1.0723	0.4836
38	-0.9891	-0.1340	-1.0424	0.2231	-1.1344	0.4166	-1.1661	0.5791
39	-0.9368	-0.1868	-0.9837	0.1638	-1.0635	0.3446	-1.0922	0.5039
40	-1.0169	-0.1060	-1.0700	0.2511	-1.1661	0.4488	-1.1986	0.6122
41	-0.8900	-0.2339	-0.9305	0.1099	-0.9999	0.2801	-1.0250	0.4356
42	-0.9676	-0.1558	-1.0209	0.2013	-1.1103	0.3921	-1.1417	0.5542
43	-1.0643	-0.0582	-1.1236	0.3055	-1.2307	0.5144	-1.2666	0.6814

7 Switzerland's plans beyond the Copenhagen Accord

For instance, in Switzerland a tax of 1,140 Swiss Francs per ton of carbon on all CO_2 emissions by the year 2050 (see Ecoplan, 2012).[9] As this tax rate will display the biggest relative welfare effects in what follows, we discuss it in detail in this section. In general, this section considers three separate scenarios. First, we look into how the Swiss economy would respond to such a drastic carbon tax. Second, we examine what would happen if Switzerland were to implement the tax *and* completely replace all nuclear power with CO_2-intensive energy production. Finally, we consider a scenario where the tax is implemented and the nuclear power is replaced with CO_2-intensive energy production (e.g., based on fossil fuels and natural gas) but partly with alternative energy sources.

By 2050, Switzerland plans to allow certain carbon-emitting firms and power plants to participate in the *European Certificate Trading System.* We take this plan into account in our general equilibrium framework as well.

In general, throughout the three scenarios considered in this section we make the following assumptions:

i. A general tax of 1,140 Swiss Francs per ton of carbon is placed on all industries.

ii. 50 gas producers (approximately 8% of total electricity production) are taxed at 70 Euros per ton of carbon (the assumed rate for the *European Certificate Trading System*).

7.1 Partial participation in ECTS with no structural shift in energy consumption

In this subsection, we assume that in 2050 a tax of 1,140 Swiss Francs per ton of carbon is placed on all CO_2 emissions. The only exception to this are some natural gas-based energy, cement, and glass producers, which we approximate by assuming that 50 gas-powered plans are allowed to participate in the *European Certificate Trading System* and are taxed at 70 Euros per ton of carbon emissions.

[9] This is generally true for all industries except for a few gas-based energy, cement, and glass producers. We discuss this issue in more details in what follows.

First, we calculate the ad-valorem tax rate that would be equivalent to 1,140 Swiss Francs (in 2050 terms) in terms of the model and our calibration year. Since, the model is calibrated to the year 2000, we have to deflate 1,140 Swiss Francs with an appropriate price deflator. For that, we take time-series data on Switzerland's GDP deflator for the time span 1980-2010, decompose them into a trend and a cyclical component at business cycle frequency using the Hodrick-Prescott filter, and predict the deflator using the trend component of the data series.

Taking into account the price deflator, a 1,140 Swiss Francs tax implemented in 2050 is equivalent to the tax of 774 Swiss Francs in the year 2000. In terms of an ad- valorem tax rate this is equivalent to a 379% CO_2 consumption tax.

Next, suppose that 50 gas-powered plants were allowed to participate in the *European Certificate Trading System*. The benchmark tax rate in the *European Certificate Trading System* is assumed to be 70 Euros in 2020 terms which is equivalent to 48 Euros in 2000.[10] In terms of the model, natural gas is aggregated together with electricity and water into a single category – *Electricity, gas, and water*. The share of natural gas in total energy consumption was 11% in 2000. Taking into account that 50 gas-powered plants account for approximately 8% of total production in that sector and would have to pay 70 Euros per ton of carbon emissions, we calculate the effective carbon tax rate as:

$$V^{25}_{Switzerland} = 0.0088 \times 57 + 0.9912 \times 774 = 767.7, \quad (7.1)$$

which is expressed in Swiss Francs and corresponds to an ad-valorem rate of 375.5%.

7.1.1 Isolated Swiss Policy Implementation

We first consider a policy implemented in Switzerland in isolation. Naturally, an aggressive tax policy towards carbon emissions with an ad-valorem tax rate on CO_2 emissions of more than 370%, would have an enormous effect on both the level of carbon emissions and real welfare. Table 36 suggests that in such a scenario Switzerland would experience an 83.32% reduction in CO_2 emissions – much more than envisaged and actually needed (hence the tax could actually be smaller than discussed in order to achieve the targeted goals). Yet, this huge decrease would be very costly.

[10]For the conversion into Swiss Francs, we assume that the exchange rate between the Euro and the Swiss Franc is 1.2 in 2020.

Switzerland would loose more than 14.27% of its real welfare.

Table 36: SWITZERLAND

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	-0.0006	0.0005	Korea	0.0135	0.0003
Austria	-0.0621	-0.0506	Mexico	-0.0154	-0.0027
Belgium	-0.1284	0.0090	Netherlands	0.0079	-0.0047
Canada	-0.0156	-0.0007	New Zealand	0.0163	-0.0013
Chile	0.0269	0.0120	Norway	0.0207	0.0014
Czech Republic	-0.0266	-0.0279	Poland	-0.0121	-0.0080
Denmark	-0.0159	-0.0107	Portugal	-0.0224	-0.0110
Estonia	0.0084	-0.0004	Slovak Republic	-0.0078	-0.0188
Finland	-0.0110	-0.0255	Slovenia	-0.2200	-0.0138
France	0.0132	-0.0007	Spain	-0.0881	-0.0125
Germany	-0.0436	-0.0446	Sweden	-0.0222	-0.0146
Greece	0.0119	-0.0052	**Switzerland**	-14.2755	-83.3225
Hungary	-0.0186	-0.0282	Turkey	-0.0022	-0.0109
Iceland	0.0116	-0.0039	United Kingdom	-0.0089	-0.0089
Ireland	-0.0631	-0.0617	United States	-0.0100	-0.0021
Israel	-0.0266	-0.2039	ROW	-0.0528	-0.0039
Italy	-0.0160	-0.0253	**OECD**	-0.1281	-0.3850
Japan	0.0109	0.0006	**World**	-0.1150	-0.2901
-	-	-	**European Union**	-0.0256	-0.0203

7.1.2 International Policy Alignment

As in the cases with carbon consumption and carbon production taxes, we consider three scenarios of international cooperation. In the first scenario, we assume that the European Union taxes carbon emissions at 70 Euros per ton of carbon. In other words, we assume that the *European Certificate Trading System* levies a 70 Euro tax in every member of the European Union. We quantify that by deflating the nominal value of the tax in 2000 terms which would be 47.5 Euros. Currently, the model implies that a 100% tax on carbon emissions in the EU is equivalent to 86 Euros per ton of emissions. Hence, a 56 Euros tax is equivalent to a 65% ad-valorem tax. We report the results corresponding to such a policy with international policy alignment (i.e., the other countries complying with their Copenhagen Accord pledges) in Table 37.

