An Assessment of Trade and Leakage Effects of Climate Policy Initiatives

Rahel Aichele*

August 2011

Preliminary version – Please do not cite

Abstract

So far, computable general equilibrium (CGE) models simulating carbon leakage effects of climate policy have not been informed by empirical estimation. And some CGE models disregard leakage effects through the trade channel altogether. We use a structural new trade theory model to evaluate and quantify the role of unilateral climate policy initiatives such as the EUs 2020 goal of reducing greenhouse gas emissions by 20% for trade flows in a way consistent with general equilibrium. We model trade in a Krugman (1980)-type framework with four input factors; labor, capital, land and energy. Climate policy has an effect on trade flows by raising the price of energy. This implies general equilibrium effects via multilateral resistance (trade diversion).

We use country-specific energy prices from the GTAP 8 model to empirically estimate the elasticity of trade flows with respect to climate policy. With structurally estimated factor cost shares and an estimate of the elasticity of subsitution, we calibrate our model to the year 2007. We then simulate the trade, emission, welfare and leakage effects of climate policy initiatives currently discussed. With our model, we can also simulate the effects of trade liberalization as well as carbon-related border tax adjustments on leakage.

JEL Classification: F18, F47, Q54, Q56
Keywords: gravity model, climate policy, leakage effects of trade, structural estimation.

---

[*] ifo Institute and LMU Munich. Corresponding author. Address: ifo Institute for Economic Research, Poschingerstr. 5, 81679 Munich, Germany. E-mail: aichele@ifo.de. Phone: +49 (0)89 92241275

1 Introduction

The willingness to reduce greenhouse gas emissions associated with global warming and the commitment to international climate policy efforts varies greatly across countries. The European Union (EU) Emission Trading System certainly constitutes the most advanced climate policy regulation. Other countries, especially the catching-up developing countries, are lacking behind. In a globalized world, these differences in climate policy stances lead to a contentious policy debate about carbon leakage and an equally contentious policy debate about the use of carbon-related border tax adjustments (BTA) to combat leakage. *Carbon leakage* refers to a situation where a stricter climate policy regulation in one country leads to higher emissions elsewhere. The extent of carbon leakage is typically quantified with a percentage number: the ratio of the total emission increases in other countries over emission savings in the climate-active region.

There are three motives for carbon leakage. First, since the global climate is a global public good there is an incentive to free-ride on others' emission savings and to relax one's own climate policy efforts in response. Second, depending on the supply elasticity of energy inputs a reduced energy demand in one part of the world may lower the world market energy price. This can lead to increased energy demand, and thus emissions, in countries which do not have a strict climate policy in place ("supply-side leakage"). The third channel relates to international trade and acts over changes in the relative goods prices (terms-of-trade effect). If climate policy leads to higher production costs this may shift production to countries with lax regulation and increase trade flows with loosely regulated countries. Independent of the channel, carbon leakage threatens to undermine the effectiveness of climate policy efforts to mitigate climate change.

With this paper, we want to contribute to the policy debate on the importance of leakage and how to prevent it. We focus on trade-induced leakage and whether it is quantitatively important. Guided by a structurally estimated gravity model, we attempt to quantify the trade, emission and leakage effects of different climate policy scenarios. We also quantify the effects of border tax adjustments. This has important implications for the design of a future climate policy architecture. Currently, the negotiations on a Kyoto follow-up treaty are under way. But the role of international trade for a non-global climate deal does not yet feature prominently.

The theoretical possibility of carbon leakage is well documented (see e.g. Copeland and Taylor, 2005). But there are also theoretical arguments diminishing the role of leakage. For example, Di Maria and van der Werf (2008) show that the existence of directed technical change weakens carbon leakage. A growing body of literature assesses the competitiveness and leakage effects of unilateral climate policy with the help of computable general equilibrium (CGE) models. Resulting leakage rates are typically moderate and lie between 5 and 20% (Felder and Rutherford, 1993; Elliott et al., 2010; Burniaux and Oliveira Martins, 2012), but the leakage rate can even exceed 100% (Babiker, 2005). In summery, the results from CGE models are inconclusive and depend on modeling assumptions and parameter choices.

