A sectoral approach balancing global efficiency and equity*

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Abstract

This paper explores the idea that a properly designed sectoral approach could be the answer to two sets of constraints that hinder international agreement on climate change: a genuine concern for economic growth from developing countries and competitiveness issues from industrialized countries. Our sectoral approach builds on three premises: (i) cap and trade systems in industrialized countries and intensity targets in developing countries, (ii) sectors subject to international trade abide to the rules of the countries in which they trade, (iii) a fraction of the revenues from permits in industrialized countries goes to improve efficiency targets in domestic production in the developing countries.

We design an economic model that features the interactions in three sectors (more or less exposed to international trade) and two countries (industrialized and developing). Two scenarios are constructed: Sectoral Approach, which refers to our proposal, and Global Cap, which implements a uniform CO2 price. We compare the two scenarios in terms of total welfare and equity. It is shown that Sectoral Approach ranks high in terms of equity for a minor welfare loss. It also eliminates competitiveness and leakage issues.

JEL Classification: D63, Q56, F18, H23

Keywords: International agreement,Sectoral approach, Equity, Competitiveness.

1 Introduction

An optimistic view of Copenhagen is that developing countries are now willing to take actions to mitigate green house gas emissions (i.e. China, Brazil, India and Indonesia are among the 55 countries that pledge to cut growth in GHG emissions by 2020,

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source the Feb 2^{nd} 2010 edition of the Guardian, http://www.guardian.co.uk). This is a radical change from the no responsibility position adopted at Kyoto. It is a significant breakthrough since "two thirds to three quarters of the 45 to 110 percent increase between 2000 to 2030 from energy use is projected to come from non-Annex I countries" (Wara, 2007). Developing countries had put forward two conditions for their involvement. First, financial and technology transfers from industrialized countries should help them to make the corresponding adaptations. Second, emission constraints should be on intensity targets, not on absolute caps based on 1990 emissions, to allow for their economic development. These constraints remain active and need be taken into account in a more systematic way than they are through the Clean Development Mechanism (Schneider, 2007; Sterk, 2008; Victor and Wara, 2008).

The generalization of cap and trade mechanisms in industrialized countries seems also a promising avenue. The EU may be joined in this process by Australia, New Zealand, Japan and possibly the US and Canada (see Climate Strategies project on linking national emissions trading schemes http://www.joanneum.at/climate/linking/). The full deployment of these schemes suffers from some difficulties (For a systematic review of the European cap and trade see Ellerman et al., 2010)). The ambitions and the perimeters of the schemes are different, which does not facilitate their interconnections. More importantly, the crucial issue of competitiveness has so far prevented such schemes to deliver their targets. For instance, a close scrutiny of the European Union Emissions Trading Scheme (EU-ETS) reveals that the number of sectors that will be eligible for some form of free allocations in Phase III (2013-2020) might be so large that it becomes easier to list the sectors which are not (mostly electricity) rather than those which are (Parliament, 2009). Across the Atlantic, intense lobbying may similarly significantly reduce, or even put into jeopardy, President Obama's cap and trade policy.

In view of these political constraints a uniform CO_2 price scheme worldwide can only be seen as a long term goal. This paper explores the idea that a sectoral approach could be a good way to make immediate progress towards this goal. A sectoral approach is a combined industry and government initiative. Such an approach stipulates that for that sector and for the countries that signed the agreement, there are joint binding rules to mitigate CO_2 emissions (Baron et al., 2008, 2009; Center for Clean Air Policy, 2009). These rules may either be a cap and trade system, a set of intensity targets or a set of technical norms. They may apply to one sector or to several sectors at once. They may differ from one country to the other one. The flexibility of sectoral approaches allows for the explicit introduction of the considerations discussed earlier. Some studies have already explored intensity targets in developing countries (See for instance the recent proposals of International Energy Agency, 2009; World Business Council for Sustainable Development, 2009). A number of questions need be addressed to demonstrate the feasibility of these schemes. Is the flexibility obtained at a large efficiency loss? Would such a "second best" approach significantly reduce the global efficiency of the scheme compared with a "first best" approach with a uniform CO_2 price, as advocated by some economists (Stern et al., 2006; Tirole, 2009). What about competitiveness issues in industrial countries? What would be the amount of financial transfers and how would they be monitored?

The contribution of the paper is threefold. First an original sectoral approach is designed to explicitly cope with the identified constraints. Our sectoral approach (to be denoted Sectoral Approach henceforth) is built on three components: (i) cap and trade systems in industrialized countries and intensity targets in developing countries, (ii) sectors subject to international trade abide to the rules of the countries in which they trade, (iii) a fraction of the revenues from permits in industrialized countries goes to improve efficiency targets in domestic production in the developing countries.

Second the paper provides a methodology to discuss the trade-off between efficiency and equity made by such second-best schemes. While it seems conceptually clear that a uniform price will achieve global efficiency, in the sense that it decentralizes the right incentives to equalize marginal abatement costs with marginal gains, the virtue of this approach in terms of equity has been much debated. For instance it would increase the electricity bill in India for a low income consumer in proportions that would be unbearable if not compensated (Sterner, 2009). Such compensations would require large transfers: from industrialized to developing countries, and within developing countries. Some authors have questioned the feasibility of international transfers and demonstrated that, without transfers, the second best scheme would lead to differentiated carbon prices (Chichilnisky and Heal, 1994; Sheeran, 2006; Godard, 2009). Our Sectoral Approach is a medium path between these two extreme cases.

Third a simple calibrated model is elaborated to apply our methodology and quantify our analysis. The model features the interactions in three sectors and two countries. This is a drastic simplification to enhance the main contributions of our approach. The model is calibrated in terms of sectors on electricity, cement and steel, and in terms of countries on the EU and China. It is assumed that electricity is not subject to international trade while the two other sectors cement and steel are. In this framework we shall first compare two scenarios: Sectoral Approach, which refers to our proposal, and, as a benchmark, Global Cap, which implements a uniform CO_2 price. Both of these scenarios by construction will achieve the same cap in terms of global CO_2 reductions.

The welfare loss associated with Sectoral Approach is precisely identified. The two scenarios are compared in terms of equity in the developing countries, i.e. prices and consumptions in China. The global financial transfer that would need to be put in place in Global Cap to Pareto dominate Sectoral Approach is derived. Altogether, Sectoral Approach ranks high in terms of equity for a minor welfare loss. The financial transfers of Sectoral Approach are targeted towards some consumers and some industries while the ones from Global Cap are higher in relative terms and spread over all consumptions. We show that an approach uniquely based on differentiated carbon prices would be Pareto dominated by the proposed approach.

We also compare Sectoral Approach with an EU-only scenario. This Eu-only scenario reflects some of the expected features of the EU-ETS 2013-2020 namely, the inclusions of free allocations based on capacities for exposed sectors. We show that sectoral Approach better address the competitiveness issue than the EU-only. Furthermore, with EU-only, because of leakage, the CO_2 price level to achieve the 20% reduction target in the EU is lower than with Sectoral Approach. This means that the fraction of revenues from permits allocated to developing countries to achieve a given carbon efficiency target can be much lower with Sectoral Approach than with the EU-only scenario. This would facilitate the needed political support to achieve the desired financial transfers associated with Sectoral Approach.

At this point our model remains quite simple to highlight our construction of an original sectoral approach and our evaluation methodology. It would be interesting to apply our framework in more comprehensive models such as with the CGE models elaborated by CIRED-IMACLIM (Sassi et al., 2007) or the MIT EPPA(Paltsev et al., 2005). A step in that direction is made by Hamdi-Cherif et al. (2009) with IMACLIM.

The paper is organized as follows: the structure of the model and the three scenarios studied are first described (section 2); we compare our proposal with other schemes (section 3) and formalize our methodology (section 4); the model is calibrated (section 5) and its results discussed (section 6). Section 7 concludes on the implementability of our scheme.

