The costs of a global climate agreement for China

A tale of carbon price, timing of emissions reduction and quota allocation

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Abstract. The recent Conferences of the Parties illustrate that a lot of uncertainties still remain about future international climate policy architecture. This paper considers the economic consequences of a binding global agreement on the Chinese economy. China is indeed a key player in climate negotiations as the first CO_2 world emitter, very carbon-intensive and fast growth economy.

We visit the question of the Chinese mitigation costs by considering different policy designs based on a uniform global carbon price that vary according to *(i)* the temporal profile of carbon emissions reductions and *(ii)* quota allocation schemes. To do so, we use the CGE model IMACLIM-R that represents the second best nature of economic interactions and the inertias that limit the flexibility of adjustments, a crucial dimension for emerging economies when envisaging large structural change over the course of the century. We find that combining delaying the efforts with an adequate quota allocation scheme can be benefic for China. However, mitigation costs remain important, which suggests the recourse to policies and measures in addition to carbon pricing to help smoothing the necessary shift to a low carbon society.

Keywords: Climate policy**;** Mitigation costs; China; when flexibility; where flexibility; CGE; second best.

JEL classification: *D58, Q43, Q54*

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I. Introduction

The second commitment period of the Kyoto protocol has officially entered into force since January first 2013 and it will last eight years. But a lot of uncertainties still remain about the future international climate policy architecture. An “Ad Hoc Working Group on the Durban Platform for Enhanced Action” has been established at COP-17 in Durban, to prepare a global agreement which would become effective in 2020 (UNFCC, 2012). The “Durban platform” agreement is innovative to the extent that it includes for the first time developing countries such as China and India in a legally binding treaty to address global warming.

The participation of emerging economies in mitigation efforts is necessary to meet any ambitious global climate target. Their share of global greenhouse gas emissions is indeed continuously and rapidly increasing as a direct consequence of their fast economic growth. There is scientific consensus to say that if developing countries continue on their current trend, their emissions alone will surpass the global emission trajectory necessary to reach any ambitious stabilization goal (Blanford et al., 2009; Clarke et al., 2009; Metz et al., 2002).

Although not yet officially involved in a binding common climate architecture in terms of emissions reduction, forty-three developing countries have announced national commitments at the end of the COP-15 in Copenhagen (UNFCC, 2009) and “anchored” those in the Cancun agreements (UNFCC, 2010). These national pledges have been assessed in many studies which conclude that they are far from complying with ambitious reduction targets (Rogelj et al., 2010; Stern and Taylor, 2010; Dellink et al., 2010; den Elzen et al., 2011, UNEP, 2011). These ambitious targets are still put on the negotiation table, and we are still talking about limiting global mean temperature increase to less than 2°C above pre-industrial levels in the official texts like in the Copenhagen Accord (UNFCC, 2009) or the Cancun Agreements (UNFCC, 2010).

Thus, faced with the necessity of reaching an acceptable global target in terms of temperature increase with regard to the pre-industrial area and the inadequacy of the regional pledges to reach such a target, this paper considers the economic consequences of a binding global agreement[1]. We consider an agreement based on carbon pricing, which is the more standard instrument to trigger decarbonization processes, but raises concerns about its effects in emerging, carbon

[1] The climate policies considered in this article lead to an increase of the temperature of +2.5°C above the pre-industrial level.

intensive economies (Hamdi-Cherif et al., 2011). We focus the analysis on China, a key player in climate negotiations (Papa and Gleason, 2012; Narlikar, 2010). China is indeed the first CO_2[2] emitter since 2006 (Olivier et al., 2012) with an average growth rate of its emissions of 10% per year over the last decade (World Bank, 2012). Nevertheless, this carbon-intensive economy has an income which is still much lower than that of developed countries and has historically less contributed to current greenhouse gas concentrations. This can explain why China is reluctant to engage in a common and uniform mitigation effort, and why it relies on the "common but differentiated responsibilities" principle of the UNFCC (van Ruijven et al., 2012).

The purpose of this paper is to analyze the Chinese macroeconomic effects of stylized global climate policy architectures that are consistent with this principle. We visit the question of the Chinese mitigation costs by considering different policy designs based on a uniform global carbon price that vary according to *(i)* the temporal profile of carbon emissions reductions and *(ii)* quota allocation schemes.

To do so, we use the Computable General Equilibrium (CGE) model IMACLIM-R that represents the second best nature of economic interactions and the inertias that limit the flexibility of adjustments, a crucial dimension for emerging economies when envisaging large structural change over the course of the century (Waisman et al., 2012).

After the presentation of this modeling framework (section II), we analyze the determinants of the Chinese mitigation costs that are generated by a benchmark global scenario (section III). We then investigate (in section IV) the dependence of these costs on two time profiles of emissions reductions (early vs. delayed mitigation action) before considering (in section V) the effects of two stylized types of quota allocation schemes (*Contraction &Convergence* and *Contraction but Differentiated Convergence*). After the conclusion (section VI), we show in the Appendix the results obtained for a larger set of time profiles of emissions reductions.

II. The modeling framework

1. The IMACLIM-R model: a modeling framework to represent a second best world

In this paper, we adopt the energy-economy model Imaclim-R, which has the specificity of incorporating some features of second-best economies (imperfect foresight, inertia of technical

[2] CO2 emissions from fossil fuel use and industrial processes (cement production)

systems, imperfect markets) in a CGE framework. It adopts a dynamic, multi-region and multi-sector representation of the world economy[3] and provides a consistent vision of economic and energy trajectories in yearly steps over 2010-2100. This is done through a recursive structure which structures a systematic exchange of information between a top-down *annual static equilibrium* providing a snapshot of the economy at each yearly time step, and *bottom-up dynamic modules* informing on the evolution of technical parameters between two equilibria (Figure I).

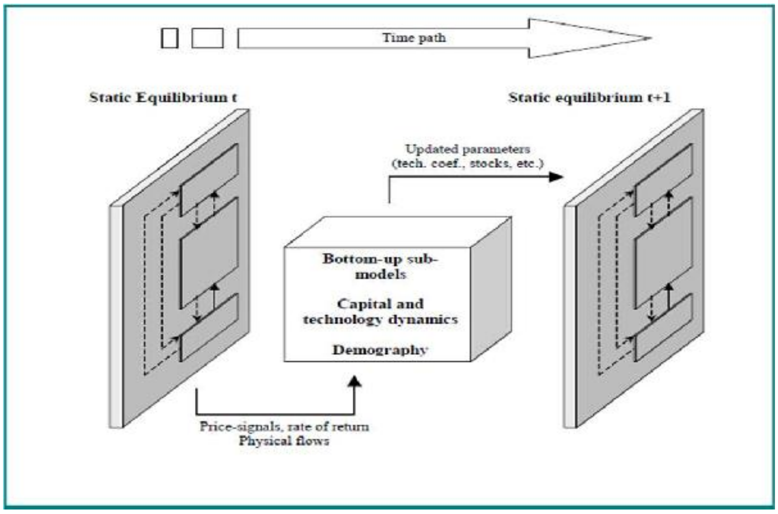

Figure I: The recursive and modular structure of the Imaclim-R model

The annual static equilibrium determines relative prices, wages, labour, value, physical flows, capacity utilization, profit rates and savings at date *t* as a result of short term equilibrium conditions between demand and supply on all markets, including energy. The bottom-up dynamic modules describe the distribution of investments and the resulting changes in technologies and consumption patterns from date *t* to *(t+1)* in function of expectations on sector profitability and agents' microeconomic decisions. The rate and direction of technical change is limited by capital availability (controlled by exogenous saving rates like in Solow (1956)) and the innovation possibility frontier (Ahmad, 1966). These investment decisions are taken under imperfect

[3]The version of the IMACLIM-R model used in this study divides the world in 12 regions (USA, Canada, Europe, OECD Pacific, Former Soviet Union, China, India, Brazil, Middle-East, Africa, Rest of Asia, Rest of Latin America) and 12 sectors (coal, oil, gas, liquid fuels, electricity, air transport, water transport, other transport, construction, agriculture, energy-intensive industry, services & light-industry).

foresight to picture that, at a given date, agents have limited information about the future and shape their expectations on the basis of past and current trends (adaptive expectations).