Table 37 suggests that a unified 65% carbon tax in the European Union would entail large welfare costs for each member. At the same time, high welfare costs (double-digit ones for Belgium, Slovenia, and Spain) would provide for a substantial 42.1% reduction in the European Union's

Table 37: SWITZERLAND AND THE EU

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0591	-0.0481	Korea	0.3693	-0.1896
Austria	-4.0333	-41.5337	Mexico	-0.3003	-0.0319
Belgium	-13.8340	-42.4887	Netherlands	-3.6072	-42.1045
Canada	-0.3094	-0.2792	New Zealand	0.4155	-0.1461
Chile	1.2088	0.6145	Norway	1.9643	0.3861
Czech Republic	-5.6559	-41.8975	Poland	-6.1706	-41.9666
Denmark	-5.4305	-43.6159	Portugal	-7.2793	-41.7349
Estonia	-4.0972	-42.3578	Slovak Republic	-4.3272	-42.0211
Finland	-3.6386	-42.2632	Slovenia	-22.7182	-42.6386
France	-4.3000	-40.3999	Spain	-14.0402	-41.2312
Germany	-3.9899	-42.2016	Sweden	-6.8069	-40.8813
Greece	-3.9821	-41.2719	**Switzerland**	-15.4013	-83.6964
Hungary	-3.4681	-41.0529	Turkey	0.0676	-0.3354
Iceland	0.6343	-0.5111	United Kingdom	-5.6341	-43.3006
Ireland	-4.3887	-42.2291	United States	-0.1780	-0.1774
Israel	0.1057	-0.3933	ROW	-1.2778	0.0152
Italy	-4.0397	-41.5462	**OECD**	-1.9047	-14.7446
Japan	0.3410	-0.0843	**World**	-1.7953	-11.0697
-	-	-	**European Union**	-5.5486	-42.1481

usage of CO_2 compared to the benchmark case. Switzerland, on the other hand, would not react much differently to this sort of alignment relative to the policy implemented in isolation. The reason for this increase in welfare costs lies in the more costly and, hence, less attractive import of carbon-using energy from the European Union.

Next, we consider policy alignment with the OECD and the world. The assumed tax rates for Switzerland and the European Union remain while other members of the OECD (and the world) implement their unconditional tax rates to achieve the corresponding pledges in these scenarios. In Tables 38 and 39 we report the results in case of cooperation within the OECD and the world, respectively.

Table 38: Switzerland and the OECD

country	% change in W_n	$CO_{2,n}$	country	% change in W_n	$CO_{2,n}$
Australia	-3.1484	-24.8940	Korea	-1.6422	-30.3193
Austria	-3.5975	-41.5829	Mexico	-5.2195	-29.5984
Belgium	-15.5698	-42.8498	Netherlands	-3.3756	-42.7747
Canada	-2.5388	-13.8218	New Zealand	-2.8999	-41.6884
Chile	-0.3314	-19.4351	Norway	-5.1983	-52.2505
Czech Republic	-5.5493	-42.1308	Poland	-6.0933	-42.0321
Denmark	-5.5177	-43.9396	Portugal	-7.4518	-41.9742
Estonia	-3.9280	-42.4167	Slovak Republic	-3.9129	-42.0755
Finland	-3.3123	-42.6514	Slovenia	-25.6010	-42.6700
France	-3.9188	-41.3632	Spain	-15.3351	-41.4371
Germany	-3.6019	-42.4650	Sweden	-7.1512	-43.3998
Greece	-3.4835	-41.3421	**Switzerland**	-15.0928	-83.7160
Hungary	-3.0479	-41.1477	Turkey	-1.3994	-20.5499
Iceland	-2.5434	-35.0334	United Kingdom	-5.5477	-43.7899
Ireland	-4.3548	-43.9180	United States	-2.5187	-16.1625
Israel	-1.0959	-20.8954	ROW	-2.5292	0.0739
Italy	-3.6439	-41.6583	**OECD**	-3.8248	-29.0014
Japan	-3.7495	-36.9305	**World**	-3.5987	-21.7622
-			**European Union**	-5.4546	-42.5382

Table 39: Switzerland and the World

country	% change in W_n	$CO_{2,n}$	country	% change in W_n	$CO_{2,n}$
Australia	-3.1521	-25.6656	Korea	-1.7456	-31.3101
Austria	-3.4618	-42.5540	Mexico	-5.3309	-29.6229
Belgium	-16.6603	-43.3196	Netherlands	-3.3856	-43.2452
Canada	-2.6774	-14.1237	New Zealand	-2.8014	-42.3751
Chile	0.0860	-20.5374	Norway	-5.0550	-52.2812
Czech Republic	-5.7001	-42.7861	Poland	-6.2410	-42.7412
Denmark	-5.5649	-44.0178	Portugal	-7.6508	-42.7153
Estonia	-4.6164	-42.9598	Slovak Republic	-3.8789	-42.7473
Finland	-3.3216	-43.2609	Slovenia	-28.2849	-43.2010
France	-3.8511	-42.4774	Spain	-16.3034	-42.3727
Germany	-3.5061	-43.0830	Sweden	-7.2624	-43.8513
Greece	-3.3045	-42.3151	**Switzerland**	-15.0733	-83.8530
Hungary	-3.0333	-42.2419	Turkey	-1.3539	-21.7891
Iceland	-2.4321	-35.1416	United Kingdom	-5.5658	-43.9169
Ireland	-4.3311	-44.0941	United States	-2.6405	-16.6577
Israel	-1.0648	-21.9662	ROW	-6.8835	-20.2888
Italy	-3.5999	-42.5667	**OECD**	-3.8956	-29.6649
Japan	-3.7172	-38.5134	**World**	-4.4170	-27.3304
-			**European Union**	-5.5297	-43.1251

As in the previous case, at very high tax rates Switzerland is not very responsive to international policy alignment. Domestic changes in carbon emissions and welfare costs relative to pursuing tax policy in isolation remain relatively stable under various degrees of international cooperation.

However, under cooperation within the OECD or the whole world, a substantial decrease in the world level of carbon emissions could be achieved. In the former case, the reduction is approximately 21.8% at a 36% welfare cost in the world. In the latter case, the world level of CO_2 emissions would decrease even further to 27.3%. However, this reduction would come at a total welfare cost of about 4.4%.

Naturally, high carbon taxes lead to considerable changes in prices and demand for carbon-intensive goods. The output price of the *Mining and quarrying* industry, depending on the level of international policy alignment, is projected to rise by 450-460%, leading to a drastic decrease in the demand that is estimated at approximately 84-85%. On the other hand, the price of *Electricity, gas, and water* supply would go up by 4-16% with an overall decrease in demand of 16-25%.

Table 40: Change in industry prices and demand (Switzerland)