A large empirical literature is dealing with the effects of environmental regulation stringency on trade flows (see Ederington et al., 2005; Levinson and Taylor, 2008, for some examples). In the context of climate regulation, the empirical evidence presented so far suggests a *direct* trade effect of climate policy (see World Bank, 2008; Aichele and Felbermayr, 2011, 2012; Sato, 2011). Employing a panel strategy to control for Kyoto's endogeneity, Aichele and Felbermayr (2011) estimate a Kyoto country increases its imports from non-Kyoto countries due to Kyoto commitment by about 5%. Sato (2011) finds that an electricity price gap of 10 US-$ per MWh reduces exports by 1-2%. The evidence is also consistent with leakage: the carbon content of imports of Kyoto countries from non-Kyoto countries increases by 8% with Kyoto commitment (Aichele and Felbermayr, 2011). But so far there are no empirical estimates on the extent of carbon leakage. Furthermore, the papers so far neglect *general equilibrium* (GE) effects. When a country strengthens its climate policy, a trade partner may increase its imports from a third country to substitute for the more expensive goods from the climate active country (*trade diversion*). Given trade diversion, the stable unit treatment value assumption is violated. In this paper, we therefore resort to structural estimation and simulation techniques to account for GE effects.

Finally, our paper is methodologically related to work on the structural estimation of gravity models. In this literature, the policy experiment simulations are concerned with the effects of trade costs on trade and welfare. For example, Egger and Larch (2011) simulate the trade and welfare effects of the Europe agreements, i.e. the integration of the Central and Eastern European goods markets with the EU market. Egger et al. (2011) quantify the trade effect of endogenous free trade agreement formation with an Armington-type gravity model. And Bergstrand et al. (2012) investigate the GE effects of abolishing the Canada-US border with a monopolistic competition-increasing returns to scale gravity model. In these models, labor is the only factor of production. So there is no role for energy prices or climate policy.

We borrow our model structure from Krugman (1980) and Bergstrand et al. (2012) and introduce several production factors into the model. In order to assess the total (i.e. direct and general equilibrium) effects of climate policy initiatives, we first set up a one sector monopolistic competition model with increasing returns to scale. Our model differs from previous ones by allowing for several production factors: labor, capital, land and energy. They are combined with a Cobb-Douglas production function to produce the sectoral varieties. Climate policy ultimately raises the price of energy, as noted e.g. in Aldy and Pizer (2011). So we assume that governments choose the energy price according to their climate policy stance and emissions result from the location of production across the globe. The resulting gravity equation is fairly standard.[1] In a next step, we identify the model's parameters with a gravity specification. To avoid omitted variables bias due to multilateral resistance terms and to identify the effect of differences in energy prices, we employ an odds specification of the gravity equation as for example used in Martin et al. (2008). The structurally estimated parameters are then fed back into our model to do counterfactual analysis.

We conduct three different policy experiments. For each thought experiment, we are interested in the implications for trade, emissions and welfare and compute the implied carbon leakage rate. (i) We quantify what happens to trade, emissions, welfare and leakage if the European Union (EU) countries strengthen their climate policy. More specifically, if they increase their carbon price by 10%. (ii) The second policy experiment deals with the effects of trade liberalization in the presence of climate policy differences. Does China become a pollution haven in the case of an EU-China free trade agreement (FTA)? How do the effects differ for an FTA between the EU and the USA? (iii) A huge policy-debate centers around carbon-related border tax adjustments (BTA) as a means to prevent leakage. We quantify what happens if the EU hypothetically were to impose a requirement to buy emission certificates for imports into the EU.

The rest of the paper proceeds as follows. Section 2 describes our model and parameter identification strategy. Section 3 presents our empirical estimates of the model's parameters. Section 4 shows the results of our counterfactual policy experiments.

2 Methodology

In section 2.1 we set up a Krugman (1980) type trade model with monopolistic competition and increasing returns to scale where labor, capital, land and energy are needed to produce output. In section 2.2 we describe our strategy to structurally estimate the model's parameters. In section 2.3 we give our methodology for evaluating counterfactual scenarios.

---

[1] Krugman (1980)'s and Bergstrand et al. (2012)'s model results as a special case of our model where the cost share of labor is one.

2.1 A Krugman (1980) type new trade theory model with energy and conventional production factors

Trade flows Our model world is populated by $i, j = 1, \ldots, N$ countries. As in Krugman (1980), there is one production sector. We assume the representative consumer's preferences display a constant elasticity of substitution (CES) over sectoral varieties. International trade of sectoral varieties is costly. τ_{ij} units have to be shipped from country i to country j for one unit to arrive, i.e. a fraction of the quantity shipped between countries melts away (iceberg trade costs). Firms are symmetric. Consequently, all firms in country i charge the same ex-factory price p_i. Then, the price of goods from i shipped to j is $p_{ij} = \tau_{ij} p_i$. Let n_i denote the number of firms/varieties in country i. So the consumer in country j maximizes her utility U_j over the consumed quantities c_{ij} of i's varieties

$$\max U_j = (\sum_{i=1}^{N} n_i c_{ij}^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}}$$

subject to the budget constraint $\sum_{i=1}^{N} p_{ij} c_{ij} = Y_j$. Income is generated from working, supplying capital and land and from energy tax rebates and equals a country's GDP Y_j.