In this framework, growth patterns are driven by (i) exogenous assumptions on regional labour productivity and demography, which specifies the 'natural' growth rate of the economy, and (ii) endogenous labour allocation across regions and sectors at each point in time, given relative productivities and short-term rigidities (capital stock inertia, frictions in reallocating labour and wage rigidity).

The IMACLIM-R model is fully detailed in Waisman et al. (2012) and a detailed algebraic description is given in its supplementary Electronic Material.

2. The baseline scenario

The baseline or reference scenario depicts a business-as-usual economic growth and ignores any type of climate policy measures during the whole century.

At the global level, economic activity remains sustained with average growth rates around 2%, mostly due to fast growth in emerging economies (*e.g.* 3% for China). In that sense, this scenario is very close to the scenario 'A2-A1 MINICAM' from the data tables in Appendix VII of the SRES Report where the mean annual global GDP growth is 1.98%. Moreover, energy efficiency diffuses largely with an average global increase around 2% over the period 2010-2100 and particularly high rates for emerging countries such as China (Table 1). Despite the assumptions about the amount of the available oil reserves that belongs to the upper range of estimations (Rozenberg et al., 2010) and a peak oil that does not arise before 2040, this high energy efficiency induces a CO_2 emission trajectory[4] that belongs to the lower class of the large SRES and post-SRES emissions range (IPCC, 2007). Indeed, the total carbon budget amounts to 946 GtC for the period 2001-2100, and CO_2 emissions increase from 24 Gt in 2001 to 38.5 in 2035 then stabilize around 37 Gt in 2100 (see Figure 1).

[4] The imaclim-R model considers only CO2 emissions from fossil fuel and combustion

	World	China	India	USA	Europe
2008-2035	1.6%	3.7%	3.7%	0.6%	1.8%
2010-2050	2.1%	3.7%	3.8%	0.9%	2.1%
2010-2100	1.9%	2.7%	2.9%	1.3%	2.0%

Table 1: Mean annual growth of the energy efficiency in the baseline scenario

In China, CO_2 emissions increase from 3.1 Gt in 2001 to their peak of 11.7 in 2035 then decrease to stabilize around 6.5 $GtCO_2$ in 2100. Let us notice the close rates of annual growth of Chinese emissions between 2008 and 2035 in this baseline (2.9%) and in the reference case scenario of the U.S Energy Information Administration (2.6%).(International Energy Outlook, 2011). Furthermore, even if any climate policy measure is explicitly implemented in this baseline, China reduces its carbon dioxide intensity per unit of GDP by 40% in 2020 compared to 2005 levels, which corresponds to its announced Copenhagen pledges.

III. A binding global emission cap: why is it costly for China?

1. The benchmark climate policy

Since the purpose of this article is to assess the impact of global emissions caps policies on the Chinese economy, we will exclusively consider exogenous global emissions constraints. Climate policies in this article are represented by the prescription of an exogenous carbon emission profile which defines, at each date, the maximum level of carbon emissions from the production and use of fossil energies (coal, oil and gas) in final goods and in transformation processes. When this maximum is binding (*i.e.*, when allowed emissions are lower than in the baseline), a carbon price is introduced: at each date, its level is endogenously calculated so that the increase in the cost of fossil energies triggers a decrease of their use consistent with the climate constraint. For the sake of clarity and simplicity, we assume that the generated carbon price is identical for all sectors, households and regions and we limit our analysis to the standard way of recycling the revenues produced through the carbon pricing: they are perceived by the governments of each region and fully redistributed to households in the form of a lump-sum transfer.

We consider a global stabilization objective expressed as the total radiative forcing in 2100, as for the Representative Concentration Pathways (RCP) developed for the fifth IPCC Assessment

Report (van Vuuren et al., 2011). The target chosen, 3.4W/m2 in 2100, leads to an increase of the temperature of +2.5°C with regard to the pre-industrial area and to a CO_2 concentration of 460ppm at the end of the 21st century. The global emission trajectory considered is elaborated by using a three-reservoir (atmosphere, biosphere + ocean mixed layer, and deep ocean) linear carbon cycle model calibrated on the IMAGE model (Ambrosi at al., 2003).

As we can see in figure 1 bellow, this global emission constraint starts in 2010[5] and considers a reduction of 24% with regard to the reference scenario in 2025, of 43% in 2050 and 85% in 2100.

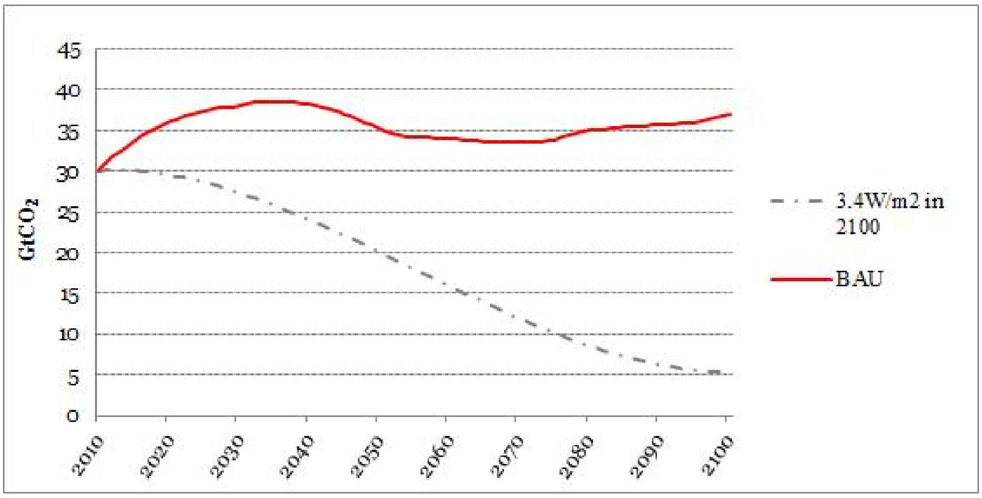

Figure 1: Global CO_2 emissions (energy only)

2. Macroeconomic effects of the climate policy at different time horizons

As it has been mentioned above, this global constraint generates a global CO2 price that penetrates into the economy of all the regions, inducing a drop of the regional emission trajectories. In China, the endogenous global carbon tax (figure 2) generates a reduction of emissions (compared to the baseline) by 39% in 2025, 50% in 2050 and 92% in 2100.

We will here show the consequences of such an early global mitigation action on the Chinese economy and try to give explanations of the generated costs by exposing their determinants at different time horizons. To do so, we investigate the temporal profile of these costs by looking at

[5] Considering the beginning of the global climate policy in 2010 is admittedly not realistic, but this should not be a problem since the purpose of the paper is not to simulate reality but rather to give some framing and understanding of the mechanisms at work in order to better understand the reality.

the difference between the Chinese GDP in the climate scenario and the GDP in the reference scenario (Figure 3).