	Non-cooperative		Cooperative					
			EU		OECD		World	
industry number	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i
1	-15.0793	2.2085	-16.9165	3.4288	-16.9765	3.9723	-17.0512	4.1261
2	-84.2326	450.4781	-84.5385	455.7821	-84.5505	458.7321	-84.5895	460.4700
3	-15.0684	2.1954	-16.5535	2.9789	-16.5881	3.4881	-16.6543	3.6302
4	-14.0522	0.9870	-15.4356	1.6176	-15.5076	2.1647	-15.5827	2.3147
5	-14.8167	1.8934	-16.3739	2.7577	-16.4112	3.2692	-16.4790	3.4127
6	-14.7710	1.8388	-16.1042	2.4274	-16.1343	2.9282	-16.2110	3.0820
7	-45.3335	58.7741	-61.1482	121.1797	-61.6413	125.0376	-61.9320	126.8869
8	-15.2789	2.4493	-19.1797	6.3252	-19.5850	7.3450	-19.8520	7.7648
9	-13.7111	0.5878	-15.1456	1.2703	-15.2130	1.8098	-15.3231	2.0010
10	-14.5135	1.5320	-16.5353	2.9564	-16.6565	3.5731	-16.7823	3.7896
11	-29.8784	23.7795	-32.6469	27.5848	-32.7320	28.3246	-32.8524	28.6292
12	-23.5338	13.5091	-28.0450	19.4251	-28.2697	20.3417	-28.4780	20.7619
13	-13.2352	0.0362	-16.0420	2.3516	-18.0861	5.3808	-20.0053	7.9713
14	-15.4838	2.6977	-17.5374	4.2076	-17.6414	4.8117	-17.7819	5.0515
15	-13.3619	0.1824	-14.8260	0.8902	-14.9005	1.4359	-15.0269	1.6455
16	-13.5310	0.3784	-14.7074	0.7500	-14.7415	1.2467	-14.8128	1.3900
17	-14.3245	1.3081	-16.0086	2.3109	-16.1125	2.9014	-16.2430	3.1214
18	-13.6382	0.5029	-14.8119	0.8735	-14.8473	1.3725	-14.9199	1.5176
19	-13.8545	0.7553	-15.0194	1.1200	-15.0595	1.6258	-15.1341	1.7739
20	-14.0589	0.9950	-15.6368	1.8600	-15.7297	2.4340	-15.8477	2.6369
21	-15.1110	2.2467	-16.6507	3.0989	-16.7022	3.6299	-16.7847	3.7926
22	-13.4355	0.2676	-14.6495	0.6816	-14.7307	1.2339	-14.8578	1.4436
23	-15.4199	2.6201	-17.1016	3.6598	-17.1927	4.2438	-17.3056	4.4464
24	-16.1148	3.4702	-18.2444	5.1087	-18.4200	5.8121	-18.6237	6.1383
25	-16.8185	4.3455	-24.9664	14.5250	-25.0701	15.2029	-25.2669	15.5730
26	-20.1561	8.7073	-21.6630	9.6956	-21.6968	10.2400	-21.7638	10.3982
27	-14.7508	1.8147	-15.8794	2.1537	-15.8805	2.6176	-15.9145	2.7185
28	-14.2739	1.2483	-15.4741	1.6639	-15.4779	2.1289	-15.5163	2.2344
29	-16.7915	4.3117	-20.3214	7.8486	-20.4261	8.4796	-20.5159	8.6649
30	-17.5488	5.2697	-21.7281	9.7868	-21.8636	10.4753	-21.9713	10.6918
31	-18.7792	6.8645	-24.1192	13.2464	-24.3026	14.0348	-24.4367	14.3033
32	-14.9239	2.0218	-16.7318	3.1994	-16.7605	3.7025	-16.8093	3.8233
33	-13.6672	0.5367	-14.5723	0.5907	-14.5623	1.0343	-14.5887	1.1240
34	-13.0362	-0.1928	-13.6200	-0.5183	-13.5908	-0.1016	-13.6024	-0.0304
35	-13.4788	0.3178	-14.0173	-0.0587	-13.9859	0.3573	-13.9972	0.4286
36	-14.0996	1.0428	-15.4495	1.6342	-15.4587	2.1057	-15.4945	2.2080
37	-13.4254	0.2559	-14.2257	0.1842	-14.2110	0.6206	-14.2335	0.7053
38	-13.5172	0.3623	-14.5120	0.5197	-14.5075	0.9696	-14.5375	1.0634
39	-13.4763	0.3149	-14.3202	0.2947	-14.3070	0.7334	-14.3308	0.8196
40	-14.0776	1.0169	-15.0923	1.2067	-15.0850	1.6563	-15.1138	1.7496
41	-13.2448	0.0472	-13.9641	-0.1204	-13.9394	0.3030	-13.9548	0.3791
42	-13.4593	0.2951	-14.3632	0.3451	-14.3603	0.7960	-14.3898	0.8890
43	-13.9965	0.9217	-15.1909	1.3244	-15.1936	1.7865	-15.2292	1.8880

7.2 Partial participation in ECTS and abolishment of nuclear power

In 2000, 38.2% of the electricity consumed in Switzerland was produced from nuclear power which is relatively much cleaner – in terms of CO_2 emissions – than fossil fuels. Switzerland has decided to completely abolish nuclear energy production by 2034. In this section, we analyze what would happen if Switzerland substituted completely its consumption of nuclear power-based energy (24,949 GWh in 2000) by CO_2-intensive (e.g., gas-produced) electricity.

We want to admit that a complete substitution of nuclear energy by gas-based energy is an extreme scenario in three terms: (i) the size of the shock (full absorption of the development between 2020 and 2034 within just one year); the carbon emission implications of the shock (gas is much more carbon-intensive than other forms of energy resources which are not available yet to the required extent); and (iii) the potential costs of the shock (the carbon tax costs as of the previous section are much more substantial when substituting nuclear power by gas-based energy due to its higher carbon content relative to other forms of energy).

In what follows, we make the following assumptions:

i. A general tax of 1,140 Swiss Francs per ton of carbon is introduced as in the previous subsection.

ii. 50 gas producers (approximately 8%) are allowed to participate in the *European Certificate Trading System.*

iii. 24,949 GWh of nuclear power is replaced with energy from gas or fossil fuels.

In the year 2000, 22% of total energy consumed in Switzerland was electricity consumption of which 38.2% was produced with nuclear power. Hence, if Switzerland were to substitute the latter in the portrayed way, the share of fossil fuels in total energy consumption would rise by 8.4 percentage points. Hence, abolishing nuclear energy would have immediate implications for the carbon intensity of energy consumption in Switzerland.

Naturally, the costs of electricity produced via nuclear energy versus carbon-emitting fuels are different. The total cost of electricity production and consumption can be expressed as:

$$TC = LC + GC, \tag{7.2}$$

where LC are levelized costs of energy and GC are associated power grid costs. The former refers to the present discounted value of building and operating a plant whereas the latter reflects the distribution costs of selling the output of such plants. The levelized and grid-level costs typically vary by energy type. We use the estimates of LC and GC for Switzerland[11] as provided by the International Energy Agency and Nuclear Energy Agency (OECD). The data were extracted from the two reports "Projected Costs of Generating Electricity" and "Nuclear Energy and Renewables" (available online). Our approach uses only relative levelized and grid costs of energy so that we can calculate the total cost of switching from nuclear to fossil fuel without using level-based estimates of the electricity production costs. In terms of the levelized costs of energy, we use 68 USD/MWh (in words, U.S. dollars per mega-watt hour) for nuclear power generated electricity and 94 USD/MWh for gas-powered plants. On average, the grid-level costs of nuclear and gas-powered plants are relatively small (for example, in Germany the grid-level costs are estimated at 2.96% for nuclear plants and 0.61% for gas-powered plants). Accordingly, we can calculate the relative change in total energy costs in terms of welfare costs as:

$$WC = 0.382 \times Y^{25}_{Switzerland} \left(\frac{94 \times (1 + 0.0061)}{68 \times (1 + 0.0296)} \right) = 0.5160 \times Y^{25}_{Switzerland}, \tag{7.3}$$

Hence, the total costs of switching from nuclear to gas-powered energy is about a half of the total revenues of industry $i = 25$ in the benchmark case. Naturally, the price of electricity is projected to go up by the same margin *ceteris paribus*.

7.2.1 Isolated Swiss Policy Implementation

First, we consider Switzerland's unconditional policy with no international cooperation. Relative to the previous section, where we assumed high taxes without a structural shift in energy, the results here indicate that with a shift towards fossil fuels Switzerland naturally would achieve a

[11] GC estimates are not available for Switzerland in certain cases. In such cases, we calibrate variables to Germany.

lower reduction in carbon emissions, but those would come at *higher* welfare costs.

Table 41: SWITZERLAND'S UNCONDITIONAL POLICY

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0001	-0.0004	Korea	0.0214	0.0013
Austria	-0.0352	-0.0411	Mexico	-0.0186	-0.0031
Belgium	-0.1929	0.0219	Netherlands	0.0193	-0.0023
Canada	-0.0190	-0.0020	New Zealand	0.0236	-0.0020
Chile	0.0370	0.0144	Norway	0.0347	0.0038
Czech Republic	-0.0065	0.0014	Poland	-0.0114	-0.0080
Denmark	-0.0155	-0.0123	Portugal	-0.0269	-0.0076
Estonia	0.0098	-0.0020	Slovak Republic	-0.0023	-0.0208
Finland	-0.0073	-0.0300	Slovenia	-0.5187	0.0097
France	0.1699	0.1282	Spain	-0.1441	-0.0045
Germany	-0.0430	-0.0503	Sweden	-0.0256	-0.0186
Greece	0.0215	-0.0050	**Switzerland**	-17.3046	-81.0458
Hungary	-0.0161	-0.0351	Turkey	0.0044	-0.0103
Iceland	0.0208	-0.0050	United Kingdom	-0.0058	-0.0097
Ireland	-0.0660	-0.0695	United States	-0.0118	-0.0032
Israel	-0.0260	-0.2044	ROW	-0.0680	-0.0039
Italy	-0.0123	-0.0282	**OECD**	-0.1365	-0.3725
Japan	0.0161	0.0002	**World**	-0.1246	-0.2807
-			**European Union**	-0.0054	-0.0121

In particular, relative to the previous section where Switzerland experienced a 81% decrease in carbon emissions at a 14.3% welfare cost, in the present scenario, the decrease in carbon emissions would be similar (about 83%) but the welfare costs would be somewhat larger (17.3%). Hence, switching from nuclear power to fossil fuels adds a margin of about 3 percentage points in terms of real welfare costs.