2 Model

We consider two countries: EU (home) and China (foreign) and three goods: electricity, cement and steel. These goods are assumed totally differentiated and goods' markets are only related via the CO_2 price. We abstract from substitutability between goods (steel and cement) and vertical relations (electricity as an input for steel and cement). The structure of the model is graphically represented on figure 1. A detailed analytical description of assumptions and scenarios is done below for one good.

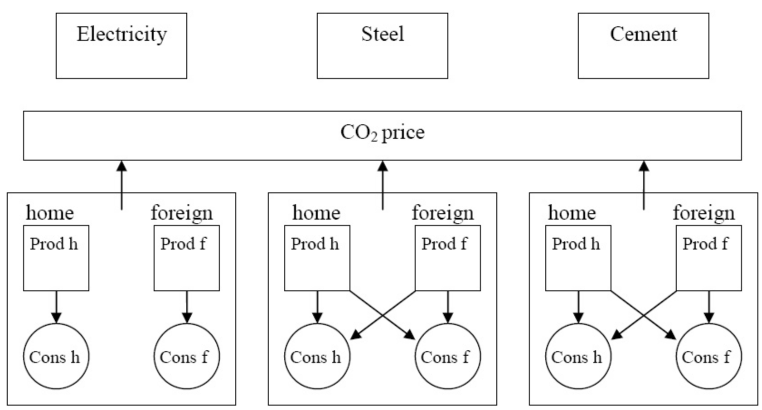

Figure 1: The structure of the model.

There are two countries $m = h, f$ (home and foreign). In each country there is a unique price for the good, the inverse price function is $P_m(Q_m)$ where Q_m is the aggregate quantity consumed in market $m = h, f$. There are n_m symmetric firms,

$i = 1..n_m$ located in country $m = h, f$; in each country firms can sell the good on the two markets. Firm $i = 1..n_m$ produces x^i for its market m and exports y^i to the other market. The aggregate quantity produced by firms m and sold in country m is $X_m = \sum_{i=1..n_m} x^i$ and the quantity sold in the other country is $Y_m = \sum_{i=1..n_m} y^i$ so:

$$Q_h = X_h + Y_f, Q_f = X_f + Y_h.$$

There are two ways for a firm to reduce emissions: to reduce its production or to reduce its emission rate. A cleaner technology with a lower emission rate has a higher variable cost (gross of emissions expenses). In a given country $m = h, f$, the variable cost of firm $i = 1..n_m$ is $c_m(u^i)$ where u^i is its emissions rate. The variable cost $c_m(u^i)$ is decreasing for $u^i < u_{m0}$ and convex. The emission rate u_{m0} is the reference emission rate when no abatement are done, $c'(u_{m0}) = 0$. The transport cost from country h to country f (resp. from f to h) is t_{hf} (resp. t_{fh}).

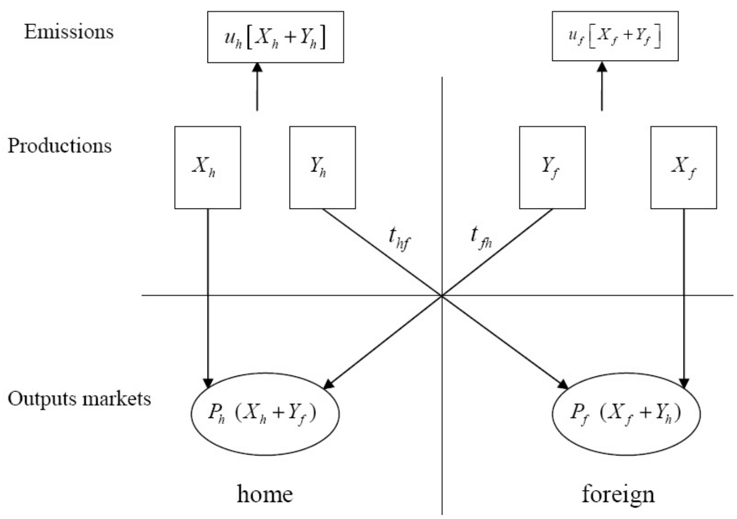

Figure 2: The product flows in a given sector.

The price of emissions in country $m = h, f$ is σ_m. The profit of a firm $i = 1..n_m$ is:

$$\pi_i^m = P_m x^i + P_l y^i - \left(c_m\left(u^i\right) - \sigma_m u^i\right)\left(x^i + y^i\right) - t_{ml} y^i + \sigma_m \epsilon_m^i, \text{ with } l \neq m; \quad (1)$$

where ϵ_m^i is the quantity of free allocation each firm received in country m. These free allocations could be 'output based', i.e. proportional to production quantities x_i or y_i. The scenarios considered differ relatively to the allocations rules, the effect of output based policy on the choice of production and technology are presented in appendix 2.

In each market firms compete *à la* Cournot by choosing quantities to maximize their profit.

Each firm chooses its emissions intensity u^i. An important feature of the model is that the emission rate u^i chosen by a firm is solely determined by the price of emissions.

For each good, all firms in a country adopt the same emissions rate $u_m(\sigma_m)$ which minimizes the net variable cost $c_m(u_m) + \sigma_m u_m$, it is the solution of:

$$\sigma = -\frac{\partial c_m}{\partial u}\left(u_m(\sigma)\right). \tag{2}$$

2.1 Specifications

For simulations we use linear demand functions:

$$P_m = a_m - b_m Q_m,$$

and costs that are linear with respect to output quantities and quadratic with respect to emission rates:

$$c_m(u_m) = c_{m0} + \frac{\gamma_m}{2}\left(u_{m0} - u_m\right)^2.$$

For a price σ of emissions the cost minimizing emissions rate is:

$$u_m(\sigma) = u_{m0} - \frac{\sigma}{\gamma_m}. \tag{3}$$

The implementation of a CO_2 price has two implications: emissions generate a unit cost for permits, $\sigma u_m(\sigma)$, and the cleaner technology generates an increase for the unit production cost, $\Delta c_m = c_m\left(u_m(\sigma)\right) - c_{m0}$. Figure 3 illustrates the choice of abatement (per unit produced) ν_h and ν_f of home and foreign firms with $\nu_m = u_{m0} - u_m$. In Figure 3, the marginal abatement cost of foreign firms is smaller than the home firms one: $\gamma_f < \gamma_h$. The increase Δc_m of marginal costs net of emissions costs is represented by the areas of triangles $OB\nu_f$ and $OA\nu_h$. As can be graphically seen, foreign firms choose a higher abatement level than home ones and their marginal cost net of emissions costs increases more than the home firms one—although their total cost change $\Delta c_f + \sigma u_f$ could be smaller. The parameter γ_m could be inferred from an estimation of $c_m(u_m(\sigma))$ for a given σ and c_{m0}.

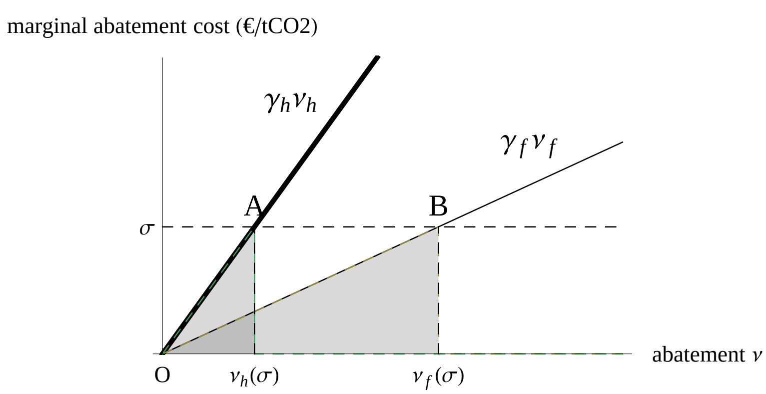

Figure 3: CO_2 price and emissions rate.