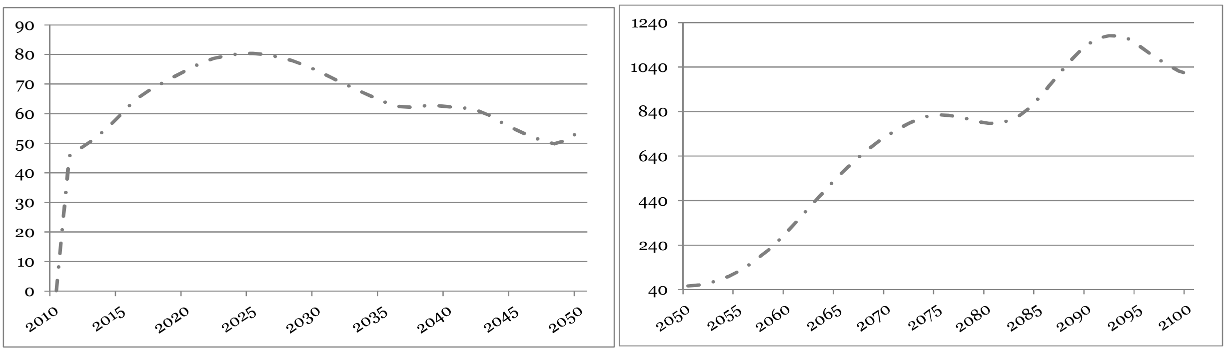

Figure 2: Global CO2 price ($/tCO2)

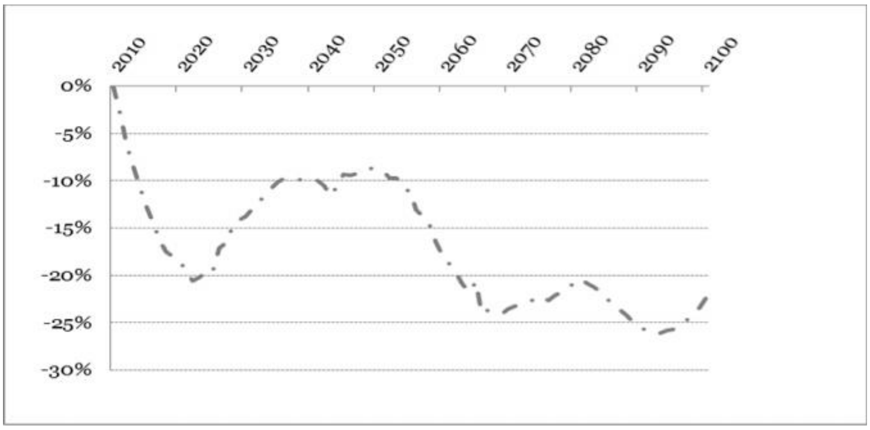

Figure 3: Chinese GDP variations between stabilization and reference scenarios

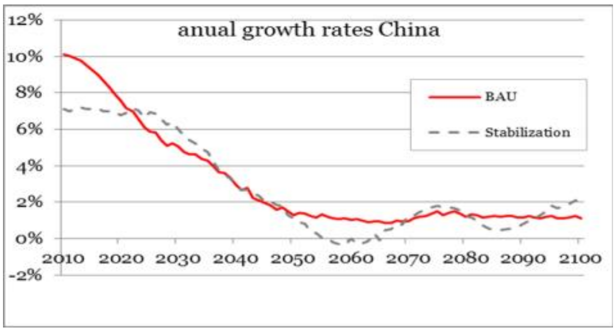

Figure 4: Chinese annual growth rates

a. In the short-term

During the first fifteen years of stabilization, we observe significant transitory costs with lower growth rates than in reference scenario (figure 4). These costs that reach 20% around 2025 are associated with a sharp increase of the carbon price (80$/tCO2 in 2025).

During this period the most important decarbonization efforts are done in the electricity and industrial sectors. For example in 2025, 56% of the Chinese emission reductions are done in the electricity sector and 30% in the industry.

Without any climate policy, the electricity sector in China relies mainly on fossil fuel and particularly on coal: the share of coal in the electricity mix represents 80% over this time period. The early action that forces fast decarbonization and adaptive expectations trigger very high prices. These are thus the only way to redirect investment choices, but they induce a steep increase of production costs in comparison with the baseline, particularly in the electricity sector where this increase generates an augmentation of the prices that reaches 51% in 2025. These augmentations have thus significant repercussions on all the sectors and particularly on the industrial sector which see its energy-to-labor cost ratio significantly increasing (Waisman et al., 2012). Indeed, at the end of this transition phase, we observe an increase of this parameter of 84% with regard to the reference case, which generates an increase of production costs of 10%.

Households are also significantly touched by these high carbon prices, since they suffer from the increase of final prices in addition to the increase of their energy bill. In 2025, they see the share of energy in their budget reaching 11% while it would amount to 9.5% in the reference scenario. All this happens because inertias on installed capital and on the renewal of households' end-use equipment (residential appliances, vehicles) limit the decrease of the economy's carbon intensity that should happen with the carbon tax. At the end of this first climate policy phase, around 2025, Chinese households turn down their final demand by more than 17% with regard to the "no policy" case. Indeed, all the effects described above contribute to hurt households' purchasing power and thus generate a drop in total final demand. This thus induces a contraction of production in many sectors generating a significant increase of unemployment. For instance, in 2025, we observe a 16% drop in the total Chinese working population, and if we look at these employment losses at the sectoral level, we find indeed that the 3 most important sectors (in terms of employment) observe significant losses when compared to the baseline scenario: 11% reduction in the industry and 6% in both agriculture and services. These losses are obviously linked to the reduction of the production in the corresponding sectors: in 2025, the industry reduces its production by 25%, agriculture by 20% and services by 4.5%. These contractions contribute to an additional weakening of households' purchasing power through lower wages and all these effects combine thus to generate significant GDP losses.

b. In the medium-term

Between 2025 and 2050, we first observe an important catch-up phase with higher growth rates under the climate policy than in the reference scenario, and then GDP losses stabilize with very close growth in both scenarios (figure 4). At this time horizon, the mitigation costs are further moderated thanks to the decrease of carbon price towards around 50$/tCO2. This latter has thus reached sufficient levels to reach most mitigation potentials in the residential, industrial and power sectors (see Barker et al., 2007, Figure SPM6), and its decrease lower the weight of energy costs in the production process. At the end of this period indeed, we can observe in the industrial sector for instance, that the share of energy in production costs is halved with regard to its level in 2025. Furthermore, carbon pricing allows for a partial correction, of sub-optimal investment decisions in the BAU scenarios thanks to the steady increase of fossil energy costs (carbon price included) which partly compensates for the imperfect anticipation of increases in oil prices in the BAU scenario. It forces myopic decision-makers to progressively internalize constraints in fossil fuel availability, and accelerate the learning-by-doing in low carbon technologies. Indeed, if we look at what happens at the end of this economic catch-up and stabilization phase, we can see that the carbon intensity of energy drops by 32% when compared to the reference case and it's halved with regard to its level in 2025.

c. In the long-term

On the long-term we first observe a second phase of increasing GDP losses which reach almost 24% around 2070. These significant losses are the consequence of a sharp increase of the carbon price between 2050 and 2070. During this period, the major emitting sectors are industry and transportation; they are respectively responsible for 41% and 27% of total Chinese emissions. As it has been mentioned above, a relatively low carbon price is enough to reach mitigation potentials in most of the sectors that are not the transportation sector, and thus in particular in the industrial sector. On the other hand, the transportation sector, the second emitter sector at this time horizon, is a sector characterized by a high inertia with a significant increase of the mobility need, which induces the need of very high carbon prices to ensure emissions reductions.