7.2.2 International policy alignment with Switzerland

In this section, we quantify the effects for Switzerland in case of international cooperation. As in the previous subsection, we assume that the *European Certificate Trading System* imposes a 70 Euro tax on carbon emissions.

In Tables 42 and 43, we consider international policy alignment with the European Union and the OECD, respectively. Relatively higher international policy alignment guarantees a higher reduction in carbon emissions for Switzerland. This, however, would come at a higher welfare cost.

Table 42: Switzerland and the EU

country	% change in W_n	$CO_{2,n}$	country	% change in W_n	$CO_{2,n}$
Australia	0.0598	-0.0494	Korea	0.3822	-0.1884
Austria	-4.0118	-41.5320	Mexico	-0.3072	-0.0328
Belgium	-13.9093	-42.4841	Netherlands	-3.5946	-42.1046
Canada	-0.3162	-0.2802	New Zealand	0.4292	-0.1466
Chile	1.2230	0.6157	Norway	1.9829	0.3884
Czech Republic	-5.6398	-41.8825	Poland	-6.1712	-41.9673
Denmark	-5.4306	-43.6175	Portugal	-7.2868	-41.7336
Estonia	-4.0942	-42.3591	Slovak Republic	-4.3179	-42.0219
Finland	-3.6315	-42.2663	Slovenia	-23.0055	-42.6240
France	-4.1507	-40.3256	Spain	-14.1049	-41.2274
Germany	-3.9916	-42.2081	Sweden	-6.8140	-40.8849
Greece	-3.9687	-41.2725	**Switzerland**	-22.8568	-83.0835
Hungary	-3.4634	-41.0587	Turkey	0.0772	-0.3356
Iceland	0.6444	-0.5132	United Kingdom	-5.6309	-43.3015
Ireland	-4.3922	-42.2352	United States	-0.1818	-0.1789
Israel	0.1078	-0.4390	ROW	-1.3049	0.0150
Italy	-4.0340	-41.5491	**OECD**	-1.9194	-14.7417
Japan	0.3506	-0.0840	**World**	-1.8122	-11.0675
-			**European Union**	-5.5308	-42.1449

Table 43: Switzerland and the OECD

country	% change in W_n	$CO_{2,n}$	country	% change in W_n	$CO_{2,n}$
Australia	-3.1477	-24.8949	Korea	-1.6295	-30.3184
Austria	-3.5746	-41.5808	Mexico	-5.2262	-29.5991
Belgium	-15.6445	-42.8453	Netherlands	-3.3628	-42.7749
Canada	-2.5456	-13.8228	New Zealand	-2.8865	-41.6887
Chile	-0.3170	-19.4339	Norway	-5.1797	-52.2491
Czech Republic	-5.5329	-42.1156	Poland	-6.0938	-42.0327
Denmark	-5.5177	-43.9411	Portugal	-7.4593	-41.9729
Estonia	-3.9251	-42.4181	Slovak Republic	-3.9034	-42.0763
Finland	-3.3050	-42.6545	Slovenia	-25.8774	-42.6556
France	-3.7680	-41.2896	Spain	-15.3995	-41.4332
Germany	-3.6033	-42.4715	Sweden	-7.1581	-43.4033
Greece	-3.4698	-41.3427	**Switzerland**	-22.5671	-83.1049
Hungary	-3.0432	-41.1535	Turkey	-1.3899	-20.5501
Iceland	-2.5315	-35.0347	United Kingdom	-5.5445	-43.7910
Ireland	-4.3585	-43.9242	United States	-2.5224	-16.1637
Israel	-1.0940	-20.9318	ROW	-2.5562	0.0736
Italy	-3.6379	-41.6612	**OECD**	-3.8396	-28.9983
Japan	-3.7404	-36.9303	**World**	-3.6156	-21.7600
-			**European Union**	-5.4364	-42.5350

In Table 44, we report the results of a counterfactual experiment with an international policy alignment in the world. The effect of carbon taxes in Switzerland are projected to be even more drastic in the case of world-wide policy alignment than without it. Under world-wide alignment, the world level of carbon emissions is projected to go down by as much as 27.3%, but this would entail a welfare cost of 4.4% for the world as a whole.

Table 44: SWITZERLAND AND THE WORLD

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	-3.1521	-25.6656	Korea	-1.7456	-31.3101
Austria	-3.4618	-42.5540	Mexico	-5.3309	-29.6229
Belgium	-16.6603	-43.3196	Netherlands	-3.3856	-43.2452
Canada	-2.6774	-14.1237	New Zealand	-2.8014	-42.3751
Chile	0.0860	-20.5374	Norway	-5.0550	-52.2812
Czech Republic	-5.7001	-42.7861	Poland	-6.2410	-42.7412
Denmark	-5.5649	-44.0178	Portugal	-7.6508	-42.7153
Estonia	-4.6164	-42.9598	Slovak Republic	-3.8789	-42.7473
Finland	-3.3216	-43.2609	Slovenia	-28.2849	-43.2010
France	-3.8511	-42.4774	Spain	-16.3034	-42.3727
Germany	-3.5061	-43.0830	Sweden	-7.2624	-43.8513
Greece	-3.3045	-42.3151	**Switzerland**	-15.0733	-83.8530
Hungary	-3.0333	-42.2419	Turkey	-1.3539	-21.7891
Iceland	-2.4321	-35.1416	United Kingdom	-5.5658	-43.9169
Ireland	-4.3311	-44.0941	United States	-2.6405	-16.6577
Israel	-1.0648	-21.9662	ROW	-6.8835	-20.2888
Italy	-3.5999	-42.5667	**OECD**	-3.8956	-29.6649
Japan	-3.7172	-38.5134	**World**	-4.4170	-27.3304
-			**European Union**	-5.5297	-43.1251

Finally, we report the effects of various alternative policies on prices and demands in the counterfactual experiments. The model predicts that under high carbon taxes (1,140 Swiss Francs per ton of carbon) and a structural shift towards a more intensive use of fossil fuels, the price of carbon-intensive goods would be higher than without such a structural shift. For example, the production and distribution of electricity using fossil fuels would be relatively more expensive than when using nuclear power.

Table 45: Change in industry prices and demand (Switzerland)

