Economic Globalization, Global energy issues and Climate Change
China in global perspective

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Abstract. Under alternative visions of globalization, this article analyzes how oil dependency and climate change create long-term macroeconomic challenges in China. Using the Imaclim-R model, we find that fragmented capital markets affect negatively technical change but release capitals for local investments, which prove beneficial for China. Regionalized good markets have a positive effect since less intense international trade moderates the effects of oil constraints. However acting on globalization processes is insufficient to avoid important socio-economic tensions caused by the sustainability constraints. We suggest that a sustainable future will require a policy mix that resorts to a plurality of complementary instruments.

Keywords: energy, resources, climate change, globalization, sustainability, CGE modelling

JEL classification: C68, F18, Q43, Q56

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1. Introduction

Twenty years after the earth summit of Rio (1992), the recent Rio+20 conference has demonstrated the difficulty to lay out a coherent roadmap forward for addressing global challenges in the framework of sustainable development (Clémençon, 2012a). In particular, the Rio process since 1992 has failed to achieve a comprehensive way between free market, trade liberalization and governmental regulation (Clémençon, 2012b). This failure emphasizes the necessity to explore more in-depth the link between sustainability and globalization processes (Bartelson, 2014).

This paper considers energy as a nodal point of the relations between sustainability and globalization processes. We focus on global environmental constraints related to the energy sector and, more specifically, on the twofold sustainability challenge caused by oil depletion and climate change. The socio-economic effects of these limitations are analyzed at the Chinese level, in relation with *(i)* the energy security concerns of this major oil-importing region and *(ii)* the transition from a carbon-intensive to a low-carbon economy. Beyond the agreed-upon role of "green" measures, in particular to foster competitiveness of the Chinese economy in the short-term, we analyze the long-term challenges posed to China by oil dependency and climate change in the context of a socio-economic and political globalization. In particular, the analyze is conducted in a context of tensions on oil markets[1], making the issue of heavy reliance on international markets to satisfy oil-dependent development patterns all the more crucial for a country like China. This is particularly true given the specificities of oil demand, i.e. low price elasticity, captive uses in transport and access to oil-based mobility in the emerging economies such as China. Indeed, energy security is a priority for China given the increase of its spending in oil and gas imports- they more than doubled between 2009 and 2011, as a result of increasing energy prices and import volumes augmentation (IEA, 2012). Note for example that oil imports represent more than 3% of the Chinese GDP in 2012 (IEA, 2012), which illustrates the importance of this issue when analyzing Chinese economic growth trajectories, particularly when adopting long-term perspectives.

Moreover, as proclaimed in its 12th Five Year Plan, the Chinese government calls for enhancing the competitiveness of strategic industries and services, increasing energy efficiency and improving the environment (OECD, 2013). The Plan put forward the

[1] Namely depletion of conventional oil reserves, uncertainties on the deployment of non-conventional resources and concentration of production in politically sensitive regions.

articulation between environmental policies, energy policies and competitiveness. It states the objective of building an "environmentally friendly" society by implementing policies to mitigate the increasing environmental pollution and climate change. For example, it includes compulsory target for carbon emissions per unit of GDP - to be reduced by 17% in 2015 relatively to 2010, in line with the 40-45% target by 2020 (Li and Wang, 2012; NDRC, 2012). But despite the implementation of policies designed to slow down the rate of carbon emissions in many regions and in China in particular (e.g., China's national agenda have now included a carbon emission trading scheme (ETS) for the industry and power sectors (Lo, 2013)), CO_2 emissions have continued to grow in the last decade even more rapidly than predicted (Raupach et al., 2007; Peters et al., 2012). This context is notably due to the rapid carbon intensive growth patterns of emerging countries. This situation raises strong doubts on the sustainability of business-as-usual development patterns in terms of long-term climate effects (Stern, 2006). It also highlights the necessity to implement ambitious measures in order to trigger a strong bifurcation away from carbon intensive development paths (IPCC, 2007). Despite this scientific consensus, the implementation of ambitious global carbon emission reductions targets remains highly uncertain as shown by the difficulties to reach a global climate agreement under the United Framework Convention on Climate Change (UNFCCC), in particular since the failure of the Copenhagen Conference in 2009. This is essentially because carbon emissions restrictions are often viewed by developing economies as an obstacle to welfare and economic growth and to the right to development (Hamdi-Cherif et al., 2011). Indeed, many concerns about the interplay of climate measures with other sensitive political issues such as poverty alleviation, distributional effects, energy and food security or health and local environmental protection are continuously put on the climate negotiations' table (see, for example, the dilemma of the climate-development Gordian knot discussed in (Hourcade et al., 2008)).

Far from being independent, the two above defined sustainability challenges posed by the energy sector –resource scarcity and climate change – are closely intertwined dimensions. Indeed, they both focus on the decline of fossil energy as the major source of anthropogenic greenhouse gas emissions. They are also a key determinant of international trade flows and a crucial component of the energy mix. A crucial methodological challenge is then to investigate the synergies and trade-offs between the tensions and future shocks on oil markets and the socio-economic effects of ambitious climate policies on China, a key figure in this context.

Furthermore, globalization processes are a decisive driver of the future of energy markets in the transition towards low-oil and low-carbon development patterns. Indeed, as stated in Waisman et al. (2014), *(i)* oil markets are internationally integrated so that oil prices and quantities depend on the interaction between supply and demand at the world level[2], *(ii)* climate impacts result from global emissions so that low-carbon trajectories must be set at the world level, and *(iii)* their implementation involves rethinking trade interactions among regions like China, that would be significantly affected by a carbon constraint.

The interplay between economic trajectories, globalization processes and environmental issues has been investigated in the literature following Copeland and Taylor (1994, 1995, 2004). Their approach provides useful insights on the environmental consequences of economic growth and international trade, but it is a theoretical approach, too general to draw policy implications at a regional level (namely for China and its specificities in the above described context). Moreover, economic implications of oil depletion and climate policies under different visions of globalization have been investigated in Waisman et al. (2014), but their study focuses on the global and European level. From a Chinese perspective, there is a wide literature on the link between trade and environment, but it is mostly done to assess the amount of embodied CO_2 emissions in China's foreign trade (e.g. Yunfeng and Laike, 2010; Su and Ang, 2014). We can also find a large literature on the links between trade and the Chinese energy sector (e.g. Kahrl and Roland-Holstahrl, 2008; Zheng et al., 2011), or on capital flows and the Chinese competitiveness (e.g. Zhang, 2013). But as far as we know, there is no quantitative assessment that explores the effects on the Chinese economy of the links between economic globalization, global energy issues and mitigation policies.