China's economic growth is accompanied with an increase of activity's indicators that are prior to the demand of energy services such as for example the number of vehicles per capita. Indeed, there is a more and more important fraction of the population that has access to private cars, in particular when no climate policy is implemented. In 2070 for instance, the number of cars per capita is multiplied by 15 with regard to 2010. Obviously, this massive access to motorized mobility is linked to the increase of carbon-intensive road-based mobility: the passenger-kilometers for cars is tenfold increased between 2010 and 2070 in the reference scenario and this increase is associated to an abundance of investments in road infrastructures, which decreases road congestion and favors the attractiveness of private cars at the expense of other transportation modes. Thus, to deal with these phenomena, carbon price rise up significantly, and its augmentation is all the more stronger as the transportation sector has a weak sensitivity to carbon prices. The very high levels of the carbon tax reached in this period (figure 2) allows for a reduction of motorized mobility: in 2070, the passenger-kilometers for cars decrease by 25% between the stabilization and reference scenario. These levels of carbon price generate a switch in the transportation modes, from cars to public transportation. During this period, we indeed observe that the share passenger-kilometers for cars in the total mobility demand decreases between the climate policy scenario and the baseline scenario, while the share of passenger-kilometers for public transportation increases. These levels of carbon prices allow reaching significant emission reductions, since we observe a reduction of total Chinese emissions by 50% in 2050 and by 76% in 2070, but they lead to significant GDP losses through the mechanisms described above (in the short term costs section) .

Finally, on the very long-term, between 2070 and the end of the century, GDP losses stagnate in spite of the necessary continual increase of the carbon price (to face the evolution of the transportation sector). During these last thirty years, China emits less than 1GtCO2 per year (869MtCO2/year), which is a very low level of emissions induced by the early mitigation efforts that generate a low carbon Chinese society at this time horizon. So, although the level of the carbon tax is high during this period, the gross burden that weighs on the economy is thus relatively slight, and even if we don't observe a catch-up of the losses strictly speaking, we even observe roughly identical growth rates between the baseline and the climate scenario. In addition, let us point out the fact that the mean annual growth rate during this period corresponds to the natural growth rate (% per year during the 30 last years), this is because the economy is at this time horizon on a stabilized long term regime where it doesn't have to face any choc.

In this section, we have pointed out how important can be the consequences of a quite early global mitigation action on the Chinese economy, and how the generated global CO2 price induce significant transition and long term costs that are hardly acceptable by China.

Since the purpose of this article is to assess the effects of a global climate agreement in China, the instinctive reaction when we look at the mitigation costs is to have recourse to some flexibility measures to go further a unique time profile of emissions reductions and domestic mitigation efforts: either by using a temporal flexibility, *i.e.* by delaying the timing of the mitigation action, or by using a regional flexibility, *e.g.* by establishing a cap and trade system. The next two sections will investigate the effects of such policies on the Chinese economy.

IV. Mitigation costs and time profile of emissions reductions

When looking at the figure 3, at first sight, short term costs could seem lower than long term ones, but in reality it is not so true. If we consider the difference between annual average growth rates of the climate scenario and annual average growth rates of the baseline scenario, we observe indeed that short term costs are seven times more important than the long term ones: over the period 2010-2020, China losses in average 2% of growth per year while it loses 0.3% per year over 2050-2100.

This suggests that the question of short term costs are a significant issue, especially as it can create high social and political obstacles for implementing a climate policy. This raises the question of how to reduce them? Let us thus see what happens if we change the timing of emission reductions.

1. Definition of alternative emission profiles

We introduce an alternative global emission trajectory where the mitigation action is delayed compared to the carbon emission profile analyzed in the previous section. This new carbon emissions profile is built with the same three-reservoir linear carbon cycle model. The two trajectories differ in terms of date and level of the emissions peak, but they both lead to the same radiative forcing, carbon concentration and temperature increase in 2100 (see section III.1)[6].

In this section, we will thus have two climate constrained scenarios: an "early action" one, where most of mitigation efforts have to be done at the beginning of the period, and a "delayed action" scenario where most important emissions reductions are done at the end of the period. As we can see in figure 5, both constraints star in 2010, but when the "early action" scenario considers a reduction of emissions of 24% with regard to the baseline in 2025, the "delayed action" scenario considers a reduction of only 9%. Likewise, in 2050, the first scenario has to reduce its global emissions level by 43% while the second has to reduce them by 29%. But at the end of the period, in 2100, the reduction of the "early action" scenario amounts to 85% with regard to the reference situation, while it amounts to 104% in the "delayed action" scenario where the emissions should even be negative.

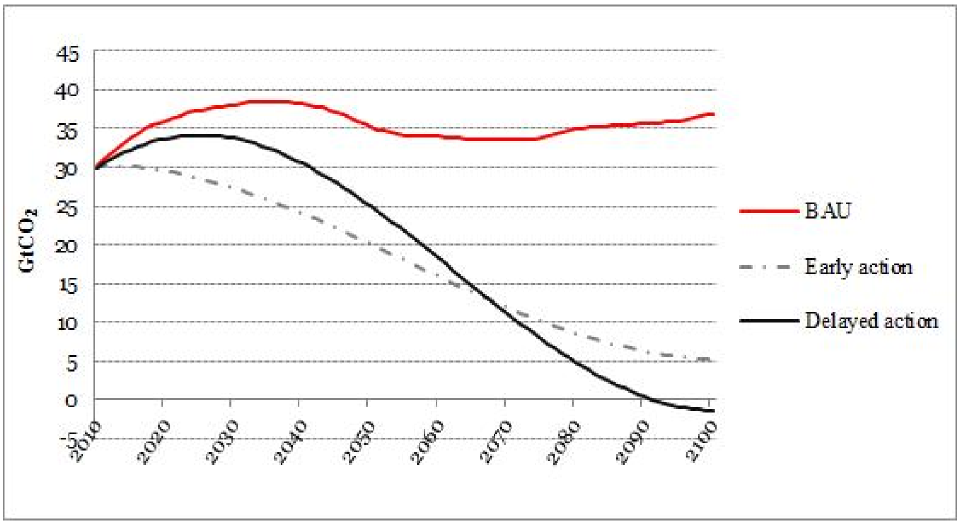

Figure 5: Global CO_2 emissions (energy only)

[6] The full study relies on a family of four emission trajectories. In addition to the early and delayed mitigation action scenarios presented here, we have also built two intermediate ones. The analyses have been conducted for the overall family (the four emissions profiles), but for the sake of clarity and simplicity, the results given in the body of the text concerns only the two extreme situations. The full set of results is given in the appendix.

The “delayed action” global constraint generates a new global carbon price that induces reductions of the Chinese emissions with regard to their baseline level that are obviously different from the reductions of the “early action” scenario: -13% vs. -39% in 2025, -33% vs. -50% in 2050 and -113% vs. -92% in 2100.

2. Cost analysis: comparison of early *vs.* delayed action

When we look at the Chinese costs in terms of annual average growth losses in the “delayed action” scenario (table 2), we find that they come to 0.4% per years over the period 2010-2020, while they amount to 1% per year over 2050-2100 (*vs.* respectively 2% and 0.3% in the “early action” scenario). So the basic intuition of this section is that delaying the mitigation action reduces significantly the Chinese transition costs but erases the catch-up phase of the medium-term and increases long term costs.