	Non-cooperative		Cooperative					
			EU		OECD		World	
industry number	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i
1	-17.9125	2.8411	-19.7970	4.1809	-19.8597	4.7218	-17.0512	4.1261
2	-84.7082	452.0570	-85.0239	457.9300	-85.0363	460.8525	-84.5895	460.4700
3	-18.3725	3.4206	-19.9618	4.3954	-20.0009	4.9066	-16.6543	3.6302
4	-16.9742	1.6788	-18.4038	2.4021	-18.4838	2.9542	-15.5827	2.3147
5	-18.3412	3.3809	-20.0159	4.4661	-20.0568	4.9799	-16.4790	3.4127
6	-18.0982	3.0742	-19.5196	3.8218	-19.5567	4.3273	-16.2110	3.0820
7	-46.8571	58.8541	-62.2551	121.3707	-62.7393	125.2356	-61.9320	126.8869
8	-17.7903	2.6881	-21.6124	6.5937	-22.0186	7.6210	-19.8520	7.7648
9	-16.2514	0.8013	-17.6992	1.5254	-17.7737	2.0651	-15.3231	2.0010
10	-17.7637	2.6549	-19.8202	4.2111	-19.9436	4.8314	-16.7823	3.7896
11	-32.5992	25.2502	-35.4320	29.4081	-35.5211	30.1578	-32.8524	28.6292
12	-26.1614	14.3299	-30.7074	20.5847	-30.9409	21.5253	-28.4780	20.7619
13	-15.6238	0.0515	-18.3745	2.3653	-20.3719	5.3954	-20.0053	7.9713
14	-18.1303	3.1146	-20.2162	4.7283	-20.3251	5.3335	-17.7819	5.0515
15	-15.7794	0.2363	-17.2341	0.9549	-17.3167	1.5009	-15.0269	1.6455
16	-16.0402	0.5476	-17.2447	0.9678	-17.2867	1.4641	-14.8128	1.3900
17	-16.8820	1.5660	-18.5886	2.6345	-18.6982	3.2257	-16.2430	3.1214
18	-16.1530	0.6830	-17.3611	1.1101	-17.4041	1.6083	-14.9199	1.5176
19	-16.2471	0.7961	-17.4493	1.2180	-17.4960	1.7216	-15.1341	1.7739
20	-16.6346	1.2646	-18.2297	2.1840	-18.3303	2.7607	-15.8477	2.6369
21	-17.9681	2.9107	-19.6113	3.9402	-19.6665	4.4699	-16.7847	3.7926
22	-15.8189	0.2834	-17.0501	0.7310	-17.1376	1.2816	-14.8578	1.4436
23	-18.1059	3.0840	-19.8549	4.2562	-19.9499	4.8397	-17.3056	4.4464
24	-18.4903	3.5701	-20.6038	5.2395	-20.7851	5.9452	-18.6237	6.1383
25	-62.7494	126.6265	-66.4057	148.7216	-66.4565	150.1954	-25.2669	15.5730
26	-21.4397	7.4584	-22.9827	8.4901	-23.0199	9.0208	-21.7638	10.3982
27	-15.5364	-0.0520	-16.6877	0.2928	-16.6912	0.7388	-15.9145	2.7185
28	-15.5536	-0.0317	-16.7918	0.4182	-16.7986	0.8688	-15.5163	2.2344
29	-17.6267	2.4842	-21.1763	6.0040	-21.2841	6.6167	-20.5159	8.6649
30	-18.5410	3.6345	-22.7426	8.1530	-22.8813	8.8249	-21.9713	10.6918
31	-19.8325	5.3040	-25.1823	11.6798	-25.3687	12.4520	-24.4367	14.3033
32	-15.7208	0.1667	-17.5533	1.3457	-17.5846	1.8309	-16.8093	3.8233
33	-14.4389	-1.3340	-15.3658	-1.2737	-15.3582	-0.8476	-14.5887	1.1240
34	-13.5985	-2.2938	-14.2000	-2.6152	-14.1723	-2.2176	-13.6024	-0.0304
35	-14.0243	-1.8099	-14.5793	-2.1827	-14.5495	-1.7861	-13.9972	0.4286
36	-14.8022	-0.9133	-16.1754	-0.3201	-16.1871	0.1330	-15.4945	2.2080
37	-14.1462	-1.6705	-14.9676	-1.7360	-14.9552	-1.3175	-14.2335	0.7053
38	-14.2956	-1.4990	-15.3127	-1.3356	-15.3108	-0.9032	-14.5375	1.0634
39	-14.2386	-1.5646	-15.1057	-1.5762	-15.0949	-1.1551	-14.3308	0.8196
40	-14.8113	-0.9028	-15.8466	-0.7097	-15.8416	-0.2782	-15.1138	1.7496
41	-13.8235	-2.0387	-14.5590	-2.2060	-14.5358	-1.8018	-13.9548	0.3791
42	-14.2021	-1.6064	-15.1248	-1.5540	-15.1243	-1.1209	-14.3898	0.8890
43	-14.8168	-0.8964	-16.0342	-0.4878	-16.0396	-0.0430	-15.2292	1.8880

7.3 Partial participation in ECTS with replacing nuclear power production with solar and hydropower

In 2000, Switzerland used 24,949 GWh of energy produced by nuclear power plants. In the previous subsection, we considered a scenario where all this energy was replaced by gas-produced energy. In this section, we examine an alternative counterfactual scenario, where we assume that 13,500 GWh of the 24,949 GWh are replaced with energy produced by renewable energy sources and only the remaining 11,449 GWh are produced by natural gas, according to the available technology in the benchmark year. In particular, we assume that 3500 GWh of the 13400 GWh are produced by hydroelectric plants and 10,000 GWh are produced by solar stations. Hence, only 11,449 GWh will exert a negative effect in terms of CO_2 emissions. The rest of the assumptions are the same as in Section 7.2.

Switching from nuclear power to renewable sources of energy, of course, is more costly than switching to natural gas. Hydro and solar stations involve relatively high (levelized and grid) costs and a corresponding increase in the price of energy. As in the previous subsection, we assume a cost of 68 USD/MWh for nuclear generated electricity. For hydro and solar power, we assume 111 USD/MWh and 304 USD/MWh, respectively.[12] Grid-level costs are also considerably higher for renewable sources of energy. In particular, while the grid-level costs amount to only 2.96% of the nuclear energy prices, they are as high as 12.5% and 13.8% for solar and hydro power, respectively.[13] We calculate the total welfare costs of switching towards alternative energy sources as follows:

$$WC = 0.382 \times Y^{25}_{Switzerland} \times A; \tag{7.4}$$

$$A = 0.4588 \times \left(\frac{94 \times (1+0.0061)}{68 \times (1+0.0296)}\right) + 0.40 \times \left(\frac{304 \times (1+0.125)}{68 \times (1+0.0296)}\right) + 0.1412 \times \left(\frac{111 \times (1+0.138)}{68 \times (1+0.0296)}\right) = 1.1633, \tag{7.5}$$

Hence, the total costs of switching from nuclear to gas-powered energy and renewable energy would cost about 1.1633 times as much as the consumption of all electricity in the benchmark year. Notice

[12] The OECD report does not have estimates of solar power costs for Switzerland. As a close approximation, we use the data for Germany.

[13] We do not have explicit data for hydro power plants. We assume that grid-level costs for this type of energy are equivalent to the average of other alternative energy sources.

that even a partial shift towards "clean" energy is much more costly than switching to gas-powered energy only.

7.3.1 Isolated Swiss Policy Implementation

First, we consider the case of implementing carbon tax and shifting towards alternative energy sources for Switzerland in isolation. The results are summarized in Table 46.

Table 46: SWITZERLAND

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0002	-0.0007	Korea	0.0260	0.0014
Austria	-0.0372	-0.0463	Mexico	-0.0222	-0.0036
Belgium	-0.2165	0.0171	Netherlands	0.0210	-0.0052
Canada	-0.0224	-0.0020	New Zealand	0.0295	-0.0020
Chile	0.0417	0.0141	Norway	0.0405	0.0043
Czech Republic	-0.0101	-0.0031	Poland	-0.0125	-0.0091
Denmark	-0.0155	-0.0134	Portugal	-0.0304	-0.0088
Estonia	0.0120	-0.0024	Slovak Republic	0.0005	-0.0218
Finland	-0.0036	-0.0310	Slovenia	-0.5687	0.0071
France	0.1707	0.1252	Spain	-0.1639	-0.0058
Germany	-0.0446	-0.0553	Sweden	-0.0290	-0.0205
Greece	0.0257	-0.0062	**Switzerland**	-21.7337	-82.6738
Hungary	-0.0139	-0.0378	Turkey	0.0071	-0.0112
Iceland	0.0242	-0.0059	United Kingdom	-0.0055	-0.0108
Ireland	-0.0667	-0.0725	United States	-0.0136	-0.0036
Israel	-0.0249	-0.2437	ROW	-0.0798	-0.0041
Italy	-0.0098	-0.0301	**OECD**	-0.1428	-0.3811
Japan	0.0201	0.0007	**World**	-0.1318	-0.2873
-			**European Union**	-0.0075	-0.0147

Relative to the previous subsection, this policy scenario suggests that Switzerland would achieve a similar decrease in CO_2 emissions but at a much higher welfare cost (by more than 4 percentage points).[14] This suggests that even at extremely high tax rates (such as considered here), switching to cleaner energy sources is relatively costly at this point.

[14] To put this into perspective, we might say that reducing welfare by almost 21.7% is equivalent of reducing real per-capita income of the average household to the level it was about 20 years ago (at times of moderate economic growth).