The equilibrium quantities in each market are derived assuming Cournot competition. These quantities are:

$$X_h = \frac{n_h}{b_h(N+1)} \left[a_h - (n_f + 1)\, C_h + n_f C_f\right] \tag{4}$$

and

$$Y_f = \frac{n_f}{b_h(N+1)} \left[a_h - (n_h + 1)\, C_f + n_h C_h\right] \tag{5}$$

assuming both types of firms produce. C_h and C_f stand for marginal costs, these differ according to scenarios. Similar formula holds for the foreign market.

2.2 The scenarios

Four scenarios are compared:

- **BAU** (Business As Usual): in the EU and in China there is no regulation of emissions, $\sigma_m = 0, m = h, f$.
- **Global Cap**: there is a uniform CO_2 price worldwide: $\sigma_h = \sigma_f$ and no free allocations, $\epsilon_m = 0$ for $m = h, f$.
- **Sectoral Approach**: there is a standard cap and trade with 0% free allocations in each sector in the EU; Chinese firms are subject to the following system:
  - For electricity, financial transfers from EU revenues (30% of total revenues) exactly compensate the total increase in costs resulting from the abatement Δc_f, the production is unchanged from BAU; the implicit CO_2 price to obtain this abatement is derived for the sake of comparison (cf appendix B).
  - For cement and steel, Chinese firms have to buy permits from the Chinese government at the EU price ($\sigma_f = \sigma_h$), there is no cap for these permits. For the domestic production in cement and steel, Chinese firms received output-based free allocations based on the relative benchmark $u_f(\sigma)$ that is, $\epsilon_f^i = u_f(\sigma)x^i$ in these sectors (cf appendix A). The profit of a Chinese firm in cement and steel in this scenario is :

$$\pi_j^f = P_f x^j + P_h y^j - c_f\left(u_f(\sigma_h)\right)(x^j + y^j) - \left(t_{hf} + \sigma_h u_f(\sigma_h)\right) y^j. \tag{6}$$

- **EU only**: there is a cap and trade in EU similar to the current EUETS and no regulation of emissions in China. In the EU, there is no free allocation for electricity producers but an output based policy in cement and steel. In these sectors, firms received free allocation according to their production $\epsilon_h^i = \alpha(x^i + y^i)$ which influences their choice of production but not their abatement (see appendix A). We specifically assume that all permits are freely allocated so $\alpha = u(\sigma_h)$.

3 Comparison of Sectoral Approach with other sectoral approaches and with border tax adjustment

To better understand the originality of our proposition it is worth comparing it with several related schemes of emissions regulation.

A proposition that has been much debated to address the issues of leakage and competitiveness is Border Tax Adjustment (Ismer and Neuhoff, 2007; Godard, 2007; Fisher and Fox, 2007). Within such a scheme, imported quantities are taxed and exported quantities are subsidized in order to compensate for the difference due to the CO_2 price. The import tax is the EU CO_2 price times a benchmark emission rate which has to be determined. This emission rate is usually fixed as the best available technology even if foreign firms technologies are much less efficient. The major distinctions with our approach are (i) BTA taxes firms imported *production* whereas Sectoral Approach taxes *emissions*, (ii) taxes are levied by the importing country with BTA and by the exporting country with Sectoral Approach, (iii) there is no regulation on foreign firm local production with BTA while there is with Sectoral Approach. The implication is that foreign firms do not modify their production technology with a BTA whereas they do with Sectoral Approach. If foreign firms may reduce their import taxes when their emissions are lower than the benchmark, BTA does provide for this incentive (see Godard, 2007).

There have been a large number of proposals under the terms "sectoral approaches". An extensive project led by the CCAP with support by the European Commission was designed to provide a "proof-concept" about the feasibility of sectoral approaches (Center for Clean Air Policy, 2009). Our approach may be seen as a combination of their "transnational sectoral approach", for cement and steel, and their "sectoral bottom-up approach", for electricity. In cement and steel firms are subject to a uniform CO_2 price but the national schemes differs: absolute targets in the EU, intensity targets in China. The intensity target is implemented through an output-based allocation policy (see appendix A) that ensures that marginal abatement cost are equalized. For electricity, there is no uniform CO_2 price. In this sector, Sectoral Approach is close to a NAMA, it seeks to implement a global benchmark for the Chinese electricity sector lower than BAU for the whole industry through eliciting individual projects up to some given budget provided by the EU.

The IEA has also explored a large variety of sectoral approaches (Baron et al., 2009). In their latest publication (International Energy Agency, 2009) they compare a scheme based on a cap and trade in industrialized countries and intensity targets in developing countries, with a uniform CO_2 price. This is also the route followed by the Cement Sustainability Initiative (World Business Council for Sustainable Development, 2009) and by Hamdi-Cherif et al. (2009). These models are based on large data sets so as to make simulations over horizons up to 2050. The data sets typically include several technologies for the electricity sectors, and sometimes for the cement sector, and technological innovation such as the availability of carbon capture and sequestration at some time in the future. The CSI model is limited to the cement sector while the other two include many more sectors. The major result from these models is that the introduction of intensity targets, relative to a uniform CO_2 approach, will not reduce that much growth in the industrialized countries while it will considerably facilitate growth in developing countries between 2010 and 2030. Because of their general nature these models are not designed to cope with imperfect competition in international trade. Competitiveness issues are not considered. These models are also less precise in terms of where the transfers come from and how they affect the economy. In both standpoints, our model completes the ongoing argumentation for an "implementable" sectoral approach.

4 Equity and efficiency of Sectoral Approach: formalizing the issues

The schemes that we propose are second-best regulation of CO_2 emissions. A first-best approach would implement an international tradable permits market (Tirole, 2009). Within such a scheme equity issues are dealt through the initial allocations to countries, which amounts to financial transfers.

Some authors argue that such a scheme would imply unrealistic amounts of financial transfers from industrialized to developing countries. If financial transfers are not possible, a second best scheme, with differentiated carbon prices, should be implemented (Chichilnisky and Heal, 1994). It will now be shown that Sectoral Approach may be interpreted as a compromise between these two views so as to balance efficiency with equity.

For simplicity the discussion will focus here on the electricity sector, but the results can easily be extended to a multi-sector model. Suppose a perfectly competitive sector and abstract from the rest of the economy. The utility of a country, without environmental damage, can be derived from the linear demand function (cf section 2.1) as:

$$\text{for } m = h, f \text{ we have } U_m(q_m, u_m, R_m) = (a_m - 0.5 b_m q_m)\, q_m + R_m - c_m(u_m) q_m, \quad (7)$$

where q_m is the quantity of good consumed in country m, and R_m is the initial endowment of a composite, not polluting and tradable good which is the numéraire; $c_m(u_m)$ is the quantity of numéraire needed to produce one unit with u_m emissions. The emission cap $\bar{e}$ is fixed.

We discuss three different approaches which respectively implement in this reduced model (i) differentiated CO_2 prices, (ii) Global Cap, (iii) Sectoral Approach. The methodology is summarized in table 1. Observe that efficiency and equity considerations are not separated in the first and third approaches.

Differentiated CO_2 prices	Global Cap	Sectoral Approach
• no transfers • national CO_2 price and emissions are simultaneously determined in connection with equity purposes	• unique CO_2 price to obtain a world cap at minimum cost • allocate initial allowances for equity purposes	• efficiency concerns in industrialized countries through cap and trade • equity concerns in developing countries through prices considerations • transfers from industrialized to developing countries through NAMAs
$\bar{e} \geq e_h + e_f$ and for $m = h, f$: $\max U_m$ s.t. $e_m \geq u_m q_m$	$\max U_h + U_f$ s.t. $\bar{e} \geq e_h + e_f$	$\max U_h$ s.t. $\bar{e} \geq e_h + e_f$; $p_f \leq p_{BAU}$ and $u_f = \phi(transfers)$

Table 1: Efficiency and equity, comparison of scenarios.