From the utility maximization problem, the value of bilateral trade flows X_{ij} from country i to j is determined as

$$X_{ij} = n_i p_{ij} c_{ij} = n_i (\frac{p_{ij}}{P_j})^{1-\sigma} Y_j. \tag{1}$$

As usual, $P_j = \left[\sum_{i=1}^{N} n_i p_{ij}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$ is the ideal price index.

Production A firm in country i combines labor, capital, land and energy to produce the output quantity y_i. For simplicity we assume a constant returns to scale Cobb-Douglas production function. We assume the firm's fixed costs F are incurred in terms of an input bundle, i.e. fixed costs require the same share of all production factors as production.[2] Let conventional production factors be indexed with f. Let $w_i(f)$ denote factor f's unit cost and t_i the energy price. For convenience, we work with the dual cost function $\Gamma_i = (y_i + F) \prod_f w_i(f)^{\alpha_f} t_i^{\beta}$, where α_f is the cost share of conventional factor f and β is the cost share of energy. Profit maximization yields the standard mark-up over marginal cost ex-factory price

$$p_i = \frac{\sigma}{\sigma-1} \prod_f w_i(f)^{\alpha_f} t_i^{\beta} = \frac{\sigma}{\sigma-1} MC_i. \tag{2}$$

---

[2] This assumption implies increasing returns at the firm level but economy-wide constant returns to scale.

Free entry-and-exit leads to zero profits. Since fixed costs are in terms of an input bundle, the scale of production is fixed and independent of the location of production:

$$y_i = (\sigma - 1)F = y. \tag{3}$$

The number of firms/varieties in each country is determined by factor market clearing conditions and the GDP function. In contrast to models with one factor of production, n_i is not solely determined by the labor endowment though. Each country i is endowed with a certain amount of the conventional production factors $L_i(f)$. Shepard's lemma gives the unit requirement for factor f as $a_i(f) = \alpha_f MC_i / w_i(f)$. The factor market clearing condition equates the factor demand with the respective endowment.

$$n_i(y_i + F)a_i(f) = L_i(f), \quad \forall f = \text{labor, capital, land.} \tag{4}$$

Each country i is also endowed with oil in the ground which can be extracted but is not traded internationally. For simplicity we assume zero extraction costs. The government sets the energy price t_i according to its climate policy stance. Oil is completely elastically supplied at this price. The energy demand in a country determines the emission level. For simplicity, we assume energy use translates one-to-one into CO_2 emissions. Similar to conventional factors, Shepard's lemma gives the emission intensity $e_i = \beta MC_i / t_i$. So a country's emission level is $E_i = n_i(y_i + F)e_i$.

A completely elastic supply of oil is certainly a simplified representation of the energy market. With this modeling assumption, we effectively shut down the leakage over changes in the world market price for energy (supply-side leakage). Supply-side leakage can only occur if the energy supply is (rather) inelastic. In our model, a change in one country's energy price has no effect on the energy price of other countries. This also prevents free-riding on other countries' climate policy efforts. So in our model, leakage only occurs due to the possibility to trade. And with our analysis, we are exactly interested in how important this leakage channel is. Apart from this research motive, the non-tradeability and elastic supply assumptions might not be too bad for some fuel types (like coal) and certainly for the electricity market while oil is certainly traded a lot internationally. And Aldy and Pizer (2011) argue that climate policy (be it a carbon tax or an emissions trading system) ultimately raises the price of energy. So with their climate policy actions governments in the end "choose" an energy price. In this respect, our modeling assumption might not be too far off.

With the factor cost representation of GDP, $Y_i = \sum_f w_i(f)L_i(f) + t_i E_i$, and the factor market clearing conditions (4), we can solve for n_i and $w_i(f)$ as a function of GDP, endowments and energy price:

$$\begin{aligned} n_i &= \frac{Y_i^{1-\beta} t_i^{-\beta} \prod_f L_i(f)^{\alpha_f}}{\sigma F a}, && (5) \\ w_i(f) &= \frac{\alpha_f Y_i}{L_i(f)}, && (6) \end{aligned}$$

where $a \equiv \prod_f \alpha_f^{\alpha_f}$. This also pins down a country's emission level as

$$E_i = \frac{\beta Y_i}{t_i}. \tag{7}$$

In consequence, energy usage – and thus emissions – react to the price level set by the government and the overall level of production.