The purpose of this paper is therefore to analyze, at the Chinese level, the interplay between global energy concerns and the transition towards sustainable futures under different visions of the globalization processes. We adopt the Computable General Equilibrium (CGE) model IMACLIM-R, which provides a multi-sectoral, dynamic modeling approach for thinking the link between growth, globalization and energy constraints given limited availability of fossil resources and carbon mitigation policies.

The following section presents this modeling approach by detailing both the macroeconomic structure as well as the representations of the oil sector and the climate policy considered. Section III presents the long-term profiles of oil markets and their macroeconomic effects on China in absence of carbon constraint for different visions of globalization processes. Section

[2] this is for example different for gas markets, which remain divided into independent regional markets because of distribution constraints.

IV extends the results to the case where a climate policy is implemented. Section V provides policy insights and concluding remarks.

2. Methods

On the backbone of a Computable General Equilibrium (CGE) structure, the adopted framework captures crucial determinants of the interplay between the energy sector, sustainability objectives and globalization processes. Indeed, *(i)* the possibility of non-marginal deviations with respect to current socio-economic trends produces room for deep technical change over the course of the century[3], *(ii)* beyond technological improvements, the integration of lifestyles, consumption patterns and preferences in driving the material content of economic activity is captured (Mitchell, 2012), *(iii)* the representation of market imperfections, technical inertias and imperfect expectations induce limitations in the flexibility of technico-economic adjustments during transition processes, which affects the adaptability of the economy to sustainability, and finally *(iv)* the competitiveness of opened economies on international markets is pictured, which impacts regional balances of payment.

2.1 An energy-economy model to investigate sustainability transitions in a globalized economy: Imaclim-R

The economic analyzes of this article are indeed conducted using the CGE hybrid energy-economy model IMACLIM-R. It adopts a dynamic, multi-region and multi-sector representation of the world economy[4] (see Waisman et al., 2012a for an extensive description). It provides a consistent vision of economic and energy trajectories in yearly steps over 2010-2100 through the recursive succession of a top-down *annual static equilibrium* and *bottom-up dynamic modules.* The former provides a snapshot of the economy at each yearly time step, whereas the latters inform the evolution of technical parameters between two equilibria (Figure 1).

[3] Technical change is a change in the amount of output produced from the same inputs. Such a change is not necessarily technological but might include organizational trasnformations or be the result of a change in a constraint such as regulation, prices, or quantities of inputs.

[4]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 and light-industry).

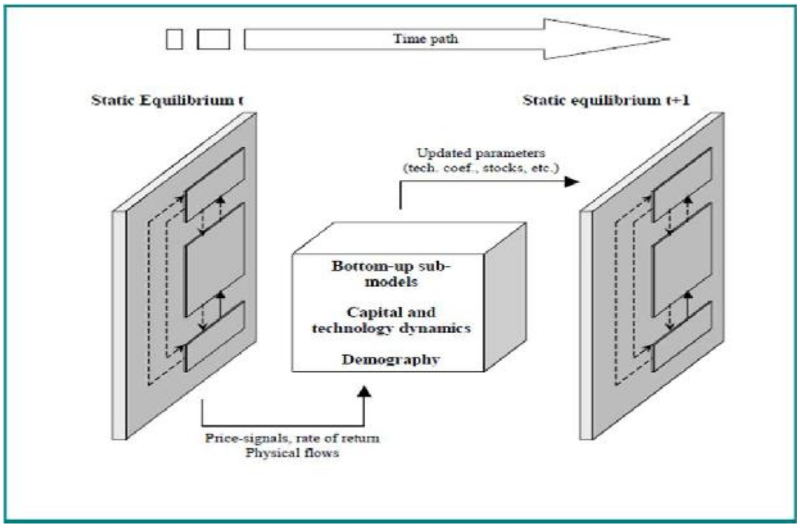

Figure 1: The recursive and modular structure of the Imaclim-R model

The *static equilibrium* represents short-run macroeconomic interactions at each date *t* under technology and capacity constraints. It is calculated assuming Leontief production functions with fixed intermediate consumption, labor inputs and mark-up in non-energy sectors. Households maximize their utility through a trade-off between consumption goods, mobility services and residential energy uses considering fixed end-use equipment. The equilibrium is given by market clearing conditions on all markets (including energy), which provides a snapshot of the economy at date *t* in terms of relative prices, wages, employment, production levels and trade flows.

The *dynamic modules* are reduced forms of bottom-up models, which describe the evolution of structural and technical parameters between *t* and *t+1* in response to past and current economic signals. Each year, the regional capital accumulation is given by firms' investment, households' savings (controlled by exogenous saving rates like in Solow (1956)), and international capital flows. On that basis, the across-sector distribution of investments is governed by expectations on sector profitability and technical conditions as described in sector-specific reduced forms of technology-rich models (see details in the Supplementary Material of (Waisman et al., 2012a)). These modules represent the evolution of technical coefficients resulting from agents' microeconomic decisions on technological choices, given the limits imposed by the innovation possibility frontier (Ahmad, 1966). The new investment choices and technical coefficients are then sent back to the static module in the form of updated production capacities and input-output coefficients to calculate the *t*+1 equilibrium.

This modeling framework differs from conventional global energy-economy models in several features that make it relevant to investigate important specificities of sustainability transitions. First, the consistency of the iteration between the static equilibrium and dynamic modules relies on 'hybrid matrices', which ensure an explicit representation of the material and technical content of production processes through a description of the economy in consistent money values and physical quantities (Sands et al., 2005). Second, the equilibrium does not necessarily correspond to economic optimality since inertias on capital stocks limit the pace of technical change, the stickiness of labor market affects labor adjustments and market power leads to departures from marginal cost pricing. This means that production factors (production capacity and labor force) are not necessarily fully used, which ensures the possibility to represent idle capacities and unemployment. Third, contrary to the conventional assumption of intertemporally optimizing models, agents have imperfect knowledge about the future and may take investment decisions according to biased expectations. This allows representing bifurcations, lock-ins and potential co-benefits in the course of sustainable trajectories. Fourth, the hybrid structure of the model allows making explicit the technical assumptions behind the trajectories, which can be informed by sector-based information and expert views about, e.g., asymptotes on ultimate technical potentials, learning-by-doing mechanisms, saturation in efficiency progress, the impact of incentive systems and the role of market or institutional imperfections. Given the uncertainty on the long-term dynamics of these dimensions, their explicit representation allows considering variants of scenarios suited to capture alternative views on these controversial parameters. Finally, contrary to the common approach of a unique composite good, the detailed multi-sectoral structure distinguishes productive sectors (agriculture, heavy industries, manufacturing and services) according to their economic characteristics and their exposure to international trade. This allows a more precise description of the determinants of international trade.

The modelling options that have been adopted in this paper are described in the three next sub-sections: oil markets (2.2), international trade and capital flows (2.3) and climate policy (2.4).