Case 1 (differentiated carbon prices): Without international financial transfer, the cap $\bar{e}$ can be reached by any allocations (e_h, e_f) with $e_h + e_f = \bar{e}$. Each country $m = h, f$ has to set its production and its technology given its emission constraint, it solves

$$\max_{q_m, u_m} U_m \text{ such that } e_m \geq u_m q_m$$

In this case, CO_2 prices are different, and in each country optimal production and emission rates satisfy

$$p_m = c_m(u_m) + \sigma_m \text{ and } c'_m(u_m) = \sigma_m. \tag{8}$$

The price of the good encompasses the full cost of the emissions' cap, and marginal abatement cost equalizes the respective carbon price. This scheme is depicted by the dotted line in figure (4), at the extreme—where the dotted line meet the axis—one country makes all effort and the other none. This corresponds to point C.

Case 2 (Global Cap): Assume transferable utilities through financial transfers. The total utility of both countries $U_h + U_m$ is maximized with a unique CO_2 price, $\sigma_m = \sigma_h$.[1] The total utility is $\max[U_h + U_f]$ and transfers allow to distribute this sum between the two countries, the CO_2 price does not depend on the transfers because

[1]We consider the unweighted sum of countries' utilities $U_h + U_m$. More generally one can consider a weighted sum $U_h + \lambda U_f$ with $\lambda \in [0, +\infty[$ to obtain all Pareto allocations. If $\lambda \neq 1$ the corresponding

of the linearity assumption on the numéraire. This is depicted by the straight line in figure 4.

This global cap situation coincides with the curve of differentiated CO_2 prices at point A where there is no transfer and carbon prices are equalized.

Case 3 (Sectoral Approach): With our sectoral approach, the quantity produced in country f is maintained at the BAU level q_{fBAU} and any reduction of u_f is financed by country h. The financial transfer from country h to producers in country f is:

$$T(u_f) = (c_f(u_f) - c_{f0})\, q_{fBAU}. \tag{9}$$

Country f utility is kept at the BAU level:

$$U_f(q_{fBAU}, u_f, R_f + T(u_f)) = U_f(q_{fBAU}, u_{f0}, R_f).$$

And the utility of country h is $U_h\left(q_h, u_h, R_h - T(u_f)\right)$. The constraint is

$$\bar{e} \geq u_h q_h + u_f q_{fBAU}.$$

This scheme is represented by the thick vertical line in figure 4. Country h has to decide how much to abate domestically and abroad.

We now derive an important property of Sectoral Approach: it implements a uniform CO_2 price for abatement decisions and a differentiated CO_2 price for output pricing decisions.

Proposition: *The policy that maximizes U_h with $\bar{e} \geq u_h q_h + u_f q_{fBAU}$ is to equalize the marginal abatement costs:*

$$c_h'(u_h) = c_f'(u_f).$$

Proof. Country h chooses q_h, u_h and u_f so as to maximize

$$U_h\left(q_h, u_h, R_h - T(u_f)\right) \text{ s.t. } \bar{e} \geq u_h q_h + u_f q_{fBAU}.$$

Thus, with the expression (7) of a country utility the price of good is such that:

$$\sigma u_h = \frac{\partial U_h}{\partial q_h} = p_h - c_h(u_h).$$

And the domestic technology is such that:

$$\sigma q_h = \frac{\partial U_h}{\partial u_h} = c_h'(u_h) q_h.$$

optimum requires the transfer of all the numéraire from one country to the other so that one country only consumes electricity. Because of the assumption of a constant marginal utility from the numéraire there are an infinite number of Pareto optimal allocation associated with $\lambda = 1$. To avoid this, and ensure that any Pareto allocation correspond to one and only one λ, we could have used concave transformations of the utility functions introduced, the argument would be similar.

And with the expression (9) of the financial transfer, the technology abroad satisfies

$$\sigma q_{fBAU} = \frac{\partial U_h}{\partial R_h}\frac{\partial T}{\partial u_f} = \frac{\partial T}{\partial u_f} = c'(u_f)q_{fBAU}$$

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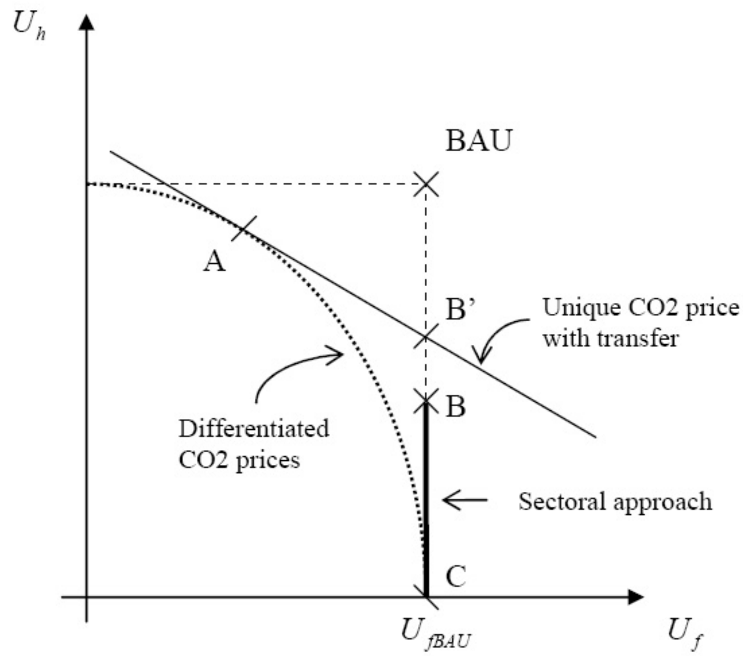

Figure 4: Second best policy

The discussion may be summarized as follows (see figure (4)). Global Cap without financial transfers would deliver point A. Equity issues, in what the objective is to maintain China utility at the BAU level, suggest differentiated carbon prices, and delivers point C. Sectoral Approach, with an identical objective, involves some financial transfers and delivers point B. Point B balances equity (same utility as C in China) and a minimal global efficiency loss (B is close to B' the unachievable first best with transfers). In section 4, our calibrated model will be used to quantify this formal discussion.

5 Calibration of the model

The data used to calibrate the strategic interactions in each sector are summarized in Table 5. These data are very rough guesses for the period 2015-2020 coming from interviews of industry experts. These experts were asked to use their best judgments to "feed our model". This led to some heroic simplifications in particular with respect to abatement curves. The exploration of the proposed scheme in a long term computational general equilibrium model would be the natural next step to pursue. This is precisely the route followed by Hamdi-Cherif et al. (2009) using the CIRED-IMACLIM model.

In our simplified static model, in each sector there are market sizes, number of players, price elasticity, unit variable costs and transport costs. From this and the Cournot assumption we can get the imports flows and the unit price in the "Business as usual" scenario. Transport costs are such that there are no exchanges in electricity, only flows from China to EU in cement and steel.

Electricity is almost perfectly concentrated. Steel and cement are more oligopolistic. The demand is the least elastic in electricity, then in cement and then in steel. In electricity and steel the variable costs are lower in China than in the EU, they are equal in steel.

We shall come back to some of these assumptions in the discussion.