Gravity equation Plugging (2), (5) and (6) into equation (1) gives an *estimable gravity equation*:

$$X_{ij} = \tau_{ij}^{1-\sigma} Y_i Y_j \frac{t_i^{-\sigma\beta} \prod_f (\frac{Y_i}{L_i(f)})^{-\sigma\alpha_f}}{\sum_{k=1}^{N} \tau_{kj}^{1-\sigma} Y_k t_k^{-\sigma\beta} \prod_f (\frac{Y_k}{L_k(f)})^{-\sigma\alpha_f}} \varepsilon_{ij}, \tag{8}$$

where ε_{ij} denotes measurement error. The j-specific denominator represents the usual multilateral resistance term. The estimable gravity equation (8) is solved subject to the goods market clearing/balanced trade condition

$$Y_i = \sum_{j=1}^{N} X_{ij}. \tag{9}$$

With labor as the only factor of production, $\alpha_{\text{labor}} = 1$, the Bergstrand et al. (2012) specification results as special case. As in Bergstrand et al. (2012), X_{ij}, Y_i and $\frac{Y_i}{L_i(f)}$ are endogenously determined in the model.

Extension with Hicks-neutral productivity differences across countries Technologies differ across countries. To incorporate this into the model, we introduce productivity differences with a technology shifting parameter. Let A_i denote productivity. Then the cost function is $\Gamma_i = \frac{1}{A_i}(y_i + F) \prod_f w_i(f)^{\alpha_f} t_i^{\beta}$. More productive countries have lower costs, lower unit input requirements and produce more varieties, all else equal. The exporter's productivity shifts up trade. And all countries' productivities enter the gravity equation via their influence on price levels:

$$X_{ij} = A_i^{\sigma} \tau_{ij}^{1-\sigma} Y_i Y_j \frac{t_i^{-\sigma\beta} \prod_f (\frac{Y_i}{L_i(f)})^{-\sigma\alpha_f}}{\sum_{k=1}^{N} A_k^{\sigma} \tau_{kj}^{1-\sigma} Y_k t_k^{-\sigma\beta} \prod_f (\frac{Y_k}{L_k(f)})^{-\sigma\alpha_f}} \varepsilon_{ij}. \tag{8a}$$

2.2 Identifying the model's parameters

In this section, we want to identify the models parameters σ, β and α_f. Typically, the gravity literature proceeds by estimating equation (8) in log-linearized form. Trade costs are not observable. They are proxied by bilateral distance dist_{ij} and dummy variables for other observables Z_{ij} like contiguity, common language, if the pair has ever been in a colonial relationship, has a bilateral free trade agreement, joint WTO membership, and joint EU membership. As in Anderson and van Wincoop (2003) and many other gravity applications, the functional relationship is assumed to be $\tau_{ij}^{1-\sigma} = \text{dist}_{ij}^{(1-\sigma)\rho} e^{(1-\sigma)\delta Z_{ij}}$. To avoid omitted variables bias due to the non-linear multilateral resistance terms, equation (8) is estimated with importer and exporter fixed effects. Consequently, the effect of country-specific variables like energy prices can no longer be identified. Bergstrand et al. (2012) then identify σ by dividing X_{ij} by X_{mj}, plugging in the estimates for $\frac{\widehat{\tau_{ij}^{1-\sigma}}}{\widehat{\tau_{mj}^{1-\sigma}}}$ and isolating σ. This strategy is not possible in the case with several production factors since σ only appears jointly with the cost share parameters.

Therefore, we choose a different strategy to identify the parameters σ, β and α_f. To get rid of the multilateral resistance terms, we divide X_{ij} by the respective trade flow of the importer j with a reference country m

$$\frac{X_{ij}}{X_{mj}} = (\frac{\tau_{ij}}{\tau_{mj}})^{1-\sigma}(\frac{Y_i}{Y_m})(\frac{t_i}{t_m})^{-\sigma\beta}\prod(\frac{Y_i/L_i(f)}{Y_m/L_m(f)})^{-\sigma\alpha_f}\frac{\varepsilon_{ij}}{\varepsilon_{mj}}. \tag{10}$$

This odds specification was for example used in Martin et al. (2008). So j's imports from country i relative to its imports from country m positively depend on the ratio of GDPs and negatively on the ratio of factor prices (which are proportional to the ratio of ex-factory goods prices) as well as the ratio of bilateral trade costs. The direct effect of an increase in country i's energy price is to lower j's imports from i with respect to m with an elasticity of $\sigma\beta$. In other words, the trade effect depends on consumers' love of variety and on how important the production factor energy is in production. Apart from this direct effect, there will be a general equilibrium effect through changes in all countries' GDPs and consequently also the factor prices.