2.2 Modeling the long-term dynamics of oil markets

Market mechanisms in the oil sector are driven by the utilization rate of production capacities, given by the ratio of total demand to production capacities (Kaufmann et al., 2004). Oil price formation is pictured through an explicit description of its geopolitical, technical and economic determinants on both the supply and the demand-side. We represent *a)* the heterogeneity of oil reserves in function of their exploitation's cost and their conventional *vs.* non-conventional nature; *b)* the limitations on the short-term adaptability of oil supply due to the geological nature of reserves; *c)* the market power of Middle-East producers until the depletion that affects the deployment of their production capacities; *d)* technical change affecting the demand for liquid fuels in industry, residential, transport and power sectors; and *e)* the potentials and obstacles to the diffusion of biofuels and Coal-To-Liquid as oil substitutes. A more extensive description of these oil market's features is given in (Waisman et al., 2012b).

In this paper, we adopt median assumptions on the crucial determinants of oil price dynamics, namely the amount of reserves (Table 1), geological inertias (assumed to be the same for conventional and non-conventional reserves) and the short-term price targeted by Middle-East producers (assumed to be the stabilized around its 2010 level).

Resources extracted before 2001	**Recoverable resources beyond 2001***				
	Conventional oil		Non-conventional oil (Heavy oil and Tar sands)		
	Middle-East	RoW	Canada	Latin America	RoW
0.895	0.78	1.17	0.22	0.38	0.4

*« recoverable resources »vare 2P reserves (Proven+Probable) remaining in the soil, which has been identified as the relevant indicator to investigate global oil peak (Bentley et al, 2007)

Table 1: Assumptions about oil resources (Trillion bbl)

2.3 Specifications for international trade and capital flows

All intermediate and final goods are internationally tradable and the total demand for each good is satisfied by a mix of domestic production and imports. Domestic as well as international markets for all goods are cleared (i.e. no stock is allowed) by a unique set of endogenous relative prices, which adjust to maintain the equilibrium of the balance of payments defined by the sum of trade flows and capital flows.

Trade flows are represented in physical quantities for energy flows (MToe) whereas all other goods are described with Armington specifications to capture imperfect substitutability among goods produced in different regions (Armington, 1969). In order to capture alternative visions of trade globalization, we consider in this article, two parametric options:

- A high value of Armington elasticities representing high substitutability between goods produced in different regions. This assumption favors a pursuing of current trends of international trade with intense competition and important export/import flows in all world regions (assumption G+);
- A low value of Armington elasticities representing low substitutability between goods produced in different regions and a preference for local goods. This assumption represents a slowing down of international trade and a re-regionalization of production close to demand markets (assumption G-).

The endogenization of capital flows has hardly been integrated in global-scale energy-economy models[5], because of a lack of shared empirical evidence[6] and unresolved controversies in the economic literature[7]. Following this diagnosis, we adopt exogenous assumptions on the share of capital exports. Capital flows are explicitly represented through the balance of payments and their dynamics are ruled by two alternative assumptions:

- A constant-over-time share of exported capital to picture a pursuing of current international capital imbalances (assumption K+);
- An exponential decrease of all capital flows to represent a progressive correction of international capital imbalances by 2050. This assumption corresponds to a vision of fragmented capital markets imposing financing of local investments with local capital (assumption K-).

[5] A notable exception is (McKibbin et al., 1999)

[6] For example, in a historical study of capital flows over the long term (1865-1992), Hogendorn (1998) demonstrates that no simple rule emerges for capital flows dynamics, given the fluctuations of capital mobility over time in parallel with different phases of international monetary and financial governance: high capital mobility during the gold standard period (1880-1913), almost closed economies during the Interwar and Bretton Woods periods (1914-1969) and increasing mobility in the modern period (1970-1992).

[7] The issue of capital mobility has given rise to a large controversy since the econometric study by (Feldstein and Horioka, 1980), who demonstrated low capital mobility over 1960-1974, in contradiction with widely shared ideas. This ‘puzzle’ was the starting point of a large body of literature trying to identify the major drivers of capital flows, but which has failed to reach consensual answers (see Apergis and Tsoumas (2009) for a survey).

By combining the assumptions on trade and capital flows, we define four scenarios representing four visions of the future of globalization processes (Table 2). The scenario 'Continued Globalization' can be viewed as a benchmark case in the sense that it assumes a pursuing of current trends in both goods' trade and capital flows. Other scenarios consider changes in the globalization process, either through a fragmentation of capital markets ('Fragmented Capital') or a regionalization of trade flows ('Regionalized Trade'). Finally, the scenario 'De-globalization' combines both breaks in the globalization process.

		Assumption on good markets	
		G+	G-
Assumption on capital markets	K+	*Continued Globalization*	*Regionalized Trade*
	K-	*Fragmented Capital*	*De-Globalization*

Table 2: Scenario definition

2.4 Climate policy and carbon price

Carbon emissions arising from the production and use of fossil energies – coal, oil, and gas – are counted *via* coefficients capturing their respective carbon content[8]. When climate polices are applied, a constraint on the profile of carbon emissions is imposed in function of the chosen climate stabilization target. The climate objective considered in this article consists in limiting the temperature increase with respect to pre-industrial levels to +2.5°C, which is commonly believed as more realistic than the +2°C normative objective[9]. Following (Barker et al., 2007, Table TS2), this objective is translated into a carbon emission profile characterized by a peak of world CO_2 emissions between 2010 and 2030 and a stabilization in 2050 with respect to 2000 levels (Figure 2).

[8]Those coefficients count only the emissions actually released in the atmosphere, at the exception of those captured either biologically (biofuels) or technologically (Carbon Capture and Sequestration).

[9] The adoption of an ambitious global agreement on climate reduction emissions by 2015 and strong assumptions on technical change are indeed necessary to comply with the 2°C objective which let few flexibility in terms of action (Edenhofer et al.,2010; Guivarch and Hallegatte, 2013).