Parameters of the Cournot models									
2015-2020	Electricity			cement			steel		
	unit	EU	China	unit	EU	China	unit	EU	China
market size	Twh	3 600	6 600	Mt	250	1 200	Mt	200	400
market structure	# players	40	40	# players	8	12	# players	10	10
elasticity		0,4	0,2		0,3	0,3		0,6	0,6
unit cost	€/Mwh	60	40	€/t	45	35	€/t	300	300
@ 0€/t	tCO2/Mwh	0,37	0,76	tCO2/tcement	0,7	0,7	tCO2/tsteel	1,3	1,3
@ 30€/t	tCO2/Mwh	0,34	0,46	tCO2/tcement	0,60	0,60	tCO2/tsteel	1,00	1,00
+ unit cost	€/Mwh	0,5	4,5	€/t	1,5	1,5	€/t	4,45	4,45
transport cost	€/unit			€/t		35	€/t		31
price BAU	€/Mwh	64	46	€/t	73	48	€/t	346	360

Table 2: Calibration of the model

6 Measuring the benefits of Sectoral Approach

6.1 Sectoral Approach versus Global-Cap.

We precisely construct the two scenarios Sectoral Approach and Global Cap, which are the counterpart in this calibrated model of those discussed in section 4.[2] Note that some premises of Sectoral Approach are contingent to the EU context (20% emissions reduction target, 30% transfer). To be used as a benchmark, the total emissions of Global Cap is taken as the one which results from Sectoral Approach (see Table 3).

[2]Actually, Global Cap is not the first best option described in section 4 because of imperfect competition. A first-best would require the correction of this imperfection. Observe that Sectoral Approach in this regard could be welfare enhancing since intensity targets encourage production. However, we do not elaborate on this point and what we are interested in, in our simulations, is the relative positioning of our scenario.

Sectoral Approach	Global Cap as a benchmark
•(EU): cap and trade (target = 20% for 2020 versus 2005); imports in the EU abide to EU rules $\rightarrow \sigma_{EU}(CO_2) = 38€/t$	•World CO_2 cap is given: 26% drop; the utilities floors are given: (U_{EU}, U_{China})
• (China): intensity targets through output based in cement and steel; no change in price for electricity	• determine the unique CO_2 price to reduce emissions by 26% at minimum cost $\rightarrow \sigma_{world}(CO_2) = 22€/t$
• 30% of the revenues in EU permits is transfered to China as NAMAs in electricity →abatement goes from .76 to .54 tCO_2/Mwh World CO_2 in percentage drops by 26% Utilities are determined: (U_{EU}, U_{China})	• define the initial allowances (transfer) that would Pareto dominate Sectoral Approach (U_{EU}, U_{China})

Table 3: Methodology for comparing scenarios.

- The CO_2 target for the EU in Sectoral Approach is assumed to be a 20% reduction relative to BAU (a crude approximation of the commitment made by the EU for 2020 relative to 2005). The corresponding CO_2 price for the EU can be determined. It depends on the leakage rate associated with the sensitive sectors. The assumptions made in Sectoral Approach for these sectors make this calculation possible: imports into the EU are subject to the same regulation as firms in the EU (their emissions support a CO_2 price equal to the EU price). The electricity sector in China does not play any role. The model determines that the CO_2 price that will generate a 20% reduction in EU emissions is 38€/t.

- It is now assumed that 30% of the revenues from the permits in the EU are transferred to the electricity sector in China to compensate for the increase in total costs associated with the implementation of a CO_2 abatement in that sector. Following appendix A it can be determined that the emission rate in China for electricity will go down from .76 to .54 tCO_2/Mwh, which is equivalent to say that abatement policies in the Chinese electricity sector are based on an implicit CO_2 price of 22€/t. Taking everything into consideration into the total CO_2 reduction at the world level is computed to be 26%.

- To construct Global Cap we determine what uniform CO_2 price will achieve 26% reduction in CO_2 emissions worldwide. The corresponding price is 22€/t. The fact that this price is numerically close to the implicit CO_2 price for electricity in China in Sectoral Approach is coincidental.

We are now in a position to compare the efficiency and equity issues associated with these two scenarios.

Global cap puts much more abatement pressure in China than in the EU, Sectoral Approach reduces this asymmetry

Table 4 summarizes the results. Observe that the Global-Cap scenario puts more pressure in China than in the EU. This comes from our assumption that it is less costly to reduce CO_2 emissions in China (in electricity) than in the EU. From an efficiency point of view, Ward's comment mentioned in the introduction is important: one needs to abate CO_2 in energy production in the developing countries. It will be interesting to see how much cost efficiency is lost when going from Global Cap to Sectoral Approach. This is reflected by the fact that the CO_2 price associated with Global Cap (22 €/t worldwide) is significantly lower than with Sectoral Approach (38 €/t in the EU).

		CO2	
		price	% abatement / BAU
CO2 impact	**scenario**	€/t	Total
EU	**Global cap 22€**	22	12%
China		22	30%
All			26%
EU	**Sectoral approach**	38	20%
China			27%
All			26%

Table 4: Emissions and scenarios.

Global Cap involves large government transfers, Sectoral Approach low industry transfers.

Consider first the financial flows associated with Global Cap scenario (Table 5). The number of permits to be allocated through auctioning is defined by the world cap, namely a 26% reduction from BAU. These permits are allocated to EU and China through some rule that needs to be determined. We shall come back to this rule shortly.

The firms in each country buy permits according to their actual emissions at the world market price of 22€/t. In each sector, in each country, consumers buy some new quantities at the new prices (i.e. Chinese consumers now spend 68 MM€ more for their electricity bills than in BAU).The profits of the firms decrease relative to BAU (i.e. Chinese electricity firms have a loss in profits of 4.5 MM€). The revenues from the permits accruing to each country are recycled in each economy through some form of tax abatement. If the face value of permits allocated to a country differs from the amount paid by the firms in that country (respectively 32.6 MM€ and 99.4 MM€ in the EU and in China), there is a financial transfer that goes from one country to the other. It is usually said that one innocuous way to make financial transfers from industrialized to developing countries would be through the permit allocation process. In Table 5, the allocation is proportional to actual emissions: at this point there are no financial transfers.

Financial flows MM€	Elec		cement		Steel		total	
	EU	China	EU	China	EU	China	EU	China
consumers								
budget change (price*quantity)	- 15,3	- 68,0	- 2,4	- 10,0	- 2,0	- 3,4	- 19,6	- 81,4
firms								
variation sales	15,3	68,0	2,6	9,8	2,3	3,2	20,1	81,0
cost w/o CO2	9,4	1,1	0,1	3,2	0,9	5,1	10,4	9,4
CO2 cost dom	- 26,1	- 73,6	- 2,9	- 15,2	- 3,6	- 9,1	- 32,6	- 97,9
CO2 cost export	-	-	-	- 0,4	-	- 1,1	-	- 1,5
free allocation	-	-	-	-	-	-	-	-
financial transfers	-	-	-	-	-	-	-	-
profit change	- 1,3	- 4,5	- 0,3	- 2,6	- 0,4	- 2,0	- 2,0	- 9,1
state								
revenues from permits	26,1	73,6	2,9	15,5	3,6	10,3	32,6	99,4
free allocation			-	-		-		-
financial transfers		-		-		-	-	-
internal tax abatement							32,6	99,4

Table 5: Financial flows with a Global Cap scenario.

In Sectoral Approach the financial flows include explicit financial transfers. Moreover, there are free allocations to firms in cement and steel in China. The overall picture is given in table 6. We discuss the financial impacts for each player separately.

Financial flows MM€	Elec		cement		Steel		total	
	EU	China	EU	China	EU	China	EU	China
consumers								
budget change (price*quantity)	- 24,2	-	- 3,7	- 1,8	- 3,1	- 1,0	- 30,9	- 2,8
firms								
variation sales	24,2	-	4,2	1,4	3,6	0,5	31,9	1,8
cost w/o CO2	14,8	- 15,3	- 0,1	- 1,4	1,0	0,4	15,7	- 16,3
CO2 cost dom	- 41,2	-	- 4,6	- 25,8	- 5,2	- 13,9	- 50,9	- 39,7
CO2 cost export	-	-	-	- 0,5	-	- 1,5	-	- 2,0
free allocation	-	-	-	25,8	-	13,9	-	39,7
financial transfers	-	15,3	-	-	-	-	-	15,3
profit change	- 2,2	-	- 0,5	- 0,5	- 0,6	- 0,7	- 3,3	- 1,2
state								
revenues from permits	41,2		4,6	26,3	5,2	15,4	50,9	41,7
free allocation			-	- 25,8		- 13,9		- 39,7
financial transfers		15,3		-		-	- 15,3	-
internal tax abatement							35,7	2,0

Table 6: Financial flows with a sectoral approach.