	2010-2025	2025-2050	2050-2100
Early action	-1.58%	0.52%	-0.32%
Delayed action	-0.47%	0.00%	-1.03%

Table 2: Difference between Chinese annual average growth rate in stabilization scenario and baseline scenario (early *vs.* delayed mitigation action)

In order assess the dependence of mitigation costs over time profiles of emission reductions, we compare the GDP losses with regard to the baseline for both scenarios “early action” and “delayed action” (figure 6). We use the mechanism at play identified in section III-2 to explain the differences between the two scenarios.

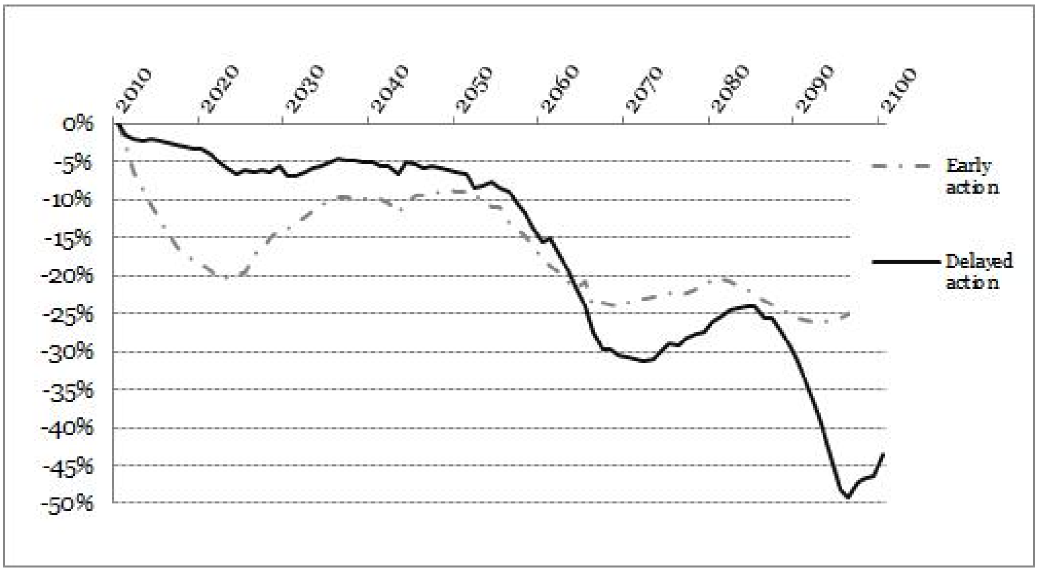

Figure 6: Chinese GDP variations between stabilization and reference scenarios (early *vs.* delayed mitigation action)

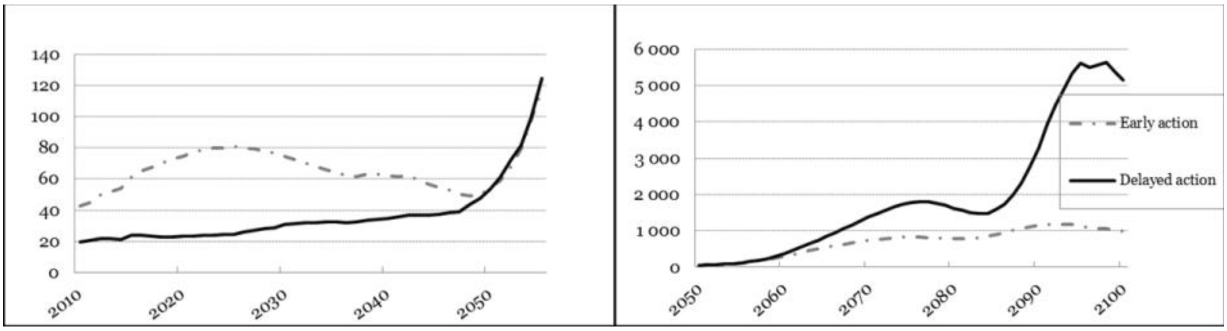

Figure 7: Global CO2 price ($/tCO2) - Early *vs.* Delayed action

a. In the short-term

Obviously, we observe that postponing the decabonization efforts improve the economic situation on the short term: the GDP losses amount to 6% in 2025 under the "delayed action" scenario while they amounted to 20% under the "early action" one. This is normal since global mitigation efforts are divided by three around this period, the generated global carbon price necessary to reach the emission target is thus less important (*e.g*. 25$/tCO2 *vs* 80$/tCO2 in 2025) and the Chinese economy is therefore less impacted. In 2025 indeed, the electricity prices increase by only 14% with regard to the baseline, while they increased by 50% in the "early action" scenario and the augmentation of energy's share in production costs of the industrial sector, still with regard to the baseline, is divided by 4 between the two climate scenarios. Households also suffer much less since the weight of energy expenditure in their budget is less important when the carbon price is lower. This allows them to consume more of non-energy goods in the “delayed action” scenario than in the “early action” one, which contribute to lower the drop in the final demand and thus reduces the impact of the mitigation policy on the economic activity.

b. In the medium-term

After 2025, in the middle of the period, the global mitigation efforts imposed at the global level continue to be lower in the “delayed action” scenario than in the “early action” one. This implies that the carbon price remains lower in the new climate scenario and the Chinese economy is still doing better. But the other side of the coin is that the speed of the learning-by-doing in low carbon technologies that occurred under the “early action” scenario is less important in the “delayed action” one. This implies that the catch-up phase observed under the first climate scenario, with higher growth rates than in the baseline is now only a stagnation phase where the economy does not observe gains with regard to the reference case but only equal growth rates. Furthermore, it also generates a less important decarbonization of the economies and particularly the Chinese economy which continue to develop production systems that rely on fossil fuel energies. For example in 2050, we observe that the share of coal in the electricity mix amount to 10% in the “delayed action” scenario while it only represents 2% in the “early action” one. Likewise, the share of fossil energies in industrial processes is much more important when mitigation efforts are postponed (x% vs. y% en 2050). Let us notice that the level of decarboinzation of the production process at this time horizon has important implications on the long term mitigation costs since the installed capital is characterized by important inertias.

c. In the long-term

After 2060, we observe a steep increase of the carbon price in the “delayed action” scenario, much more than in the “early action” situation. In the latter, the most important challenge is the transportation sector (see section III-2-c) and the carbon price rise up significantly to allow reaching the emission target since this sector has a weak sensitivity to carbon pricing. In the “delayed action” scenario, the issue of transportation is obviously still relevant but comes in addition to the decabonization efforts that have to be done in most of the other sectors that are still far from reaching their mitigation potential. In this latter scenario, the most important mitigation efforts have indeed to be done at this time horizon, and carbon price needed to reach the emission target soars necessarily. On the one hand, like in the “early action” scenario, the inertia of transportation sectors added to the increase of mobility need induce an increase of the carbon price. On the other hand, a great part of decarbonization efforts that have been done at the beginning of the period in the “early action” situation have to be done at the end of the period in the “delayed action” scenario, and economies –particularly energy intensive economies such as China- suffer from inertias on their installed carbonized capital: the steep increase of the carbon price observed in the transition phase of the first scenario is thus much more important. The combination of these phenomena generates soaring carbon prices which come down on the Chinese economy and generate much higher GDP losses than in the “early action” situation (*e.g.* 50% *vs.* 25% at the end of the period).