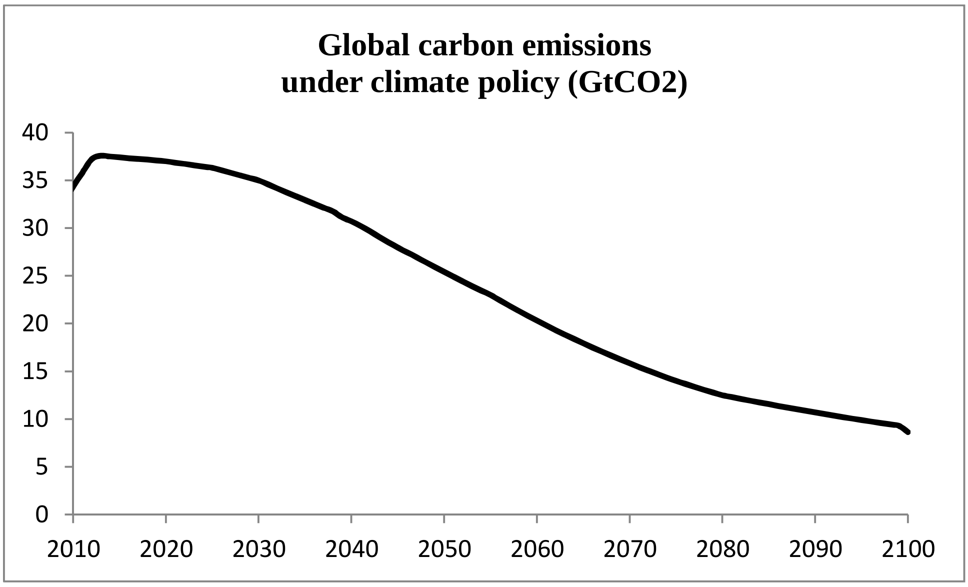

Figure 2: Carbon emission profile under climate policy

This constraint on carbon emissions is satisfied thanks to the introduction of a market based instrument in the form of a carbon price, which is considered by economists as the most efficient way to tackle the diversity of emissions of greenhouses gases and abatement sources in the economy (Aldy and Stavins, 2012). The carbon price increases the cost of final goods and intermediate consumptions in function of the carbon content of the energy used, and favors the adoption of carbon mitigation options in carbon-intensive sectors (power generation, industry, residential and transport). At each date from 2010, the carbon price value is endogenously calculated to curve carbon emissions according to the prescribed objective. We consider a homogeneous carbon price across sectors, households and regions; and the associated revenues are collected by the government that reallocates them to households through lump-sum transfers. Note that a climate policy applied uniformly to all regions and sectors and relying on a world-level carbon price instrument is obviously a simplification of what can be reasonably expected in the future, but it is chosen for the sake of clarity and simplicity. It poses in particular number of questions that are far beyond the scope of this paper but that are worth noting here: *(i)* monetary transfers to gain compliance of emerging countries[10], *(ii)* tax exemptions to protect certain specific activities[11] and *(iii)* the role of accompanying measures to climate policies like fiscal reforms (Combet et al., 2010), specific

[10] See, for example, Luderer et al. (2012) for an analysis of different cap-and-trade schemes and their consequences on climate policy costs.

[11] See for example Hamdi-Cherif et al. (2011) who consider an exemption for developing countries in a form of “sectoral target”: only their electricity sector is targeted by the global carbon price.

labor market policies (Guivarch et al., 2011) or complementary infrastructure policies (Waisman et al., 2013a).

3. Fossil fuels profiles and macroeconomic trajectories

We consider in this section only scenarios without any climate policy implementation, i.e. where no carbon emissions constraint is imposed. Nevertheless, the scenarios are constrained by trends of oil availability and their implications on oil market, as well as tensions on coal market. This section investigates the effects of these dynamics on the Chinese macroeconomic transition towards low-oil development patterns.

3.1 Dynamics of oil and coal markets

In all scenarios, world oil production follows an inverted-U shape reaching a maximum around 2030 (the so-called Peak Oil) before a continuous decrease over the long-run. Oil prices follow a slightly increasing plateau around 100 $/bbl before a sudden increase at the moment of Peak Oil reaching 350 $/bbl in 2050. They then follow a continuous augmentation until reaching 500 $/bbl in 2100. Coal production increase continuously over the whole century triggering an increase of coal prices: they almost triple during the first 20 years, and then stabilize between 2030 and 2050 before increasing continuously until 2100. These outcomes are illustrated for the 'Continued Globalization' scenario in Figure 3.

Note that we have chosen to place in a context where energy difficulties are important. Indeed, in a context that will most probably be increasingly strained, it is particularly interesting to analyze the economic effects of fossil energy tensions on an energy-intensive country like China.

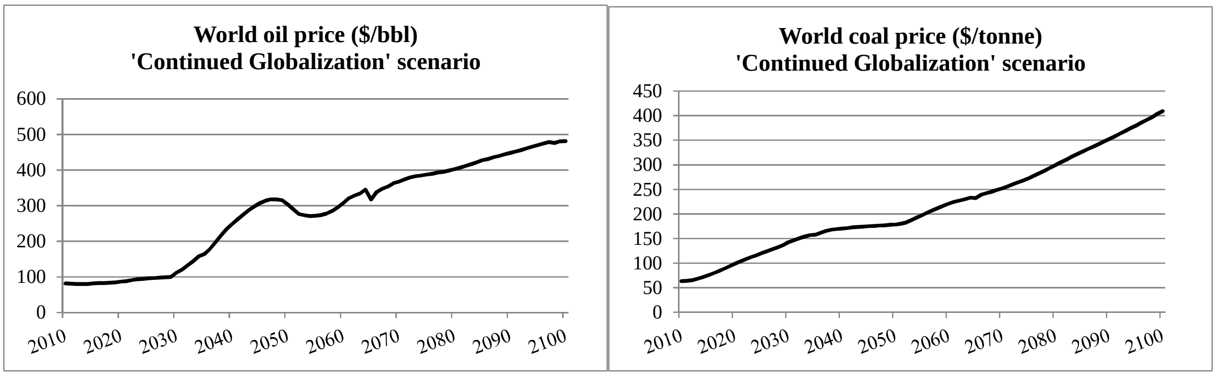

Figure 3: World oil and coal price in the 'Continued Globalization' scenario

To analyze the effect of globalization assumptions in such a context, we compare oil production and price trajectories in the three other scenarios with the above trends[12] (Figure 4).