European consumers would pay 50% more than in Global Cap (30.9 MM€ instead of 19.6 MM€). However, the extra bills for Chinese consumers are respectively zero in electricity and considerably reduced in cement and steel. Altogether their total bill is reduced from 81.4 MM€ to 2.8 MM€. This can be seen as subsidies for these basic products.

The profit of cement and steel EU firms is not much affected by the change since in both cases the competitiveness impact is expected to be low. The electricity EU firms suffer from the demand decrease (due to high competition the pass through rate is close to 100%). Chinese firms are better off with Sectoral Approach (no loss by construction in electricity, almost no demand decreases in cement and steel due to the output based mechanism) than with Global Cap. The small amount of these losses relative to BAU (approximately 3%) means that Sectoral Approach would certainly be easier to implement.

The net revenue the EU gets from the sales of permits is 37.7 MM€ with Sectoral Approach as compared to 32.6 MM€ with Global Cap. It is higher because of the higher price of permits. Sectoral Approach generates more money in the EU for R&D initiatives in spite of the 15.3 MM€ transferred to China.

The situation in China changes dramatically since with Sectoral Approach the transfers are "internalized" (only 2 MM€ tax abatement are available for redistribution) while with Global Cap the allocation of the 99.4 MM€ remains to be specified.[3] This amount will be even larger if the allocation of permits were related to GDP/head. Global Cap makes a very challenging bet on the capacity of governments in developing

[3]In our partial equilibrium approach, the way government revenues is recycled does not influence welfare; with a general equilibrium setting it would matter.

countries to manage the revenues of their permits.

Global Cap generates large equity issues, Sectoral Approach none.

The benefits of Sectoral Approach are expected to be in terms of equity, i.e. how the Chinese consumers are affected by the two scenarios. Table 7 compares the price increase and the quantity decrease in each sector and in each country relative to BAU.

With Global Cap, there would be a significant price increase in electricity and in cement in China, with corresponding quantity decreases, less so in steel because of the higher price elasticity in that sector.

By construction, there would be no change relative to BAU in electricity in China with Sectoral Approach, and minimal changes in cement and steel (recall that with an output based scheme there is some increase in unit costs after abatement even with free allocations).

This comparison is the major argument put forward against a uniform price system, given the incapacity of a government to centrally allocate subsidies to mitigate these price increases.

On the contrary, Sectoral Approach subsidizes pre-identified targets (Chinese consumers in electricity, cement and steel) and these consumers indeed benefit directly from the mechanism design.

		elec		cement		steel	
Consumption	scenario	price increase %	quantity decrease %	price increase %	quantity decrease %	price increase %	quantity decrease %
EU	Global cap 22€	12%	5%	19%	5%	7%	4%
China		30%	6%	27%	8%	7%	4%
EU	Sectoral approach	20%	8%	32%	9%	12%	7%
China		0%	0%	5%	1%	2%	1%

Table 7: Price and quantity impacts.

Overall Sectoral Approach balances efficiency and equity with manageable transfers.

While the two scenarios differ widely in terms of who gets what, it may be that the welfare cost to be paid for this difference be too high. To compare the welfare efficiencies of the two scenarios we compute, in each country, the net production costs, excluding the cost of permits but taking into consideration the fact that abatement cost in electricity in China are paid by the EU in Sectoral Approach, and the gross consumer surplus (cf section 4 for the formulation of the utility functions).

The results are detailed in Table 8, both in absolute (M€) and relative terms (%).

Welfare analysis M€	Utility		
	EU	China	All
BAU	407 100	1 049 955	1 457 055
Global Cap	403 078	1 024 711	1 427 789
Sect Ap	382 541	1 043 511	1 426 052

Welfare analysis %	Utility		
	EU	China	All
BAU	100	100	100
Global Cap	99,0	97,6	98,0
Sect Ap	94,0	99,4	97,9

Table 8: Welfare impacts of scenarios.

Consider first the changes in total welfares in the EU and in China. Global Cap (without transfers) puts less pressure on the EU than in China (1% versus 2.4%) while Sectoral reverses the pressure (6% versus 0.6%).

Consider now the total welfare, adding up EU and China. Because of the cost to reduce the CO_2 emissions by 26% the welfare decreases from 1 457 055 M€ for BAU to 1 428 676 M€ for Global-Cap.

The welfare associated with Sectoral Approach is lower than with Global Cap (in accordance with section 3). Yet the loss is amazingly small .2%!

Another way to look at these numbers is to say that Global Cap with a financial transfer of

$$1\,043\,511 - 1\,025\,491 = 18\,015 \text{ M€}$$

would Pareto dominate Sectoral Approach, point B' as depicted in figure 5. Recall that Sectoral Approach is based on a financial transfer of 15 283 M€ which may be considered as close to 18 015 M€. Yet 15 283 M€ represents 30% of the revenues of permits with the Sectoral Approach while 18 015 M€ represents almost 55% of these revenues with Global Cap. If these transfers are indeed made through the permit allocation process, this would mean that the Chinese government would now have approximately 115 MM€ to re-allocate internally.

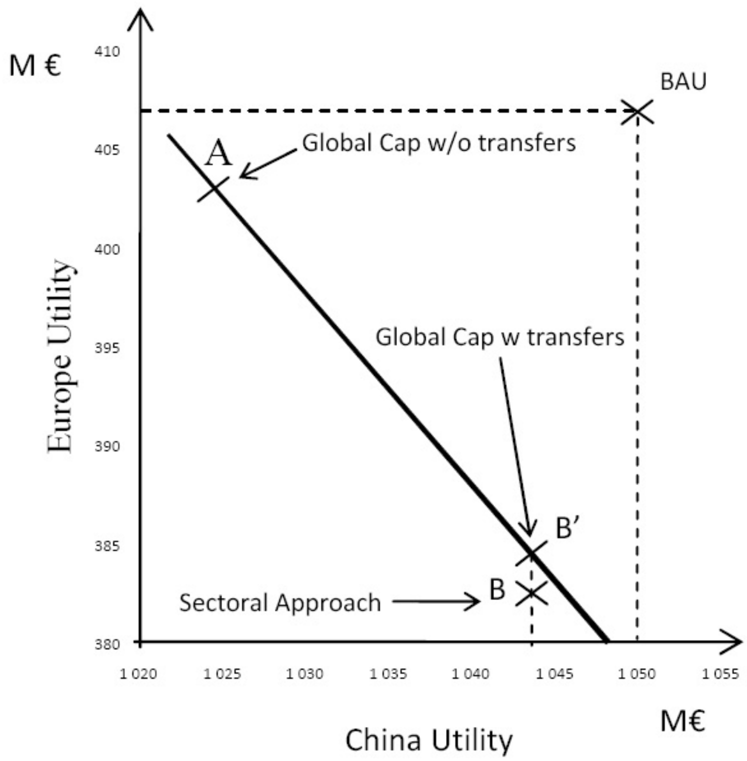

Figure 5: Efficiency of Sectoral Approach.

There is a simple way to summarize this discussion by bringing into the picture the arguments for and against a uniform CO_2 price (table 9).

Scenario	Global Cap w/o transfers	Differentiated CO_2 prices	Sectoral Approach
Equity	−	++	+
Cost efficiency	++	−	+

Table 9: Efficiency and equity, comparison of scenarios.