In log-linearized form and with the standard assumption $\tau_{ij}^{1-\sigma} = \text{dist}_{ij}^{(1-\sigma)\rho} e^{(1-\sigma)\delta Z_{ij}}$, this gives our estimation equation

$$\begin{aligned}\ln\frac{X_{ij}}{X_{mj}} &= (1-\sigma)\rho\ln\frac{\text{dist}_{ij}}{\text{dist}_{mj}} + (1-\sigma)\delta(Z_{ij}-Z_{mj}) + \ln\frac{Y_i}{Y_m} \\ &\quad -\sigma\beta\ln\frac{t_i}{t_m} - \sigma\sum_f \alpha_f \ln\frac{Y_i/L_i(f)}{Y_m/L_m(f)} + u_{ijm}, \end{aligned} \tag{11}$$

where $u_{ijm} = \ln\frac{\varepsilon_{ij}}{\varepsilon_{mj}}$ is an idiosyncratic error term.

With this specification, we can identify the joint effect of, for example, $\sigma\beta$ as the estimated coefficient on $\ln(\frac{t_i}{t_m})$. If the constant returns to scale assumption $\sum_f \alpha_f + \beta = 1$ is correct, we are even able to identify σ, β and α_f separately.

International technology differences are a potential confounding factor. Productivity is related to GDP and factor prices. To avoid omitted variables bias due to productivity differences we also estimate (11) with i and m fixed effects. The estimation equation becomes:

$$\begin{aligned} \ln\frac{X_{ij}}{X_{mj}} &= (1-\sigma)\rho\ln\frac{\text{dist}_{ij}}{\text{dist}_{mj}} + (1-\sigma)\delta(Z_{ij}-Z_{mj}) + \ln\frac{Y_i}{Y_m} \\ &\quad -\sigma\beta\ln\frac{t_i}{t_m} - \sigma\sum_f \alpha_f \ln\frac{Y_i/L_i(f)}{Y_m/L_m(f)} + \eta_i + \zeta_j + u_{ijm}, \end{aligned} \tag{12}$$

where the i fixed effect is $\eta_i \equiv \sigma\ln A_i$ and the m fixed effects is $\zeta_j \equiv \sigma\ln A_m$.

2.3 Comparative statics methodology

With the estimated parameters $\hat{\sigma}$, $\hat{\beta}$ and $\widehat{\alpha_f}$, we can assess the trade, emission and welfare effects of counterfactual scenarios. For example, we might be interested in the effect of a stricter climate policy on trade flows and emissions with the ultimate aim to assess the extent of carbon leakage. We can simulate this with a variation in the energy price. Or we might be interested in the effect of trade liberalization – say for example an FTA between the EU and the USA or the EU and China – when the prices of energy and thus the implicit carbon price differs. Does this lead to leakage? To simulate this scenario, we can change Z_{ij}.

Let ^{c} denote a variable's counterfactual value and $\hat{}$ denote estimated values. The percentage change of GDP-normalized trade flows is

$$\Delta\frac{X_{ij}}{Y_iY_j} = 100\cdot\left[\frac{\widehat{\tau_{ij}^{1-\sigma}}^{c}(t_i^c)^{-\widehat{\sigma\beta}}\prod_f(\frac{Y_i^c}{L_i(f)})^{\widehat{\sigma\alpha_f}} / \left[\sum_k \widehat{\tau_{kj}^{1-\sigma}}^{c}Y_k^c(t_k^c)^{-\widehat{\sigma\beta}}\prod_f(\frac{Y_k^c}{L_k(f)})^{\widehat{\sigma\alpha_f}}\right]}{\widehat{\tau_{ij}^{1-\sigma}}(t_i)^{-\widehat{\sigma\beta}}\prod_f(\frac{Y_i}{L_i(f)})^{\widehat{\sigma\alpha_f}} / \left[\sum_k \widehat{\tau_{kj}^{1-\sigma}}Y_k(t_k)^{-\widehat{\sigma\beta}}\prod_f(\frac{Y_k}{L_k(f)})^{\widehat{\sigma\alpha_f}}\right]} - 1\right]. \tag{13}$$

Likewise the percentage change in a country's emission level is

$$\Delta E_i = 100\cdot\left[\frac{Y_i^c/t_i^c}{Y_i/t_i} - 1\right]. \tag{14}$$

Note that a change in the energy price of another country, say k, has no direct effect on i's emission level. However, there are GE effects via changes in GDPs (or trade diversion). The extent of carbon leakage of a climate policy change in country i is then given by

$$\text{Leakage} = 100\cdot\frac{\sum_{k\neq i}\Delta E_k}{-\Delta E_i}. \tag{15}$$