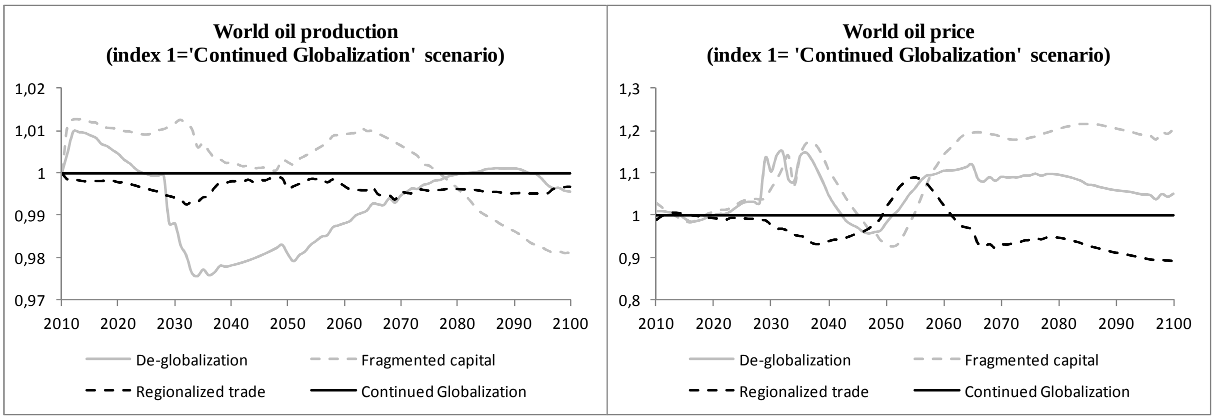

Figure 4: World oil production and oil price in the four globalization scenarios

The trends for the 'Regionalized trade' scenario (black dotted line) proves that less intense international trade favors a moderation of oil demand and around 10% lower oil prices in the long-term. Indeed, the increased preference for local goods favors a reduction of international trade and hence triggers a lower dependence on fuels for transportation activities. This is confirmed by the significantly lower global energy intensity of GDP (Figure 5). The trends for the 'Fragmented Capital' scenario (grey dotted line) show that, on the contrary, the decrease of capital transfers causes a higher energy intensity of GDP. Indeed, less capital fluidity slows down the pace of technical change and triggers a higher dependence on oil, which results in a significantly higher oil demand in the first twenty years, a strong increase of oil prices after Peak Oil and 20% higher long-term level. The 'De-Globalization' scenario combining both fragmentations represents a mix of the two above described effects.

Note that in all analyzes that follow, including in the following sections, we will not discuss the results of this latter scenario. The De-Globalization's results prove indeed to be systematically a combination of the outcomes of the 'Regionalized Trade' and 'Fragmented Capital' scenarios as it is illustrated in all the figures of this article.

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[12] Since globalization assumptions have no significant impact on coal production and price trajectories, we focus the analysis of this sub-section on oil.

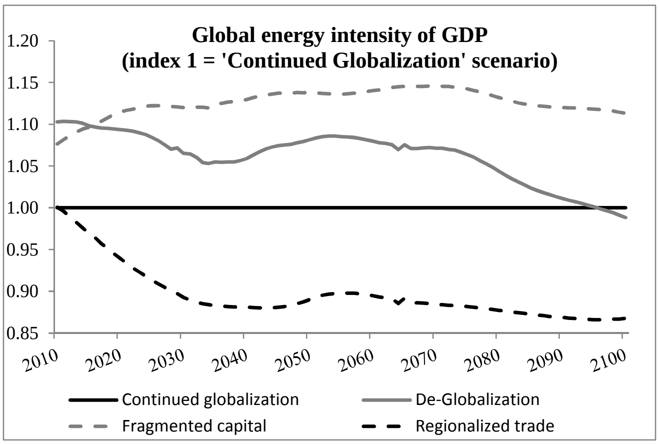

Figure 5: Global Energy intensity of GDP in the four globalization scenarios

3.2 Long term impacts of oil and coal markets on the Chinese economy

We now investigate the consequences of the sustainability challenge posed by tensions of oil and coal markets on the stability of the Chinese socio-economic trajectories. To do so, we look at the trends of Gross Domestic Product (GDP) over the whole century. More precisely, we compare the effective growth rate of the Chinese economy with its 'natural growth' rate. The natural growth rate of an economy is given by the sum of population and labor productivity growths. It corresponds to the growth rate that an economy would follow if considering a unique sector and full employment of production factors, like for instance in the standard Solow model. This indicator allows assessing the sustainability of growth patterns in the sense that an effective growth that is lower than its natural rate is the sign that constraints affect the economy. They prevent from exploiting all the productivity potentials, causing unemployment, losses of purchase power and a decrease of production. The natural growth captures indeed the impossibility of the economy to absorb the total labor force at constant wages, due to particularly important adaptation difficulties in sectors where the growth is low. For China, as we can see in Table 3, it turns out that this situation happens on average over the whole century, with particularly important gaps in the post Peak Oil period and in the very long term. The Chinese economy, as a major oil importer and very energy-intensive, is indeed particularly vulnerable to oil and coal price variations. The country thus experiences long periods of unsustainable trajectories, characterized by socio-economic tensions.

	2010-2100	2010-2030	2030-2040	2040-2050	2050-2100
Effective growth rate	2.67%	6.82%	2.52%	2.43%	1.13%
Natural growth rate	2.98%	7.52%	3.31%	1.86%	1.38%

Table 3: Chinese Growth rates in the 'Continued Globalization' scenario

More precisely, the time profile of Chinese growth rates defines four major periods over 2010-2100:

(i) A first period (2010-2030), where although oil prices are moderate, the growth is lower than its natural rate due to the significant increase of coal prices.

(ii) A deep economic crisis consecutive to Peak Oil (2030-2040) during which a surge in oil price divides growth rates by three;

(iii) An important recovery phase (2040-2050) fostering a post crisis catch-up, in the sense that the effective growth is 30% higher than the natural one. This catch-up happens thanks to the adaptation of the economy to high oil prices, and despite a temporal trend that is still downward due to the decrease of the Chinese population;

(iv) And finally a long-term regime (2050-2100) in which the Chinese economy experiences particularly low growth rates (20% lower than natural levels). This is due to issues related to the transportation sector. During this period indeed, where oil and coal prices are very high, an important fraction of the Chinese population gains access to fossil fuels intensive road-based mobility.

To test the effect of globalization on these outcomes, we compare the Chinese GDP levels in the two other scenarios with the one obtained in the 'Continued Globalization' case (Figure6).

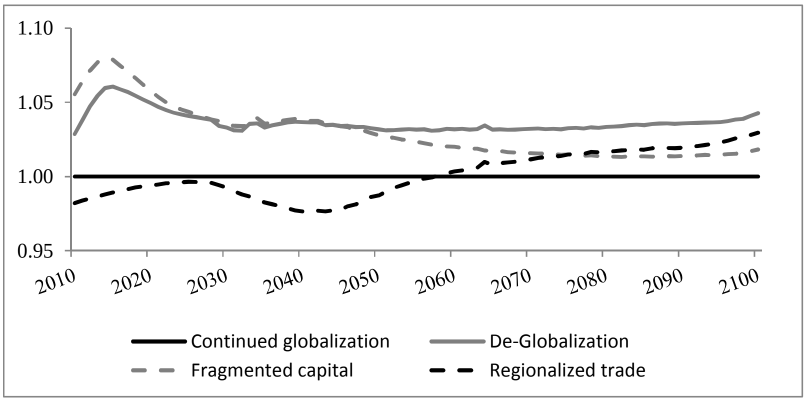

Figure 6: Chinese GDP levels in the four globalization scenarios

(Index1= 'Continued Globalization' scenario)

The fragmentation of capital markets (grey dotted lines) has a positive effect on the Chinese economy during the whole century and particularly at the beginning of the period where the GDP can be 8% higher. This is the result of the constraints this assumption imposes on capital availability for investments in technical change. Indeed, China is a net capital exporter over the whole period, and assuming fragmented capital markets is thus equivalent to release capitals for local investments. China has then, from the beginning of the period where coal prices increase, and despite higher oil prices, more resources to invest in production capacities. This effect is less significant but persists on the long-run (2% increase of GDP in average over 2050-2100) due to the cumulative effect on technical change that helps China facing the rising oil prices.