Finally, we can say that delaying mitigations efforts allows for significant reductions in the transition costs, but makes the situation worse on the long term due to inertias limiting the flexibility of adjustments. So the issue can be shifted from the short to the long term but it appears that the “when flexibility” lever is not the solution particularly for an energy intensive country like China.[7]

V. Mitigation costs and quota allocation

In the previous section, we have considered a temporal way of application of the “common but differentiated responsibilities” principle. Another way to take into account the differentiated responsibilities of the regions in the mitigation action issue, is to consider specific emission burden sharing rules under a global-cap-and-trade agreement: we have chosen to investigate two stylized rules that take into account some specificities of developing countries. After presenting the two allocation schemes of emissions’ permits that are considered in this article, we analyze their effects on the Chinese mitigation costs.

1. Scenarios definition

The international permit market is modeled by defining regional allocations and introducing money transfers according to the difference between these and actual emissions. Regions trade

[7] The interpretation of the results is robust when looking at the full set of emission profiles (see Appendix 2)

allowances with each other at a single world CO_2 price. The revenues from the carbon market are assumed to be recycled directly to households so that a part of these revenues is saved and thus invested while another part is consumed[8].

The global emission constraint that is imposed is the one used to analyze the determinants of the mitigation costs in section III-1. Let us remind that this target corresponds to the radiative forcing of 3.4W/m^2 in 2100. We consider two types of permit allocations (a Contraction & Convergence scheme and a Common but Differentiated Convergence one) and we compare the Chinese mitigation costs generated in these two situations to the case where no carbon international transfer is established.

The Contraction & Convergence (*C&C*) scheme (Meyer, 2000) considers a linear progression of the regional emissions shares from status-quo in 2010 to equal per capita emissions in 2100. In such a scheme, regions with comparatively high 2010 per capita emissions must reduce their emissions relatively more than those regions with comparatively low 2010 per capita emissions so that they converge towards the identical per capita emission level in 2100. This approach combines elements of grandfathering–allocation (based on current emissions) and equal per capita emissions (Agarwal proposition) which allow somehow taking into account some equity principles.

The Common but Differentiated Convergence (*CDC*) scheme (Höhne et al., 2006) is similar to the *C&C* approach, but in addition to taking populations of each region into account, it considers their historic responsibility. In this scheme indeed, Annex-I countries are more constrained than in C&C, while developing countries are less constrained. Annex-I countries's per capita emission allowances converge to a certain level, which is equal per capita emissions in 2100. Developing countries converge to the same level in 2100 ('common convergence'), but they start entering into the scheme later than Annex-I countries ('differentiated convergence'); before their entrance, they receive allocations according to their business-as-usual emissions. In the original CDC scheme, developing countries start mitigation efforts when their per-capita emissions are a certain percentage above global average. For the sake of clarity and simplicity, this entrance criterion has

[8] When these revenues are negative, it reduces the households' income and thus their consumption as well as the available investment level.

been modified in this article: we have fixed the date of entrance for China in 2020[9] and for all the other non-Annex-I regions in 2050. Let us notice that this allocation permit scheme appears like a burden sharing approach that is consistent with the "common but differentiated responsibilities" principle.

2. Cost analysis

When we compare the Chinese macroeconomic situation under the two quota allocation scenarios with its situation when no carbon trade is set up (*No Transfer* scenario), we find that both *CDC* permit allocation and Contraction & Convergence scheme do not improve the Chinese economy over the whole mitigation period, but may either improve it or worsen it a little bit on the short term. Indeed, we observe that in both scenarios, China still loses in average 0.3% of growth per year over the whole century like in the *No Transfer* scenario, while it loses in average 2.3% per year in the *C&C* situation and 1.8% per year in the *CDC* scenario during the transition period (*vs.* 2.2% in the *No Transfer* scenario).

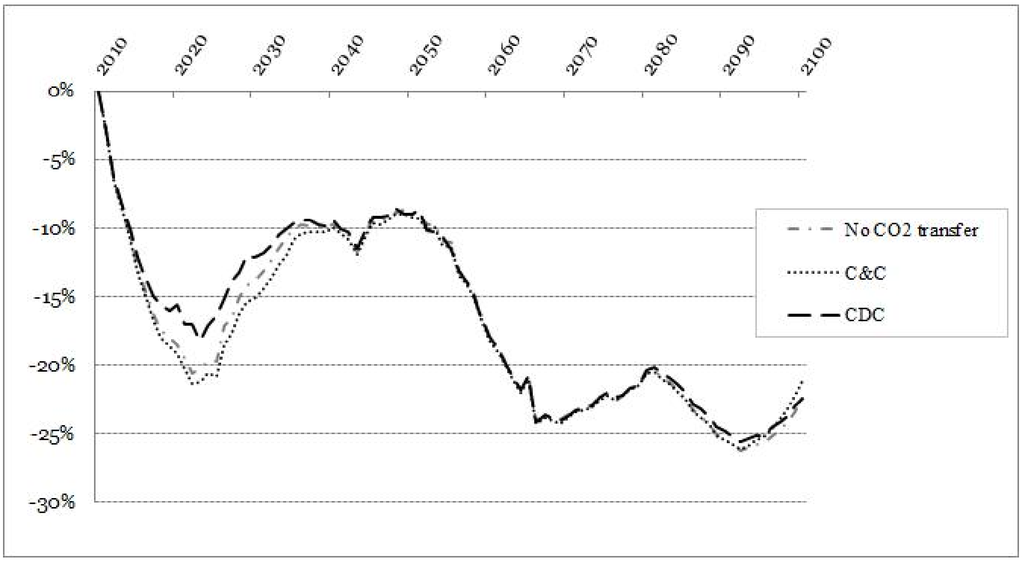

Figure 8: Chinese GDP variations between stabilization and reference scenarios (for the different allocation schemes)

[9] Considering the baseline used in this article, this corresponds to a per capita emissions threshold of 75% above world average.

In the *C&C* scenario, GDP variations with regard to the baseline are very slightly different from the variations obtained under the *No Transfer* scenario (see figure 8). Mitigation costs are barely higher in the short term: for example in 2025, GDP losses amount to 21% under the C&C scenario and 20% under the *No Transfer* one. On the medium term, this allocation scheme doesn't provide any substantial change, since the losses are the same in both scenarios. Then, on the long term, the situation reverses and even if the it is not really significant, the C&C allocation scheme provides a small improvement (e.g. the losses are 5% lower in 2100).

If we look now at the *CDC* scenario, and focus on the short term, we can see that the situation is clearly different in terms of improvement and magnitude (figure 8). For instance in 2025, GDP losses amount to 16% which corresponds to an improvement of the macroeconomic situation by 17% with regard to the *No Transfer* scenario. But on the medium term, from 2040 and after, we don't observe any changes between all the costs of all the scenarios. Later, on the long term, the *CDC* scheme provides a very small improvement of the situation that is roughly as much important as the improvement provided by the C&C scenario.