7.3.2 International Policy Alignment

In this section, we examine the economic consequences for Switzerland and the world in case of international cooperation. First, we consider scenarios where Switzerland cooperates with the European Union and the OECD, respectively. As before, the tax rate for the *European Certificate Trading System* is assumed to be 70 Euros per ton of carbon. The results are summarized in Tables 47 and 48.

Table 47: SWITZERLAND AND THE EU

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	0.0598	-0.0494	Korea	0.3822	-0.1884
Austria	-4.0118	-41.5320	Mexico	-0.3072	-0.0328
Belgium	-13.9093	-42.4841	Netherlands	-3.5946	-42.1046
Canada	-0.3162	-0.2802	New Zealand	0.4292	-0.1466
Chile	1.2230	0.6157	Norway	1.9829	0.3884
Czech Republic	-5.6398	-41.8825	Poland	-6.1712	-41.9673
Denmark	-5.4306	-43.6175	Portugal	-7.2868	-41.7336
Estonia	-4.0942	-42.3591	Slovak Republic	-4.3179	-42.0219
Finland	-3.6315	-42.2663	Slovenia	-23.0055	-42.6240
France	-4.1507	-40.3256	Spain	-14.1049	-41.2274
Germany	-3.9916	-42.2081	Sweden	-6.8140	-40.8849
Greece	-3.9687	-41.2725	**Switzerland**	-22.8568	-83.0835
Hungary	-3.4634	-41.0587	Turkey	0.0772	-0.3356
Iceland	0.6444	-0.5132	United Kingdom	-5.6309	-43.3015
Ireland	-4.3922	-42.2352	United States	-0.1818	-0.1789
Israel	0.1078	-0.4390	ROW	-1.3049	0.0150
Italy	-4.0340	-41.5491	**OECD**	-1.9194	-14.7417
Japan	0.3506	-0.0840	**World**	-1.8122	-11.0675
-			**European Union**	-5.5308	-42.1449

Table 48: Switzerland and the OECD

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	-3.1477	-24.8949	Korea	-1.6295	-30.3184
Austria	-3.5746	-41.5808	Mexico	-5.2262	-29.5991
Belgium	-15.6445	-42.8453	Netherlands	-3.3628	-42.7749
Canada	-2.5456	-13.8228	New Zealand	-2.8865	-41.6887
Chile	-0.3170	-19.4339	Norway	-5.1797	-52.2491
Czech Republic	-5.5329	-42.1156	Poland	-6.0938	-42.0327
Denmark	-5.5177	-43.9411	Portugal	-7.4593	-41.9729
Estonia	-3.9251	-42.4181	Slovak Republic	-3.9034	-42.0763
Finland	-3.3050	-42.6545	Slovenia	-25.8774	-42.6556
France	-3.7680	-41.2896	Spain	-15.3995	-41.4332
Germany	-3.6033	-42.4715	Sweden	-7.1581	-43.4033
Greece	-3.4698	-41.3427	**Switzerland**	-22.5671	-83.1049
Hungary	-3.0432	-41.1535	Turkey	-1.3899	-20.5501
Iceland	-2.5315	-35.0347	United Kingdom	-5.5445	-43.7910
Ireland	-4.3585	-43.9242	United States	-2.5224	-16.1637
Israel	-1.0940	-20.9318	ROW	-2.5562	0.0736
Italy	-3.6379	-41.6612	**OECD**	-3.8396	-28.9983
Japan	-3.7404	-36.9303	**World**	-3.6156	-21.7600
-			**European Union**	-5.4364	-42.5350

While international policy alignment is necessary to achieve sizable reductions in carbon emissions either in the European Union or the OECD, it does not have a big impact on Switzerland in terms of domestic emissions and welfare, as long as other countries only stick to their pledges in the Copenhagen Accord. At high levels of carbon taxation any additional policy (e.g., replacing nuclear power with hydro and solar power) would be relatively inelastic to different levels of international cooperation. This is confirmed by the results presented in Table 49.

We report changes in prices for 43 industries under different levels of international policy alignment in Table 50. Naturally, distortive taxes of 1,140 Swiss Francs along with the structural shift towards natural gas and renewable sources of energy distorts prices to a relatively high extent. In particular, under the scenario considered here the price of output of the *Mining and quarrying* industry would increase by as much as 452%-462% with a corresponding 84-85% decrease in total demand. Other industries that use carbon-intensive inputs such as *Electricity, gas, and water* would also experience drastic increases in prices (by around 127-151%) and a large decline in total demand (around 63-67%).

Table 49: Switzerland and the World

country	% change in W_n	% change in $CO_{2,n}$	country	% change in W_n	% change in $CO_{2,n}$
Australia	-3.1514	-25.6665	Korea	-1.7329	-31.3092
Austria	-3.4383	-42.5518	Mexico	-5.3376	-29.6235
Belgium	-16.7348	-43.3151	Netherlands	-3.3727	-43.2454
Canada	-2.6843	-14.1247	New Zealand	-2.7880	-42.3754
Chile	0.1006	-20.5361	Norway	-5.0361	-52.2797
Czech Republic	-5.6836	-42.7711	Poland	-6.2415	-42.7419
Denmark	-5.5649	-44.0193	Portugal	-7.6584	-42.7140
Estonia	-4.6130	-42.9610	Slovak Republic	-3.8701	-42.7486
Finland	-3.3143	-43.2640	Slovenia	-28.5368	-43.1887
France	-3.6989	-42.4043	Spain	-16.3677	-42.3689
Germany	-3.5078	-43.0895	Sweden	-7.2693	-43.8548
Greece	-3.2907	-42.3157	**Switzerland**	-22.5614	-83.2485
Hungary	-3.0285	-42.2476	Turkey	-1.3443	-21.7893
Iceland	-2.4202	-35.1430	United Kingdom	-5.5626	-43.9180
Ireland	-4.3348	-44.1003	United States	-2.6443	-16.6589
Israel	-1.0630	-22.0023	ROW	-6.9096	-20.2890
Italy	-3.5939	-42.5695	**OECD**	-3.9104	-29.6619
Japan	-3.7081	-38.5133	**World**	-4.4338	-27.3282
-			**European Union**	-5.5113	-43.1220

Table 50: Change in industry prices and demand (Switzerland)