The regionalization of good markets has very different effects (black dotted lines), at least during the first half of the century. Assuming preference for local goods induces a significant reduction of the Chinese exportations and thus a drop of the production. This production decrease induces an increase of unemployment triggering lower wages and thus a lower demand. However, the magnitude of the generated GDP contraction remains small (at most 2.5% in 2040) as a result of the 'regionalized trade' assumption. Indeed, the preference for domestic goods constraint can be satisfied only if China reduces its competitiveness. But given the reduction of oil prices (see section 3.1), this can only happen through real wages adjustments, preventing their excessive decrease and inducing a moderate decrease of households' power purchase and production (to be able to satisfy the domestic demand). At a longer term horizon, the overall effect of good fragmentation is on the contrary positive (3% higher GDP in 2100) thanks to the cumulative effects of the real wages adjustments.

Moreover, lower reliance on international trade at the global level, in patterns where demand is mostly satisfied by local production entails lower oil demand and prices. This drives down the Chinese energy dependency and facilitates the development of local production capacities[13] able to satisfy local demand. Production costs decrease enhancing households' purchase power, which offsets the effect of the Chinese exportations' reduction on the GDP.

These outcomes demonstrate that the globalization processes are not neutral for the Chinese growth trajectories, in particular to face the post-Peak oil period and long-term related issues. However, whether gains or losses, the Chinese GDP variations are not so significant. The maximum gaps in GDP levels are indeed +8% and -2.5%. And when considering the average growth rates, we find that the variation is at most 0.07% on the short to medium term and 0.05% over the whole century (see Table 4). This proves that acting on globalization processes is insufficient to avoid important socio-economic costs due to the sustainability challenge raised by oil availability.

	Continued Globalization	**Fragmented Capital**	**Regionalized trade**	**De-Globalization**
2010-2050	4.62%	4.56%	4.64%	4.63%
2010-2100	2.67%	2.63%	2.72%	2.68%

Table 4: Effective Chinese GDP growth rates in the four globalization scenarios

4. The transition towards a low-carbon society

We now investigate the impact of implementing a global climate policy in the form discussed in section 2.4, that aims at stabilizing temperature increase at +2,5°C with respect to pre-industrial levels.

4.1 Carbon pricing and global natural resource exploitation

We start by analyzing the consequences of the introduction of a constraint on world's carbon emissions in the 'Continued Globalization' scenario. The constraint on carbon emissions is met through the introduction of a global carbon price (Figure 7), for which four distinct

[13] China is indeed a developing country that still has room for increasing its production capacities, in contrast with mature industrial systems.

phases can be distinguished, consistent with climate policy analysis in (Waisman et al., 2012a).

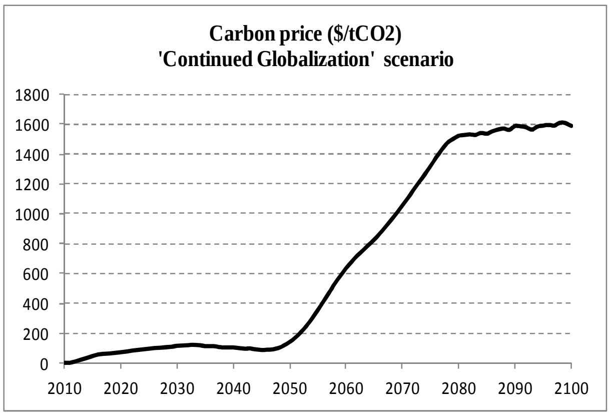

Figure7: Carbon price in the 'Continued Globalization' scenario

During the first twenty years (2010-2030), the carbon price progressively increases to reach 120$/t$CO_2$ around 2030, with hardly no effect on oil prices, which remain controlled by Middle-East producers. This carbon price level is necessary to tap most mitigation potentials in power, residential and industrial sectors, which represent the core of emissions reductions at that time horizon (IPCC, 2007). Between 2030 and 2050, the carbon price stagnates and even slightly declines without hampering emission reductions. Indeed, two mechanisms combine to sustain the decarbonization process: *(i)* the cost decrease of carbon-free options implied by the cumulative effect of learning-by-doing and *(ii)* the sudden rise of oil prices following Peak Oil, although moderated by the climate policy, stimulates fossil-free technical change. Between 2050 and 2080, in order to reach the high-cost mitigation potentials in the transportation sector, maintaining efforts to reduce emissions is necessarily based on a steep increase of carbon prices up to 1400$/t$CO_2$. Indeed, the climate policy has fostered low-oil technologies and structural changes inducing low oil prices at this time horizon (around 70$/bbl). This in addition to the weak sensitivity of transport activities to energy prices induces a need for strong carbon prices to mitigate sufficiently carbon emissions. After 2080, carbon prices, albeit high, reach a constant value around 1500$/t$CO_2$. This level is sufficient to maintain total emissions below 10GtCO_2 as imposed by the long-term emission constraint in Figure 2.

The production patterns of oil, coal and gas show that the implementation of a climate policy significantly moderates the exploitation of these fossil non-renewable energies (Figure 8). Until 2030, the carbon price fosters a meaningful lower oil and coal production with, in particular, a plateau instead of a peak oil production profile. Gas demand increases as substitute of oil and coal, given the competitiveness advantages of this low-carbon energy. The situation is opposite between 2030 and 2050, when the stagnation of carbon prices favors the return of coal. Finally, after 2050, carbon prices are so high that the use of the three carbon-intensive energies progressively decline.