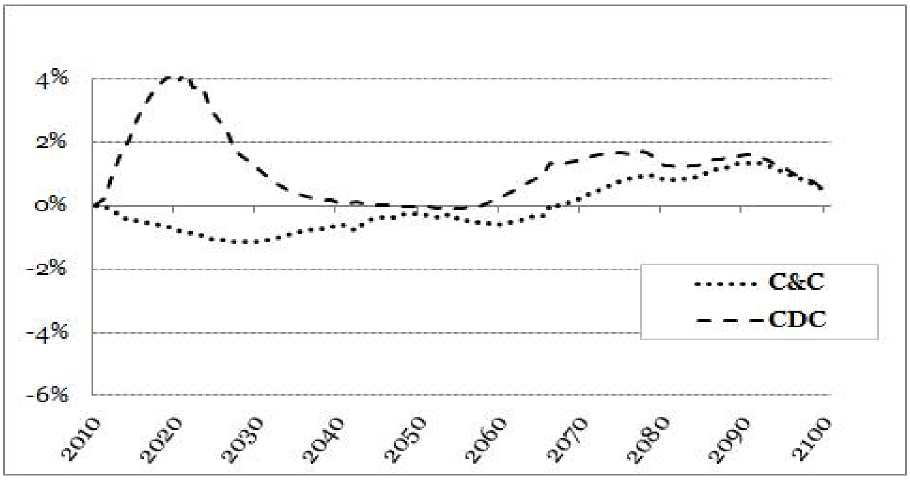

Figure 9: Share of CO2 capital transfers in the GDP for China

The differences between the effects of the two allocation schemes scenarios can be explained by the amount of carbon money transfers that are operated in China. These are negative when the amount of the allowances is smaller than actual emissions, so that China has to buy emissions permits, and it is positive when the situation reverses, i.e. China can sell permits.

Figure 9 shows the share of carbon capital transfers in the Chinese GDP for both *C&C* and *CDC* scenarios. During the first mitigation period, there is a clear difference between the two situations, in terms of sign as well as in terms of magnitude: the level of these transfers can reach +4% of the GDP in the *CDC* scenario, while it hardly exceeds -1% in the *C&C* situation, which results in roughly the same amounts of improvements of the macroeconomic situation with regard to the *No Transfer* scenario (figure 8). On the medium and long term, whether positive or negative, the amounts of carbon transfers are not significant: they never go below -0.5% of the GDP when China have to buy emissions permits (in the C&C scenario), and never exceed +2% when it is seller of permits (in both C&C and CDC scenarios), which lead to very small or inexistent variations of the costs with regard to the *No Transfer* situation.

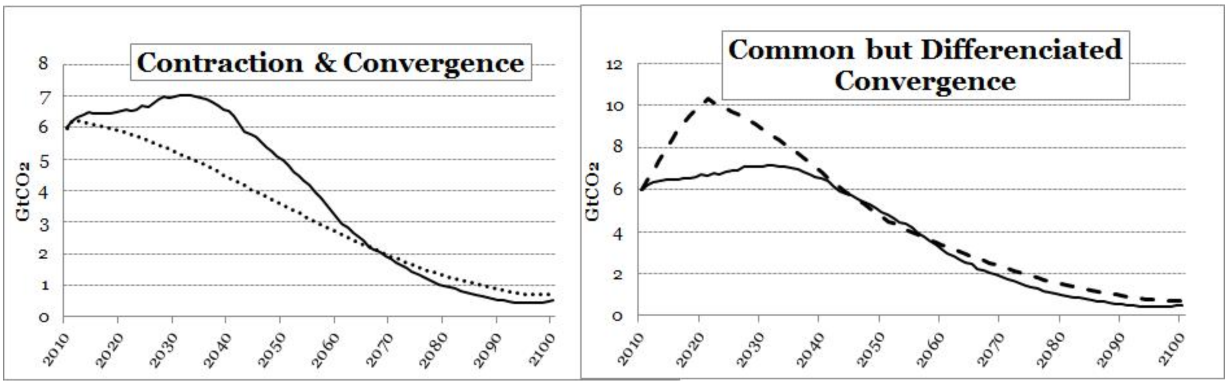

Figure 10: Chinese actual emissions (full lines) *vs* quota allocations (dotted lines)

These relatively small effects are obviously linked to the amounts of quotas allocations on the one hand, and to the level of the carbon price on the other hand.

When we look at figure 10, we can notice that the volume of the Chinese bought permits (in the C&C scheme) as well as the volume of the sold permits (in the CDC scheme) is quite important at the beginning of the mitigation period: it can reach respectively 2GtCO$_2$ and 3.3GtCO$_2$. At that time, the amounts of carbon transfers are not so important, they are governed by a price effect: although increasing rapidly, the carbon price is indeed not so high during this period (the maximum reached amounts to 80$/tCO2). Conversely, when the carbon price starts to increase significantly, reaching very high levels, the volume of the sold permits become very small (its maximum hardly exceeds 0.3GtCO$_2$ in the *C&C* scenario and 0.5GtCO2 in the *CDC* one). This volume effect induces small carbon transfers with small consequences on the mitigation costs when compared to the *No Transfer* situation.

Let us notice here, that the relatively small effects generated by the introduction of an international carbon market with these two stylized allocation schemes is specific to China and is not generalized to all developing countries. In the case of India for instance, our results show that trading allowances improves significantly the economic situation. In that case indeed, we can observe positive losses, which mean that India's GDP in the C&C and the CDC scenarios is better off than in the baseline scenario[10].

As a conclusion, we can say that although in line with the "common but differentiated responsibilities" principle, a pure Contraction and Convergence scheme does not advantage the Chinese economy without really worsening it, while delaying the entrance of China into such a scheme, can be considered as being more consistent with this UNFCC principle and allows for some improvements at least during the transition phase.

VI. Conclusion

This paper considers the economic consequences of a binding global agreement based on uniform carbon pricing on the Chinese economy. We use the IMACLIM-R model that captures key features of second-best economies (e.g. imperfect foresights) and represents inertias on technical systems, a key dimension of emerging economies when envisaging a transition to low carbon pathways.

We take the example of China because it plays an essential role in the climate negotiations arena. This emerging economy is indeed the first CO2 emitter, very energy intensive with a booming growth, but still has a high development constraint which makes it relying on the "common but differentiated responsibilities" principle of the UNFCC as a condition to engage in a global mitigation agreement.

We visit the question of the Chinese mitigation costs by considering different policy designs based on a uniform global carbon price that vary according to *(i)* the temporal profile of carbon emissions reductions and *(ii)* quota allocation schemes.

We first have shown the consequences of an early global mitigation action, as a benchmark case, and gave explanations of the generated costs by exposing their determinants. Two principal sources of high costs have been identified. On the one hand, the increase of the energy-to-labor

[10] A follow-up of this article is to compare China and India's mitigation costs in a similar framework to this article, and to assess how the structure of the economy is an important determinant of costs formation for emerging countries.

costs ratio consecutive to the introduction of the carbon price in the short-term; on the other hand, transport-related emissions which force a rise of carbon prices in the long-term. We have pointed out the importance of these costs, especially on the short term. This question of short-term costs is of the most importance, since it can create high social and political obstacles for implementing a climate policy. A possible solution, consistent with the principle of "common but differentiated responsibilities", is to postpone the mitigation efforts. We found that delaying the action allows indeed for significant reductions in the transition costs, but makes the situation worse on the long term, mainly due to inertias that limits the speed at which the economy can adjust. So we have shown that the issue can be shifted from the short to the long term, but it appears that the "when flexibility" lever is not the solution, particularly for an energy-intensive country like China.

We then have investigated the effects of two stylized allocation schemes of emissions permits on the Chinese mitigation costs. We found that although in line with the "common but differentiated responsibilities" principle, a pure *Contraction & Convergence* scheme does not advantage the Chinese economy without really worsening it, while delaying the entrance of China into such a scheme (*Common but Differentiated Convergence*) is not only more consistent with this UNFCC principle, but allows also for some improvements, at least during the transition period.

This quantitative assessment leads to the conclusion that in a worldwide emissions cap situation, generating a global carbon price, combining delaying the mitigation efforts with an adequate quota allocation scheme can be beneficial for China. However, mitigation costs remain significant and may continue to be an obstacle to the entrance of a country like China in a global agreement. This suggests the recourse to complementary domestic measures, in addition to carbon pricing, in order to help smoothing the necessary shift towards a low carbon society.