Global Gap is the best in terms of cost efficiency but without financial transfers it performs poorly in terms of equity. The amount of financial transfers to achieve equity goals seems very difficult to implement. The use of differentiated CO_2 prices could in principle solve equity issues but it creates important perverse effects in terms of abatement policies. Sectoral approach combines the respective benefits of these two approaches leaving aside the respective drawbacks: the abatement policies and the equity issues are addressed through different instruments.

We could directly apply the theoretical result of section 3, namely the amount of financial transfers to the electricity sector in China to bring the implicit CO_2 price at the EU level. This Sectoral Approach would be even closer to Global Cap in terms of total welfare.

On the other hand, a scheme purely based on differentiated CO_2 prices can physically not achieve a 26% CO_2 reduction worldwide while keeping the China welfare unchanged relative to BAU, simply because the EU emissions already represents no more than 20% of total emissions. This comes from the relative weights of the two economies in this model and need not be true in a more global one.

Note that in our sectoral approach the marginal abatement cost in the electricity sectors the EU and in China are different, respectively 38€ and 22€. To move in the direction of proposition 1 our construction should be changed to a lower target for EU emissions reduction and a higher percentage for transfers of EU revenues from permits. Such a change could be interpreted as a global Clean Development Mechanism (CDM) up to the point where marginal abatement costs are equalized. In a way, our scheme is compatible with such private financial transfers. Still one should be well aware of the practical limitations of CDM (Schneider, 2007; Sterk, 2008; Victor and Wara, 2008).

6.2 Sectoral Approach versus EU-only

While Sectoral Approach has some advantages relative to Global Cap as discussed in the preceding section, it also has advantages relative to EU-only.

Sectoral Approach eliminates competitiveness and leakage.

In EU-only scenario China remains at BAU while in the EU a mechanism close to Global-Cap is introduced with the major difference that cement and steel receive free allocations. Due to their international exposure, it may be assumed that these industries will not pass through the CO_2 price in their selling prices but only the fraction which is not free (this is the assumption made in the Cement Sustainability Initiative). A simple way to implement such a behavior in our model is to consider that an output based mechanism is used in which the output based rate is such that, at equilibrium, the amount of free allocations is equal to a sectoral relative benchmark, for simplicity we take $\alpha = u(\sigma)$ (all allocations are freely distributed).

		CO2					
		price	% abatement / BAU	leakage		Imports	
CO2 impact	scenario	€/t	Total	cement	steel	cement 14% BAU	steel 25% BAU
EU	EU-only	36	20%	21%	20%	18%	30%
China	BAU		0%	NB	NB	NB	NB
All			4%				
EU	Sectoral approach	38	20%	-37%	-39%	10%	23%
China			27%	NB	NB	NB	NB
All			26%				

Table 10: EU-only.

Under this scenario, the CO_2 price in the EU will decrease from its 38 €/t level with Sectoral Approach to 36 €/t. In spite of the output-based policy, the levels of imports increase both in cement and in steel because of the impact of abatement on unit costs. This increase of imports puts a downward pressure on the EU firms demand for emissions. Competitiveness of EU firms is affected (imports increase from 14% to 18% in cement and from 25% to 30% in steel), and there is leakage in terms of CO_2 emissions (21% for cement and 20% for steel).

The figures for imports and leakage rates go in the other directions with Sectoral Approach: decreases in imports and so negative leakage rates. Still the magnitude of the changes in imports remains small. Consequently the % in leakage rates are not significant.

The conclusion is clear, Sectoral Approach performs better than EU-only.

Sectoral Approach requires less financial transfers.

The fact that Sectoral Approach is almost neutral in terms of competitiveness and leakage means that to achieve the 20% reduction target in the EU one may set a higher CO_2 price (from 33€/t to 36€/t). It would also make it easier to go from a 20% reduction goal in the EU to a 30% goal because one may expect less lobbying from sensitive industries. Of course, the firms in the electricity sectors will pay more but in this sector, the pass through rate is close to 1.

Table 11 gives the total revenues from permits and its sources for the two scenarios. In some sense one can talk of a "double dividend" as one goes from EU-only to Sectoral Approach: the elimination of free allocations increases the revenues for the EU, and the elimination of the pressure from sensitive sectors allows an increase in the price of CO_2. Both factors make it easier to provide financial transfers to developing countries, a mere 30% compared to almost 40% with EU-only.

		MM € Revenues EU from permits			
Double Dividend	**scenario**	Total	elec	cement	steel
EU	**EU-only**	40	40	0	0
China	**BAU**	0		0	0
EU	**Sectoral approach**	51	41	5	5
China				1	2

Table 11: Double dividend.

7 Conclusions and limitations

This paper builds on the idea of sectoral approaches to propose a global architecture that integrates two sets of constraints: equity issues from developing countries (through financial transfers and intensity targets), and competitiveness issues from industrialized countries. It is shown that such a scheme satisfies these constraints without a substantial welfare loss, relative to a first best approach based on a uniform CO_2 price.

It would be interesting to test our Sectoral Approach and our methodology in more "realistic" models such as the ones discussed in section 3. This is a necessary step to explore the full relevance of our formal proposition, which is the main justification for leaving aside an approach purely based on different carbon prices and no financial transfers. It would also be interesting to detail the financial flows in such more comprehensive models. We believe that this is necessary to give full strength to a proposal.

As mentioned in the introduction our reference to developing countries should be refined at least to distinguish between emerging countries (such as Brazil, Russia, India, China...) and lower income countries that will be directly impacted by climate change (such as Africa, Bangladesh.... The former neither need nor ask for financial transfers, while these transfers are crucial for the latter. Our approach would also gain to be more explicit in this respect.

In parallel, it seems interesting to pursue the exploration in terms of implementation. Some directions for future work can be mentioned. Take for instance the cement sector, our approach differs from the one explored by the CSI: we take for granted that it is easy to monitor "measurable, reportable and verifiable" policies in that sector (Winkler, 2008) to the point that we explicitly embed all the cement plants in a global transnational approach. This is an extreme view. The fact that the cement market is concentrated, the fact that the major firms have very similar technologies, and the fact it is simple to monitor modern cement plants in terms of CO_2 emissions through independent auditing entities, these three facts make our assumption reasonable for a large share of the industry, and precisely for the share that is active internationally. This leaves aside a number of "old plants" such as vertical kilns (a substantial share of the industry in some countries). That part of the industry should indeed be left out and addressed through a policy similar to the one proposed in our model for the electricity sector.

An avenue for future work precisely concerns the policy suggested in that case: it is formalized in our model through an output based scheme using an implicit CO_2 price. This is convenient from an analytical point of view but clearly unsatisfactory from a policy perspective. A policy in which the financial transfer would be allocated to competitive projects using a cost/benefit analysis, the benefit being associated with CO_2 reductions, could be explored for various carbon intensive sectors, including deforestation. This top down approach would avoid the pitfalls associated with the project by project approach such as the one adopted with the MDP, in which a deep pocket is provided by the resale of permits on the EU CO_2 market and the benchmark is the BAU.

References

Baron, R., I. Barnsley, and J. Ellis (2008), "Options for integrating sectoral approaches into the UNFCCC."

Baron, R., B. Buchner, and J. Ellis (2009), "Sectoral Approaches and the Carbon Market." *IEA/OECD paper for the Annex I Expert Group on the UNFCCC, OECD/IEA, Paris.*

Center for Clean Air Policy (2009), "Status of Policy Findings from the Global Sectoral Study." *summary note.*

Chichilnisky, G. and G. Heal (1994), "Who should abate carbon emissions?: An international viewpoint." *Economics Letters*, 443–449.

Ellerman, D., F. J. Convery, and C. de Perthuis (2010), *Pricing Carbon, The European Union Emissions Trading Scheme:*. Cambridge University Press.

Fischer, C. (2001), "Rebating Environmental Policy Revenues: Output-Based Allocations and Tradable Performance Standards." *Resources For the Future, Discussion Paper*, 01 22.