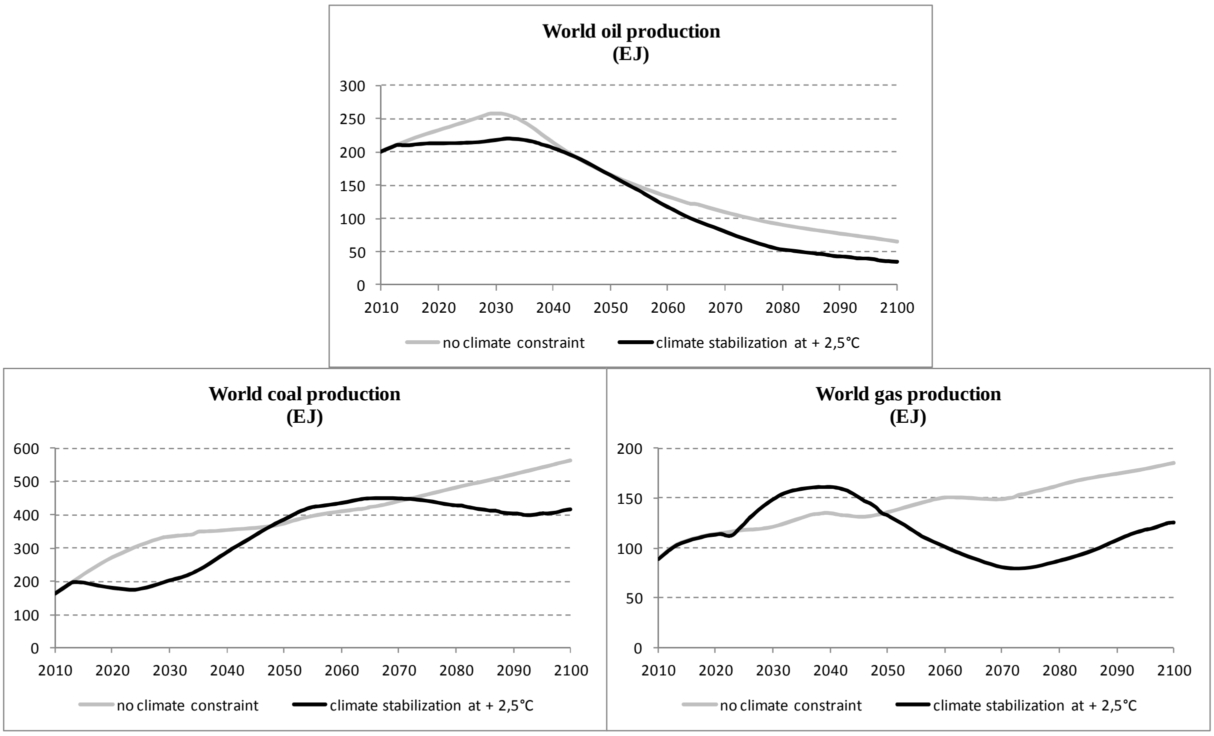

Figure 8: (a) Oil production; (b) Coal production; (c) Gas production

4.2 Macroeconomic effects of climate policies on China

The considered global climate policy, based on a uniform carbon price, decreases the Chinese average growth rate from 2.67% to 2.51% in the 'Continued Globalization' scenario. This shows that maintaining the global temperature at an "acceptable" level is not neutral for China, in particular in terms of sustainability.

	2010-2100	2010-2030	2030-2040	2040-2050	2050-2100
Effective Growth rate Climate stabilization at +2.5°C	2.51%	6.15%	3.13%	2.59%	0.96%
Natural growth rate	2.98%	7.52%	3.31%	1.86%	1.38%

Table 5: Chinese GDP growth rates under climate policy in the 'Continued Globalization' scenario

But beyond this aggregate picture, a global climate policy with a unique carbon price has different macroeconomic effects on China depending on the time horizon considered (Table 5). At a short-term horizon (2010-2030), it significantly slows down economic growth (from 6.82%/year without climate policy to 6.15%/year). This is the result of the introduction of the carbon price which impacts the carbon-intensive Chinese economy, increasing the gap with its natural level. Conversely, at a medium-term horizon (between 2030 and 2050), the climate policy triggers a much faster economic growth. This is a co-benefit of low-carbon measures that foster a decreased oil dependency and moderate the effects of Peak Oil. In particular, the climate policy reduces the gap observed between the effective and the natural growth rates over the decade 2030-2040, which corresponds to a reduction of the socio-economic tensions experienced during the post-Peak Oil crisis. This underlines the role of climate policies in preparing a sustainable future by building a hedge against the uncertainty concerning oil supply (Rozenberg et al., 2010). But the picture changes when considering the long-term period, after 2050. Indeed, Table 5 indicates that a climate policy may cause important losses as captured by the particularly low growth rate (0.96%/year). This value increases significantly the gap with the natural rate during the last fifty years, picturing a long-lasting socio-economic crisis. This is in particular due to the necessity to control transport-related emissions, which requires a fast increase of carbon price given the weak sensitivity of the transportation sector to price signals (Waisman et al, 2013a).

4.3 Macroeconomic effects and globalization

We finally turn to analyze the major effects of globalization under climate constraints on these results. Similarly to section 3.2, we compare the Chinese GDP levels under climate policy in the two other scenarios with the GDP obtained under the "continued globalization" scenario (Figure 9).

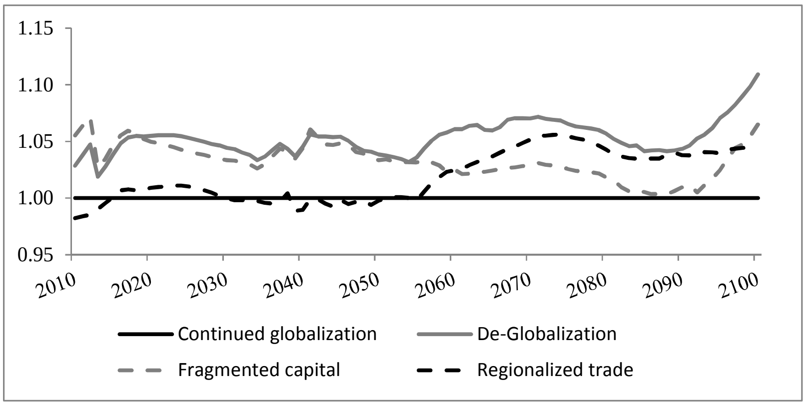

Figure 9: Chinese GDP levels under climate policy in the four globalization scenarios (Index1= 'Continued Globalization' scenario)

As in the case without climate policy, the GDP obtained under the "Fragmented Capital" scenario (grey dotted lines) is higher than the one obtained under the "Continued Globalization" scenario, thanks to the higher availability of capitals in China for investments in new production capacities (see section 3.2). But note that on the short to medium term, the gap between the two scenarios is smaller under climate policy (on average 5% higher in the climate scenario vs. 6% over 2010-2030). This means that in a "Fragmented Capital" world, China is more hurt by a global carbon pricing policy than in a "Continued Globalized" world. Indeed, less capital fluidity at the global level hampers the pace of technology diffusion between regions, in particular concerning low carbon technologies that are more necessary when a climate policy is implemented. Moreover, restrictions on the global availability of capital impose higher carbon prices (e.g. in 2030, it is around 150\$/tCO_2 in the 'Fragmented Capital' scenario vs. 120\$/tCO_2 in the 'Continued Globalization' one), which affects particularly the Chinese economy[14] and slows down its growth considerably (e.g. 6.04% vs. 6.15% over 2010-2030- see also Table 6, first raw).