	Non-cooperative		Cooperative					
			EU		OECD		World	
industry number	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i	ΔY_n^i	Δp_n^i
1	-17.9125	2.8411	-19.7970	4.1809	-19.8597	4.7218	-19.9413	4.8716
2	-84.7082	452.0570	-85.0239	457.9300	-85.0363	460.8525	-85.0755	462.5582
3	-18.3725	3.4206	-19.9618	4.3954	-20.0009	4.9066	-20.0757	5.0480
4	-16.9742	1.6788	-18.4038	2.4021	-18.4838	2.9542	-18.5695	3.1049
5	-18.3412	3.3809	-20.0159	4.4661	-20.0568	4.9799	-20.1321	5.1222
6	-18.0982	3.0742	-19.5196	3.8218	-19.5567	4.3273	-19.6452	4.4852
7	-46.8571	58.8541	-62.2551	121.3707	-62.7393	125.2356	-63.0278	127.0868
8	-17.7903	2.6881	-21.6124	6.5937	-22.0186	7.6210	-22.2920	8.0441
9	-16.2514	0.8013	-17.6992	1.5254	-17.7737	2.0651	-17.8935	2.2560
10	-17.7637	2.6549	-19.8202	4.2111	-19.9436	4.8314	-20.0780	5.0510
11	-32.5992	25.2502	-35.4320	29.4081	-35.5211	30.1578	-35.6467	30.4655
12	-26.1614	14.3299	-30.7074	20.5847	-30.9409	21.5253	-31.1579	21.9587
13	-15.6238	0.0515	-18.3745	2.3653	-20.3719	5.3954	-22.2504	7.9863
14	-18.1303	3.1146	-20.2162	4.7283	-20.3251	5.3335	-20.4734	5.5733
15	-15.7794	0.2363	-17.2341	0.9549	-17.3167	1.5009	-17.4531	1.7106
16	-16.0402	0.5476	-17.2447	0.9678	-17.2867	1.4641	-17.3686	1.6065
17	-16.8820	1.5660	-18.5886	2.6345	-18.6982	3.2257	-18.8374	3.4453
18	-16.1530	0.6830	-17.3611	1.1101	-17.4041	1.6083	-17.4869	1.7522
19	-16.2471	0.7961	-17.4493	1.2180	-17.4960	1.7216	-17.5798	1.8668
20	-16.6346	1.2646	-18.2297	2.1840	-18.3303	2.7607	-18.4587	2.9648
21	-17.9681	2.9107	-19.6113	3.9402	-19.6665	4.4699	-19.7555	4.6288
22	-15.8189	0.2834	-17.0501	0.7310	-17.1376	1.2816	-17.2732	1.4894
23	-18.1059	3.0840	-19.8549	4.2562	-19.9499	4.8397	-20.0693	5.0396
24	-18.4903	3.5701	-20.6038	5.2395	-20.7851	5.9452	-20.9970	6.2730
25	-62.7494	126.6265	-66.4057	148.7216	-66.4565	150.1954	-66.5506	151.0023
26	-21.4397	7.4584	-22.9827	8.4901	-23.0199	9.0208	-23.0920	9.1679
27	-15.5364	-0.0520	-16.6877	0.2928	-16.6912	0.7388	-16.7294	0.8265
28	-15.5536	-0.0317	-16.7918	0.4182	-16.7986	0.8688	-16.8421	0.9632
29	-17.6267	2.4842	-21.1763	6.0040	-21.2841	6.6167	-21.3783	6.7884
30	-18.5410	3.6345	-22.7426	8.1530	-22.8813	8.8249	-22.9940	9.0290
31	-19.8325	5.3040	-25.1823	11.6798	-25.3687	12.4520	-25.5078	12.7082
32	-15.7208	0.1667	-17.5533	1.3457	-17.5846	1.8309	-17.6377	1.9385
33	-14.4389	-1.3340	-15.3658	-1.2737	-15.3582	-0.8476	-15.3888	-0.7710
34	-13.5985	-2.2938	-14.2000	-2.6152	-14.1723	-2.2176	-14.1871	-2.1606
35	-14.0243	-1.8099	-14.5793	-2.1827	-14.5495	-1.7861	-14.5638	-1.7292
36	-14.8022	-0.9133	-16.1754	-0.3201	-16.1871	0.1330	-16.2269	0.2218
37	-14.1462	-1.6705	-14.9676	-1.7360	-14.9552	-1.3175	-14.9817	-1.2461
38	-14.2956	-1.4990	-15.3127	-1.3356	-15.3108	-0.9032	-15.3450	-0.8223
39	-14.2386	-1.5646	-15.1057	-1.5762	-15.0949	-1.1551	-15.1228	-1.0820
40	-14.8113	-0.9028	-15.8466	-0.7097	-15.8416	-0.2782	-15.8743	-0.1984
41	-13.8235	-2.0387	-14.5590	-2.2060	-14.5358	-1.8018	-14.5545	-1.7399
42	-14.2021	-1.6064	-15.1248	-1.5540	-15.1243	-1.1209	-15.1578	-1.0412
43	-14.8168	-0.8964	-16.0342	-0.4878	-16.0396	-0.0430	-16.0796	0.0458

8 World-wide Adoption of a CO_2 Tax as in Switzerland

In the previous sections, we dubbed international policy alignment with Switzerland what was compliance of other countries than Switzerland with the Copenhagen Accord pledges. This was done since other countries do not across the board contemplate drastic policy changes beyond the Copenhagen Accord, unlike Switzerland (with individual exceptions). In this subsection, we redo Tables 39, 44, and 49 under the alternative assumption that the whole world would adopt an ad-valorem tax rate on CO_2 emissions as Switzerland does in the previous three subsections.

More precisely, we assume that each country implements a 375.5% ad-valorem tax on CO_2 emissions (including Switzerland) in each one of the three world-wide ciompliance scenarios as in the previous subsections. Hence, the only difference between those scenarios is whether and how nuclear energy is replaced in Switzerland. First, we look at how Switzerland and the world respond to a uniform world-wide tax given that Switzerland does not implement any structural changes in energy as in Subsection 7.1. The results are summarized in Table 51.

Table 51: Uniform world-wide tax: Case 1 (compare to Table 39)

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	-27.6499	-86.0215	Korea	-14.6105	-86.0310
Austria	-13.3619	-86.0179	Mexico	-37.1321	-86.0490
Belgium	-62.7110	-86.0416	Netherlands	-14.5343	-85.9167
Canada	-37.1933	-86.0178	New Zealand	-12.1934	-86.0207
Chile	-13.2019	-86.0226	Norway	-12.2986	-86.0913
Czech Republic	-24.7957	-85.9646	Poland	-26.8328	-85.9651
Denmark	-23.3819	-86.0343	Portugal	-32.5541	-85.9559
Estonia	-23.9615	-85.8734	Slovak Republic	-15.9445	-85.9880
Finland	-13.4174	-86.0619	Slovenia	-84.8484	-86.0138
France	-15.7469	-85.9918	Spain	-61.4307	-85.9583
Germany	-13.9432	-86.0282	Sweden	-30.3948	-86.0179
Greece	-12.1374	-85.8798	**Switzerland**	-15.2518	-86.0304
Hungary	-12.2453	-85.9818	Turkey	-17.7564	-85.9417
Iceland	-14.7828	-86.0394	United Kingdom	-23.5748	-85.9978
Ireland	-18.5657	-86.0588	United States	-33.8221	-86.0138
Israel	-15.3294	-85.9676	ROW	-52.2603	-86.0570
Italy	-14.7520	-86.0258	**OECD**	-26.4142	-86.0134
Japan	-18.2244	-86.0417	**World**	-30.9251	-86.0243
-			**European Union**	-22.1746	-86.0000

In Table 39 of Subsection 7.1, the welfare effects for Switzerland were quantified at -14.3%. In

Table 51, they are projected at -15.3% percent. The reason for why compliance with Switzerland leads to even more drastic changes than Switzerland's adoption in isolation with alignment at the Copenhagen Accord pledges is that the proposed tax cuts as severely into the world economy that Switzerland suffers from a decline in foreign demand more than from the relative relaxation of competitive pressure. Under the scenario in Table 51, the world level of CO_2 emissions is projected to decline by 86%. Yet, this comes at (likely untenable) gigantic welfare costs of 31% for world welfare (i.e., real per-capita income).

The second scenario considers the case described in Section 7.2 with foreign compliance at a uniform 375.5% ad-valorem tax on CO_2 emissions. Here, we assume that Switzerland switches from nuclear energy to natural gas while a uniform 375.5% tax is being implemented at home as well as abroad (without any exceptions neithzer across countries nor across industries). The results are reported in Table 52:

Table 52: Uniform world-wide tax: Case 2 (compare to Table 44)

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	-27.6492	-86.0217	Korea	-14.5952	-86.0307
Austria	-13.3404	-86.0177	Mexico	-37.1387	-86.0492
Belgium	-62.7577	-86.0401	Netherlands	-14.5200	-85.9170
Canada	-37.2000	-86.0181	New Zealand	-12.1767	-86.0208
Chile	-13.1813	-86.0217	Norway	-12.2738	-86.0907
Czech Republic	-24.7796	-85.9600	Poland	-26.8340	-85.9653
Denmark	-23.3832	-86.0348	Portugal	-32.5621	-85.9555
Estonia	-23.9577	-85.8738	Slovak Republic	-15.9348	-85.9884
Finland	-13.4094	-86.0631	Slovenia	-84.9172	-86.0100
France	-15.5667	-85.9672	Spain	-61.4717	-85.9570
Germany	-13.9490	-86.0308	Sweden	-30.4026	-86.0190
Greece	-12.1206	-85.8800	**Switzerland**	-23.4662	-85.6236
Hungary	-12.2421	-85.9840	Turkey	-17.7469	-85.9419
Iceland	-14.7667	-86.0398	United Kingdom	-23.5723	-85.9983
Ireland	-18.5740	-86.0615	United States	-33.8262	-86.0141
Israel	-15.3287	-85.9759	ROW	-52.2796	-86.0570
Italy	-14.7473	-86.0270	**OECD**	-26.4328	-86.0114
Japan	-18.2136	-86.0416	**World**	-30.9439	-86.0228
-			**European Union**	-22.1504	-85.9991

The results are summarized in Table 52 and they compare to the ones in Table 44 in a similar way as the ones in Table 51 compared to Table 39. Under a world-wide uniform tax, Switzerland is able to achieve a slightly higher reduction in carbon emissions but at inevitably higher welfare costs for the same reasons as above: the decline in world-wide demand outweighs the relative gains in comparative advantage in this Subsection relative to Subsection 7.2.