A country's welfare is given by $U_i = Y_i/P_i$. Note that this does not take into account welfare effects from changes in the global emission level, however. Welfare damages of increased pollution are typically modeled with an additively separable damage function. Lacking an estimate of the damage function, we only look at the percentage change in welfare from goods consumption

$$\Delta U_i = 100 \cdot \left[\frac{Y_i^c / \left[\sum_k \widehat{\tau_{kj}^{1-\sigma}}^{c} Y_k^c (t_k^c)^{-\widehat{\sigma\beta}} \prod_f (\frac{Y_k^c}{L_k(f)})^{\widehat{\sigma\alpha_f}} \right]^{\frac{1}{1-\hat{\sigma}}}}{Y_i / \left[\sum_k \widehat{\tau_{kj}^{1-\sigma}} Y_k (t_k)^{-\widehat{\sigma\beta}} \prod_f (\frac{Y_k}{L_k(f)})^{\widehat{\sigma\alpha_f}} \right]^{\frac{1}{1-\hat{\sigma}}}} - 1 \right]. \tag{16}$$

3 Empirical evidence

In section 3.1 we describe the data we use. In section 3.2 we present results for our structural gravity parameter estimates obtained with the methodology laid down in section 2.2.

3.1 Data

We investigate a cross-section of country pairs in the year 2007.[3] Data on bilateral exports in free-on-board values stem from the UN Comtrade database.[4] Bilateral distance and dummies for contiguity, common language, and colonial history are obtained from the CEPII distance dataset. The WTO and EU dummy are constructed from the homepage of the WTO and the EU, respectively. Data on bilateral free trade agreements (FTA) stem from the WTO homepage. Data on labor and land endowments are taken from the UN World Development Indicators (WDI) 2011. The laborforce series comprises the economically active population aged 15 and older. For land endowments, we use the arable land series. A country's physical capital stock is computed with the perpetual inventory method.[5] The necessary data on investment and GDP in constant PPP-adjusted dollars are taken from the Penn World Tables 7.0.

Finally, energy prices are constructed from the Global Trade Analysis Project (GTAP) 8 database. For its base year 2007, GTAP 8 provides information on a country's firms' expenses on fuels[6] and electricity (in million US-dollars) and on firms' fuel and electricity usage (in mill tons of oil equivalents, Mtoe). This allows us to experiment with three price series, each given in

---

[3] We choose 2007 since we have a cross-section of energy prices for this year.

[4] The exports series originally includes re-exports. The data series is adjusted for re-exports with the re-exports data provided by UN Comtrade.

[5] The respective STATA routine "stockcapit" is due to Amadou (2011).

[6] The fuels are oil, gas, coal and petroleum products.

US-dollars per toe: a fuel price, an electricity price and an energy price which is computed as sum of fuel and electricity expenses divided by the sum of fuel and electricity usage. Alternatively, we can also express the price in US-dollars per ton of CO_2 emission because GTAP also features information on firms' CO_2 emissions. This could be interpreted as implicit CO_2 price. This price may differ from the energy price due to differences in countries' fuel mixes. GTAP also provides data on firms' tax expenses for fuel and electricity use. This allows us to construct a tax-induced implicit CO_2 price which may be interpreted as a measure of a country's climate policy stringency.

Table 1 provides summary statistics. There are 8,523 country pairs or equivalently 98 countries in the dataset.[7] Average bilateral exports amount to about one billion US-$. A country pair's major economic centers on average lie about 7,000 kilometers apart. Roughly 95% of all country pairs are jointly members to the World Trade Organization (WTO). About 30% of the country pairs have signed a free trade agreement. The average physical capital stock amounts to 1,591 billion US-$. The average country's labor force is about 27 million people and its arable land area amounts to 110,000 square kilometers. In terms of energy prices, we observe quite some variance in our data. The average price for one toe energy is 623 US-$ with a standard deviation of 179 US-$ per toe. With below 300 US-$ per toe, China, Qatar, Kazakhstan and South Africa have the lowest energy prices. On the other end of the distribution are Croatia, Zambia, Austria, Luxembourg, Sweden, Great Britain and Italy with energy prices above 900 US-$ per toe. A country's energy and fossil fuel price are highly significantly correlated. The correlation coefficient is 0.95. The correlation between electricity and energy as well as energy and implicit CO_2 price are about 0.61 and also highly statistically significant.