Fisher, C. and A.K Fox (2007), "Comparing policies to combat emissions leakage: border tax adjustments versus rebates." *working paper, Resources for the Future, Washington DC.*

Godard, O. (2007), "Unilateral european post-kyoto climate policy and economic adjustment at eu borders." *École Polytechnique, Paris*, cahier DX-07-15.

Godard, O. (2009), "Quelle architecture internationale pour la politique climatique ?" *École Polytechnique, Paris.*

Hamdi-Cherif, M., C. Guivarch, and P. Quirion (2009), "Sectoral targets for developing countries: Combining "Common but differentiated responsibilities" with "Meaningful participation" ." *Working Paper CIRED.*

International Energy Agency (2009), "How the energy sector can deliver on a climate agreement in Copenhagen. Special delivery excerpt of the World Energy Outlook 2009 for the Bangkok UNFCCC meeting." *OECD/IEA, Paris*, octobre.

Ismer, R. and K. Neuhoff (2007), "Border tax adjustment: a feasible way to support stringent emission trading." *European Journal of Law and Economics*, 24, 137–164.

Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J.R. McFarland, M.C. Sarofim, M.O. Asadoorian, and M.H.M. Babiker (2005), "The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4." *MIT Joint Program on the Science and Policy of Global Change.*

Parliament, European (2009), "Directive 2009/29/ec of the european parliament and of the council of 23 april 2009 amending directive 2003/87/ec so as to improve and extend the greenhouse gas emission allowance trading scheme of the community."

Quirion, P. (2007), "Comment faut-il distribuer les quotas échangeables de gaz à effet de serre." *Revue française d'économie*, 22, 129–164.

Sassi, O., R. Crassous, J.-C. Hourcade, V. Gitz, H. Waisman, and C. Guivarch (2007), "Imaclim-R : a modelling framework to simulate sustainable development pathways." *International Journal of Global Environmental Issues*, accepted.

Schneider, L. (2007), "Is the CDM fulfilling its environmental and sustainable development objec-tives? An evaluation of the CDM and options for improvement." *"Oko-Institut, report for the WWF.*

Sheeran, K.A. (2006), "Who should abate carbon emissions? A note." *Environmental and Resource Economics*, 35, 89–98.

Sterk, W. (2008), "From Clean Development Mechanism to Sectoral Crediting Approaches–Way forward or wrong turn." *JIKO Policy Paper*, 1, 2008.

Stern, N., S. Peters, V. Bakhshi, A. Bowen, C. Cameron, S. Catovsky, and D. Crane (2006), "Stern Review: The economics of climate change."

Sterner, T. (2009), "Climate and poverty alleviation time for a truly global deal." *X-HEC Economic Policy Seminar*, October.

Tirole, J. (2009), "Politique climatique : une nouvelle architecture internationale." *Conseil d'Analyse Economique.*

Victor, D. and M. Wara (2008), "A Realistic Policy on International Carbon Offsets." Technical report, Working Paper 74. Stanford, USA.

Wara, M. (2007), "Measuring the clean development mechanism's performance and potential." *UCLA L. Rev.*, 55, 1759.

Winkler, H. (2008), "Measurable, reportable and verifiable: the keys to mitigation in the Copenhagen deal." *Climate Policy*, 8.

World Business Council for Sustainable Development (2009), "A sectoral approach." *Cement Sustainability Initiative.*

A Technology choice, CO_2 price and output based allocations

We briefly expose how technology choice and output base allocations interact: (i) with a fixed CO_2 price and (ii) with fixed emissions cap and an endogenous CO_2 price. Fischer (2001) and Quirion (2007) provide a detailed analysis.

(i) Consider the incentive of a firm with net variable cost $c(u)$. If α is the rate of output based free allocation, the firm receives α permits for each unit produced. For a CO_2 price σ its profit on a given market is:

$$\pi(q, u) = Pq - (c(u) + \sigma u)q + \sigma\alpha q = Pq - [c(u) + \sigma(u - \alpha)]q.$$

The firm chooses its production q and its technology u to maximize its profit. The optimal u minimizes its net variable cost; it is $u(\sigma)$ that solves $c'(u) = -\sigma$.

The choice of technology is neither affected by the production q nor by the allocation policy α. The output base rate α has no direct influence on this choice but on the production. The Cournot equilibrium production is increasing with the output based rate. When α increases the "pass-through" rate decreases, i.e. the output price is less affected by the CO_2 price.

The output based rate can be chosen according to various criteria, this rate is often considered as defining a benchmark technology because firms that performs better ($u < \alpha$) are net seller of permits whereas more pollutant firms are net buyers. The ratio $\alpha/u_m(\sigma)$ represents the share of permits that are freely allocated. In the scenario *EU only* we set α so that the quantity of free allocations is half of the BAU emissions. In Sectoral Approach we consider a complete recycling of permits: α is chosen so that all permits are freely allocated and the direct cost σuq is canceled i.e.

$$\alpha = u(\sigma).$$

With such a policy the direct effect of CO_2 pricing on the net variable cost is canceled but there is still an indirect effect–the variable cost $c(u(\sigma))$ is higher than the BAU cost $c(u(0))$. This explains the expression of Chinese firm profit (6) in Sectoral Approach.

(ii) With a cap and trade system, the CO_2 price is endogenous and clears the market for emissions permits: it ensures that the cap, denoted $\bar{e}$, is equal to the aggregate quantity of permits demanded. Sectoral emissions are the quantity produced times the emissions rate $\bar{e} = u(\sigma)q$. With an output based policy the production increases so the efficiency of the technology should be higher and this is done via a higher CO_2 price. Therefore, with a cap and trade system an output based policy has an indirect effect on the technology which is cleaner to compensate for the rise of production.

B Revenue recycling and technological transfer

Technological transfer can be represented in a very simple way within our framework. We consider that technological transfer is done in the Chinese electricity sector.

The variable cost of Chinese electricity producers is $c_f(u_f)$ and u_{f0} is the BAU rate of emissions. The technological transfer is done by financing the use of a cleaner technology with $u_f < u_{f0}$; the increase of variable cost $c_f(u_f) - c_{f0}$ is paid to Chinese firms. This policy has no effect on the perceived cost of a Chinese firm:

$$\pi = pq + c_f(u_f)q + (c_f(u_f) - c_{f0})\, q = pq - c_{f0}q,$$

thus, the production of Chinese electricity producers is not affected by the transfer. The total financial transfer amounts to

$$\Delta = (c_f(u_f) - c_f(u_{f0}))\, q_{BAU}.$$

For the sake of illustration, we consider that Δ is set at 30% of the revenue from the permits markets in the EU, this gets the abatement induced in the electricity sector $u_{f0} - u_f(\Delta)$, we can then determine the "shadow" permit price corresponding to this transfer, that is, the price $\sigma(\Delta)$ such that $\sigma = -c_f'(u_f)$ where $c_f(u_f) = c_{f0} + \Delta/q$.

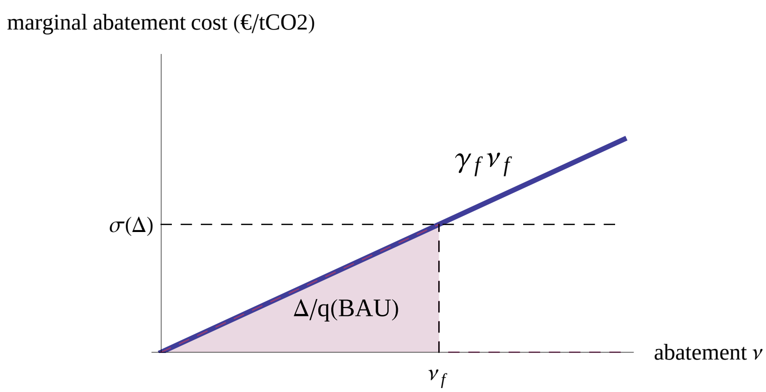

Figure 6: Technological transfer