The same holds in qualitative terms in a scenario which corresponds to Section 7.3 plus the uniform world-wide tax of 375.5% on CO_2 emissions. The results are summarized in Table 53.

Table 53: UNIFORM WORLD-WIDE TAX: CASE 3 (COMPARE TO TABLE 49)

	% change in			% change in	
country	W_n	$CO_{2,n}$	country	W_n	$CO_{2,n}$
Australia	-27.6494	-86.0217	Korea	-14.6022	-86.0308
Austria	-13.3352	-86.0164	Mexico	-37.1346	-86.0491
Belgium	-62.7416	-86.0391	Netherlands	-14.5219	-85.9162
Canada	-37.1962	-86.0181	New Zealand	-12.1855	-86.0208
Chile	-13.1904	-86.0220	Norway	-12.2829	-86.0909
Czech Republic	-24.7739	-85.9587	Poland	-26.8323	-85.9651
Denmark	-23.3822	-86.0346	Portugal	-32.5576	-85.9552
Estonia	-23.9603	-85.8737	Slovak Republic	-15.9389	-85.9883
Finland	-13.4143	-86.0628	Slovenia	-84.9038	-86.0094
France	-15.5665	-85.9663	Spain	-61.4581	-85.9566
Germany	-13.9443	-86.0294	Sweden	-30.3983	-86.0186
Greece	-12.1266	-85.8797	**Switzerland**	-18.6981	-84.1922
Hungary	-12.2439	-85.9832	Turkey	-17.7499	-85.9416
Iceland	-14.7728	-86.0396	United Kingdom	-23.5722	-85.9980
Ireland	-18.5705	-86.0605	United States	-33.8238	-86.0140
Israel	-15.3292	-85.9682	ROW	-52.2694	-86.0570
Italy	-14.7490	-86.0264	**OECD**	-26.4238	-86.0047
Japan	-18.2192	-86.0418	**World**	-30.9347	-86.0177
-			**European Union**	-22.1479	-85.9984

In general, implementing relatively aggressive, uniform world-wide taxes would be extremely difficult to pursue in welfare terms. Notice that for some countries (e.g., Slovenia), the total welfare loss is projected in excess of 80%. No political system in the world would survive that, and technical progress will unlikely come at the required speed (i.e., within just two to four decades) and the required low costs to make up for such a gigantic loss.

9 Discussion

A discussion of the aforementioned results should address two main questions. First, how can the effects be so large, when energy consumption does not amount to more than 3-4% of total industry production in most industrial countries? Second, are the costs in fact not small when considering that some of the policies will not materialize with full effect until 2034 or 2050?

Let us first turn to the first question. The reason for why a small fraction of energy costs in industry revenues does not imply small welfare costs of energy policy is simple: technology. Energy can not be arbitrarily and costlessly substituted by other production factors. In fact, taxing a production factor – no matter how high its relative share – will induce bigger or smaller effects on total costs and welfare, depending on how difficult or easy it can be substituted. The results in the previous sections are based on technological relationships that are consistent with input output tables of the year 2000. Clearly, if the price of energy falls for exogenous reasons (technical progress), e.g., since energy becomes more easily substitutable with other production factors, this will moderate the consequences of CO_2 taxation in Switzerland and elsewhere.

Second, suppose that Swiss firms and consumers have 30 years to accommodate the aforementioned policies. Roughly speaking, a welfare cost of, say, 15% then implies an annual welfare cost of about 0.5%. Notice that this is not a small cost for a mature, developed economy which grows at 1-2% per annum. Hence, even a piecemeal approach to the aforementioned policies entails a serious welfare cost in the absence of technical progress which renders energy (at least, carbon-intensive energy or other forms of high-cost energy) much less important than nowadays. Certainly, such technical progress will come about. Of course, we do not know when and to which extent. What we can establish at some confidence is that, in order to accommodate welfare costs of energy policy of about 15% over a 30-years time span, the rate of technical progress in a country such as Switzerland will have to be one-quarter to one-third (if not one-half) faster than it used to be over the last years so that the country could grow (and have an employment rate) as it did in the last 1-2 decades. It may well be that energy-efficiency and technical progress will proceed at that rate, but the quantification in this study suggests that in order to accommodate the present discounted value of a tax of about 1'140 Swiss Francs in the year 2000, efficiency would have had to increase to that extent in the year 2000 in order to neutralize the tax effects.

10 Conclusions

This study builds a multi-country, multi-industry, open-economy general equilibrium model which is estimated and calibrated to data on economic size, input-output relationships, and CO_2 emissions of 32 OECD countries and the rest of the world. The main goal of the analysis is a quantification of the effects of two types of carbon tax rates – consumption and production – on industry-level prices and demand, and aggregate carbon emissions and welfare. In particular, we study environmental tax policy with the aim of meeting the targeted emission levels in the Copenhagen Accord, and we distinguish between an isolated implementation of these tax rates in individual countries versus an aligned implementation in blocs of countries or the world as a whole.

We pay specific attention to the effects in four individual countries that may be distinguished in terms of their size (small: Norway and Switzerland; large: Germany and the United States) and their abundance in carbon-intensive natural resources (abundant: Norway and the United States; scarce: Germany and Switzerland). For each of these countries, we find the exact tax rates on carbon consumption or production which would be required to achieve the level of carbon emissions pledged at the Copenhagen Accord. For example, the model suggests that in order to achieve a 23% reduction in CO_2 emissions relative to the level in 2000, Switzerland should implement a carbon consumption tax of 57 Swiss Francs per ton of carbon, if the policy is implemented in isolation. We find that international cooperation within the European Union, the OECD, and the world as a whole could play an important role in terms of minimizing welfare losses for individual countries under various environmental policy scenarios. We find a carbon-related consumption tax is preferable over a carbon-related production tax if countries practice environmental policies in isolation. We find that a carbon-related production tax might be optimal for some countries if international cooperation (policy alignment in pursuit of the Copenhagen Accord) is strong.

From the perspective of policy making, a carbon consumption tax seems preferable as it appears hard and costly to formulate a legally binding, international environmental agreement that might support the carbon production tax. Hence, even though some countries could be better off with using a carbon production tax under policy alignment, other countries would unlikely adopt them due to somewhat more detrimental welfare effects that would be particularly large in case of uncoordinated environmental policies.

Switzerland's plans go substantially beyond the pledges formulated in the Copenhagen Accord. To meet those goals, for instance, a step-wise implementation of a tax on CO_2 at the level of 1,140 Swiss Francs by 2050 has been proposed by Ecoplan (2012). Moreover, the country plans to abolish its nuclear power production and substitute it partly by CO_2-intensive and partly by alternative energy resources. According to the quantification in this study, a tax on CO_2 emission at the level of 1,140 Swiss Francs would be very costly and even exceed the CO_2 reduction goals. At the margin, replacing nuclear power plants per se is not as costly in comparison. The results suggest that, atv the level of technology of the year 2000, replacing nuclear energy with alternative energy sources at the planned extent together with imposing the present discounted value of a tax rate of 1,140 per ton of $\mathrm{CO_2}$ would have been quite costly. Hence, a significant efficiency improvement would have been necessary to accommodate those costs.

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