3.2 Structural gravity parameter estimates

Now we are ready to estimate our structural gravity equation in its odds specification. Table 2 shows the estimated parameters. The parameters of the trade cost proxies are all sensible. Bilateral distance affects trade flows negatively, whereas a shared border or a common language or a bilateral FTA have a direct trade-increasing effect. The GDP-elasticity of trade flows is estimated to be 1.346 and highly statistically significant. This is statistically significantly above the theoretical value of one. The cost shares of production factors multiplied with $-\sigma$ all appear with the expected negative sign. They are all statistically different from zero at the 1% level. The absolute value of $-\sigma\alpha_{\text{capital}}$ is highest suggesting capital has the highest cost

---

[7] A country list is relegated to the Appendix.

Table 1: Summary statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Bilateral variables					
Exports, million US-$	8,523	1,247	7,993	0	310,480
Distance, km	8,523	7,335	4,485	60	19,812
Contiguity	8,523	0.03	0.16	0.00	1.00
Common language	8,523	0.12	0.33	0.00	1.00
Colonial relationship	8,523	0.02	0.13	0.00	1.00
FTA	8,523	0.29	0.46	0.00	1.00
Joint WTO membership	8,523	0.94	0.23	0.00	1.00
Joint EU membership	8,523	0.07	0.26	0.00	1.00
Country-specific variables					
GDP, billion US-$	98	531	1,591	4	14,062
Physical capital, billion US-$	98	1,609	4,381	18	33,245
Laborforce, thousands	98	27,369	90,623	172	771,079
Arable land, km^2	98	111,159	281,106	6	1,704,280
Energy price, US-$ per toe	98	623	179	233	1,130
Fuel price, US-$ per toe	98	539	163	210	1,095
Electricity price, US-$ per toe	98	1,299	429	396	3,108
CO_2 price, US-$ per ton CO_2	98	431	230	113	1,322

Note: The table shows summary statistics of bilateral and country-specific gravity variables in the year 2007. The physical capital stock is given in PPP-adjusted 2005 constant US-$. Other monetary variables are in current US-$.

share in production. It is followed by energy and labor; whereas land seems less important as a production factor.

With the assumption of constant returns to scale, we are able to back out $\hat{\sigma}$, $\hat{\beta}$ and $\widehat{\alpha_f}$ separately. The cost share of energy is estimated at about 9%, which is a plausible value. The cost share of land is estimated to be 2%. A reasonable value if we compare this to the average cost share of land in GTAP 8. The estimate for the cost share of labor, however, is 5% only and thus very far from average values as e.g. the GTAP data. On the other hand, the cost share of capital is 84% and certainly exaggerated. The resulting elasticity of substitution is $\hat{\sigma} \approx 1.7$, and therefore rather at the lower end of typical values as described in Anderson and van Wincoop (2003).

4 Counterfactual analysis

4.1 How much leakage does a strengthening of the EU's implicit carbon price induce?

— to be completed —

4.2 What are the trade, welfare and leakage effects of an EU-USA free trade agreement?

— to be completed —

5 Conclusions

— to be completed —

Table 2: Gravity parameter estimates

Dep. var.: $\ln(X_{ij}/X_{mj})$	(1)
GDP ratio	1.346***
	(0.006)
$-\sigma\alpha_{\text{labor}}$	-0.089***
	(0.015)
$-\sigma\alpha_{\text{capital}}$	-1.419***
	(0.021)
$-\sigma\alpha_{\text{land}}$	-0.033***
	(0.004)
$-\sigma\beta$	-0.155***
	(0.048)
$(1-\sigma)\rho$	-1.306***
	(0.004)
$(1-\sigma)\delta_{\text{contiguity}}$	0.739***
	(0.015)
$(1-\sigma)\delta_{\text{language}}$	0.882***
	(0.008)
$(1-\sigma)\delta_{\text{colony}}$	0.605***
	(0.014)
$(1-\sigma)\delta_{\text{FTA}}$	0.390***
	(0.006)
$(1-\sigma)\delta_{\text{WTO}}$	1.934***
	(0.033)
$(1-\sigma)\delta_{\text{EU}}$	0.851***
	(0.078)
Observations	779,706
Adj. R^2	0.731

Note: Standard errors in parentheses. i and m fixed effects included (not shown). *, **, *** denotes statistical significance at the 10, 5 and 1% level, respectively.

References

Aichele, Rahel and Gabriel Felbermayr, "Kyoto and Carbon Leakage: An Empirical Analysis of the Carbon Content of Bilateral Trade," CESifo Working Paper 3661, (Munich: CESifo) 2011.