A follow-up of this paper is thus to consider domestic policies that act both on the short term (*e.g*. fiscal reform) and on the long-term (*e.g*. infrastructure policy), and to investigate how a global agreement such as a global emissions cap can be more acceptable with such accompanying measures.

References

Ambrosi, P., J.-C. Hourcade, S. Hallegatte, F. Lecocq, P. Dumas and M. Ha-Duong. Optimal control models and elicitation of attitudes towards climate damages. *Environmental Modeling and Assessment* 8 (3), 135–147, 2003.

Barker T, Bashmakov I, Bernstein L, Bogner JE, Bosch PR, Dave R, Davidson OR, Fisher BS, Gupta S, Halsnæs K, Heij GJ, Kahn Ribeiro S, Kobayashi S, Levine MD, Martino DL, Masera O, Metz B, Meyer LA, Nabuurs G-J, Najam A, Nakicenovic N, Rogner HH, Roy J, Sathaye J, Schock R, Shukla P, Sims REH, Smith P, Tirpak DA, Urge-Vorsatz D, Zhou D, 2007. Technical Summary. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Blanford, G.J., Richels, R.G., Rutherford, T.F., 2009. *Revised emissions growth projections for China: why post-Kyoto climate policy must look east*. In: Stavins, R., Aldy, J. (Eds.), Implementing Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World. Cambridge University Press, Cambridge.

Clarke, Leon, Jae Edmonds, Volker Krey, Richard Richels, Steven Rose, and Massimo Tavoni. 2009. “International Climate Policy Architectures: Overview of the EMF 22 International Scenarios.” *Energy Economics* 31, Supplement 2: S64–S81. doi:10.1016/j.eneco.2009.10.013
Dellink, R., G. Briner and C. Clapp (2010), "Costs, Revenues, and Effectiveness of the Copenhagen Accord Emission Pledges for 2020", OECD Environment Working Papers, No. 22, OECD Publishing. doi: 10.1787/5km975plmzg6-en

den Elzen, M.G.J., Hof, A.F., Mendoza Beltran, A., Grassi, G., Roelfsema, M., van Ruijven, B., van Vliet, J., van Vuuren, D.P., 2011. The Copenhagen Accord: abatement costs and carbon prices resulting from the submissions. Environmental Science & Policy 14, 28–39.

Hamdi-Cherif M., Guivarch C., Quirion P., 2011, ‘Sectoral targets for developing countries: Combining "Common but differentiated responsibilities" with "Meaningful participation’, Climate Policy, Volume 11, Number 1, 2011, p 731-751(21)

Höhne N., den Elzen M. and Weiss M., 2006. “Common but differentiated convergence (CDC): a new conceptual approach to long-term climate policy”. *Climate Policy*, 6(2), 181-199.

IEA, 2007. World Energy Statistics 2007. International Energy Agency, Paris, France.

International Energy Outlook, 2011. U.S Energy Information Administration. [available at http://www.eia.gov/oiaf/aeo/tablebrowser/#release=IEO2011&subject=0-IEO2011&table=10-IEO2011&region=0-0&cases=Reference-0504a_1630]

IPCC Summary for Policymakers. In: B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds) Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. CambridgeUniversity Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2000, Special Report on Emissions Scenarios, Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, New York.

Metz, B., Berk, M., Den Elzen, M., De Vries, B., Van Vuuren, D., 2002. Towards an equitable global climate change regime: compatibility with Article 2 of the Climate Change Convention and the link with sustainable development. Climate Policy 2, 211–230.

Meyer A, 2000. Contraction & convergence. The global solution to climate change. Schumacher Briefings, 5. Green Books, Bristol, UK. http://www.gci.org.uk/Briefings/ICE.pdf

Narlikar, Amrita. 2010. *New Powers: How to Become One and How to Manage Them*. Columbia University Press.

Olivier Jos G.J., Janssens-Maenhout Greet, Peters Jeroen A.H.W., 2012. TRENDS IN GLOBAL CO2 EMISSIONS - 2012 report - Background Studies; *PBL Netherlands* Environmental Assessment Agency [available at http://edgar.jrc.ec.europa.eu/CO2REPORT2012.pdf]

Papa, Mihaela, and Nancy W. Gleason. 2012. “Major Emerging Powers in Sustainable Development Diplomacy: Assessing Their Leadership Potential.” *Global Environmental Change* 22 (4) (October): 915–924. doi:10.1016/j.gloenvcha.2012.06.003

Rogelj, J., Nabel, J., Chen, C., Hare, W., Markmann, K., Meinshausen, M., Schaeffer, M., Macey, K., Hohne, N., 2010. Copenhagen Accord pledges are paltry. Nature 464, 1126–1128.
Stern, N., and Taylor, C., 2010. What do the Appendices to the Copenhagen Accord tell us about global greenhouse gas emissions and the prospects for avoiding a rise in global average temperature of more than 2°C? Policy paper, Grantham Research Institute on Climate Change and the Environment, London, UK.

Rozenberg J., S. Hallegatte, A. Vogt-Schilb, O. Sassi, C. Guivarch, H. Waisman and J.-C. Hourcade, 2010. Climate policies as a hedge against the uncertainty on future oil supply., Climatic Change 101(3-4) : 663-668

Tirole, J., 2009. *Politique climatique : une nouvelle architecture internationale*, Rapport du Conseil d'analyse économique, La Documentation française, Paris, octobre

UNEP, 2011. Bridging the Gap Report. United Nations Environmental Programme, Geneva.

UNFCCC, 2009. Copenhagen Accord. Retrieved 15March 2010, [available at http:// unfccc.int/resource/docs/2009/cop15/eng/l07.pdfS.]

UNFCCC, 2010. Decision1/CP.16, The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention in Report of the

Conference of the Parties on its Sixteenth Session, held in Cancun from 29 November to 10 December 2010, Addendum, Part Two: Action taken by the Conference of the Parties at its Sixteenth Session, UNFCCC [available at http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page= 2%20UNFCCCS]

UNFCC, 2012. Report of the Conference of the Parties on its seventeenth session, held in Durban from 28 November to 11 December 2011, Addendum, Part Two: Action taken by the Conference of the Parties at its seventeenth session [available at http://unfccc.int/resource/docs/2011/cop17/eng/09a01.pdf#page=2]

van Ruijven, Bas J., Matthias Weitzel, Michel G.J. den Elzen, Andries F. Hof, Detlef P. van Vuuren, Sonja Peterson, and Daiju Narita. 2012. "Emission Allowances and Mitigation Costs of China and India Resulting from Different Effort-sharing Approaches." *Energy Policy* 46: 116–134. doi:10.1016/j.enpol.2012.03.042.

van Vuuren Detlef P., Jae Edmonds, Mikiko Kainuma, Keywan Riahi, Allison Thomson, Kathy Hibbard, George C. Hurtt, Tom Kram, Volker Krey and Jean-Francois Lamarque, et al., 2011. The representative concentration pathways: an overview. *Climatic Change* Volume 109, Numbers 1-2, 5-31.

Waisman H., Guivarch C., Grazi F. and Jean Charles Hourcade The Imaclim-R model : infrastructures, technical inertia and the costs of low carbon futures under imperfect foresight. *Climatic Change* accepted for publication online first, 2012.

World Bank, 2012. World Development Indicators. [available at

http://data.worldbank.org/indicator/EN.ATM.CO2E.KT]