_ and _ , "Estimating the effects of Kyoto on bilateral trade flows using matching econometrics," *The World Economy*, 2012, *forthcoming.*

Aldy, Joseph E. and William A. Pizer, "The Competitiveness Impacts of Climate Change Mitigation Policies," NBER Working Papers 17705, National Bureau of Economic Research December 2011.

Amadou, Diallo Ibrahima, "STOCKCAPIT: Stata module to calculate physical capital stock by the perpetual-inventory method," Statistical Software Components, Boston College Department of Economics April 2011.

Anderson, James E. and Eric van Wincoop, "Gravity with Gravitas: A Solution to the Border Puzzle," *American Economic Review*, March 2003, *93* (1), 170–192.

Babiker, Mustafa H., "Climate change policy, market structure, and carbon leakage," *Journal of International Economics*, 2005, *65* (2), 421 – 445.

Bergstrand, Jeffrey H., Peter Egger, and Mario Larch, "Gravity Redux: Estimation of gravity-equation coefficients, elasticities of substitution, and general equilibrium comparative statics under asymmetric bilateral trade costs," *Journal of International Economics*, 2012, *forthcoming.*

Burniaux, Jean-Marc and Joaquim Oliveira Martins, "Carbon leakages: a general equilibrium view," *Economic Theory*, 2012, *49* (2), 473–495. 10.1007/s00199-010-0598-y.

Copeland, Brian R. and M. Scott Taylor, "Free trade and global warming: a trade theory view of the Kyoto protocol," *Journal of Environmental Economics and Management*, March 2005, *49* (2), 205–234.

Ederington, Josh, Arik Levinson, and Jenny Minier, "Footloose and Pollution-Free," *Review of Economics and Statistics*, February 2005, *87* (1), 92–99.

Egger, Peter and Mario Larch, "An assessment of the Europe agreements' effects on bilateral trade, GDP, and welfare," *European Economic Review*, February 2011, *55* (2), 263–279.

_ , _ , Kevin E. Staub, and Rainer Winkelmann, "The Trade Effects of Endogenous Preferential Trade Agreements," *American Economic Journal: Economic Policy*, August 2011, *3* (3), 113–43.

Elliott, Joshua, Ian Foster, Samuel Kortum, Todd Munson, Fernando Pérez Cervantes, and David Weisbach, "Trade and Carbon Taxes," *American Economic Review: Papers and Proceedings*, May 2010, *100* (2), 465–69.

Felder, Stefan and Thomas F. Rutherford, "Unilateral CO_2 Reductions and Carbon Leakage: The Consequences of International Trade in Oil and Basic Materials," *Journal of Environmental Economics and Management*, September 1993, *25* (2), 162–176.

Krugman, Paul, "Scale Economies, Product Differentiation, and the Pattern of Trade," *The American Economic Review*, 1980, *70* (5), 950–959.

Levinson, Arik and M. Scott Taylor, "Unmasking The Pollution Haven Effect," *International Economic Review*, February 2008, *49* (1), 223–254.

Maria, Corrado Di and Edwin van der Werf, "Carbon leakage revisited: unilateral climate policy with directed technical change," *Environmental and Resource Economics*, February 2008, *39* (2), 55–74.

Martin, Philippe, Thierry Mayer, and Mathias Thoenig, "Make Trade Not War?," *Review of Economic Studies*, 07 2008, *75* (3), 865–900.

Sato, Misato, "Near-term impacts of asymmetric climate change mitigation polices," Technical Report 2011.

World Bank, *International Trade and Climate Change - Economic, Legal, and Institutional Perspectives*, (Washington: IBRD/The World Bank), 2008.

Appendix

Data

The 98 countries are: Albania, Argentina, Armenia, Australia, Austria, Bahrain, Bangladesh, Belarus, Belgium, Bolivia, Botswana, Brazil, Bulgaria, Cambodia, Cameroon, Canada, Chile, China, Colombia, Costa Rica, Croatia, Cyprus, Czech Republic, Côte d'Ivoire, Denmark, Ecuador, Egypt, El Salvador, Ethiopia, Finland, France, Georgia, Germany, Ghana, Greece, Guatemala, Honduras, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Kazakhstan, Kenya, Kuwait, Kyrgyzstan, Latvia, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Malta, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Namibia, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Republic of Korea, Romania, Saudi Arabia, Senegal, Singapore, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Thailand, Tunisia, Turkey, United States of America, Uganda, United Arab Emirates, United Kingdom, United Republic of Tanzania, Uruguay, Vietnam, Zambia