The effect of the regionalization of good markets (black dotted lines) under climate constraint differs from its effects when no climate policy is implemented; it proves indeed beneficial over the whole period. While the level of the Chinese GDP was, in the short to medium term, lower than in the continued globalization scenario, it is now overall similar (figure 9). This means that the Chinese economy is less affected by a climate policy when the world is regionalized in terms of good markets than in a more globalized world. This is due to the level

[14]When considering inertial constraints and imperfect markets, a difference of 30\$/tCO_2 is significant for a carbon intensive economy like China, for which the energy share in production costs is high and the salaries share is low (Waisman et al, 2012a).

of exportations that is less sensitive to a climate policy when the world is more regionalized. Indeed, the “Regionalized Trade” assumption is implemented through Armington elasticities (see section 2.3), which control in particular the sensitivity of exportations to prices’ competitiveness. The smaller this parameter is, the less sensitive are the exportations to the variations of prices. The reduction of exportations, due to the climate policy[15], is thus less significant than with higher Armington elasticities (i.e. in a more globalized world). On the long-term, the regionalization of trade triggers a significant better situation, in particular when compared to the case where no climate policy is implemented. For example in 2070, the Chinese GDP under climate constraint is 5.5% higher than in the continued globalization scenario, while it is only 1.3% higher in the business-as-usual situation. Similarly to the case without climate policy, the lower reliance on international transport reduces the oil dependency of the economy and generates a higher GDP (see section 3.2). In addition to that, this decrease of global oil demand in the ‘Regionalized Trade’ scenario induces a lower carbon price than in the ‘Continuous Globalization’ one (e.g. 970 $/tCO_2$ vs. 1050 $/tCO_2$ in 2070), which induces a less hurt Chinese economy.

These results show that globalization processes are not neutral for the Chinese economy when a global carbon pricing is used as the major mitigation policy instrument. However, similarly to the case without climate policy, the assumptions on globalization prove to hardly affect the average trends, as demonstrated by the close values of average growth rates in Table 6.

	Continued Globalization	**Fragmented Capital**	**Regionalized trade**	**De-Globalization**
2010-2050	4.49%	4.44%	4.53%	4.52%
2050-2100	0.96%	1.02%	1.05%	1.09%

Table 6: Effective Chinese GDP growth rates under climate policy in the four globalization scenarios

Moreover, it is worth noting the mechanisms at play between 2050 and 2070 when the dominant effect is due to the fast increase of carbon prices. In the long-term indeed, different visions of globalization do not radically change the conclusions of a long-lasting crisis with growth rates below their natural level (1.38% over 2050-2100). The assumptions on globalization do not modify the basic cause of this outcome i.e. the necessity to control

[15] The climate policy, namely the carbon pricing policy, generates variations in the prices’ competitiveness of goods.

transport-related emissions. This proves that acting on globalization processes is insufficient to avoid important socio-economic costs due to the sustainability challenge raised by climate change.

5. Conclusion and policy implications

Building upon the main results of the paper, this section summarizes the salient macroeconomic effects on China of the different constraints imposed by the depletion of fossil fuel resources, global mitigation policies and different visions of globalization. Furthermore, it provides principles to frame the implementation, at the Chinese level, of climate and energy policies consistent with the challenges raised in the "green growth policies" announced in the 12th Five Year Plan[16].

5.1 Incentives for energy security and climate stabilization: are global prices appropriate instruments?

The economic theory advocates market prices as the most efficient way of addressing environmental constraints, whether it be international energy or carbon prices. This modeling exercise thus considers these economy-wide instruments as major determinants of changes since they provide signals affecting agents' behaviors in different components of economic activities.

The analysis of the results demonstrates that these types of instruments can trigger deep changes required under energy and climate constraint, but not without adverse effects on the Chinese economy. In particular, the analysis reveals that market price instruments may induce risk of large economic downturns when the environmental constraints (depletion of fossil fuel resources and carbon constraint) force drastic but unanticipated economic changes. Indeed, market prices under imperfect expectations (about oil scarcity in particular), may provide "wrong" incentives likely to induce allocations of investments that may reveal ill-adapted to future energy-economy conditions. This is notably the case in Section III where moderate oil prices during the first decades do not prepare the Chinese economy to oil disruptions that occur during Peak Oil period. Whatever the globalization process considered, this causes low medium-term growth rates that remain well below their natural level, revealing large socio-economic tensions. This illustrates that energy price signals, and oil prices in particular, are insufficient to support a transition towards sustainable low-oil patterns for a big oil-importer country like China. The same phenomenon is observed when a carbon price is introduced to

[16] In particular in its third and sixth chapter (see Li and Wang (2012) for details on these chapters content)

force the economy to adjust to a global climate constraint, inducing very low Chinese growth rates. Indeed, the results in Section IV display that a global carbon price allows for reaching an ambitious stabilization target (+2.5°C with respect to pre-industrial level) but entails significant Chinese socio-economic costs throughout the century. Moreover, we find that the different assumptions on globalization, with or without climate constraint, do not modify the long-lasting crisis relative to the transportation sector, due to the significant increase of the fraction of the Chinese population that gains access to road-based mobility.

These results concur to demonstrate that global price signals resorting to market adjustments may not be suitable to provide "correct" information on future energy conditions and may hence favor "wrong" allocation of investments hampering growth and welfare. They can be a useful tool to frame the Chinese transition process towards a sustainable energy future, but if they are used alone, they may entail significant socio-economic costs that make the double sustainability challenge hardly viable and acceptable for China. This calls for the introduction of investment incentives that depart from pure market price signals and that incorporate long-term views on resource and climate through a strong political will. In particular, complementary instruments must be considered both at the local level through sectoral and fiscal measures and, at the global level, through non-pricing policies.

5.2 Complementary local policies

The Chinese demand for energy resources is expected to grow significantly in the future, which is notably due to the rapid growth of urbanization, per capita incomes, stock of motor vehicles and energy intensive industries (like power generation, steel and cement). Facing the double challenge of oil depletion and climate change, local policies are thus of the most importance for the economic sustainability of China. Aware of this situation, the Chinese government has already announced and undertaken numbers of measures in crucial sectors for energy and climate issues (as part of the Five Year Plans) [17]. The complexity is to implement

[17] See for example the different energy efficiency standards and labelling programs for appliances and equipment like the minimum energy performance standards (MEPS), the mandatory categorical energy information label (China Energy Label), the voluntary efficiency certification label or the National and Local Enforcement of Energy Efficiency Standards and Label Project (Zheng Khanna et al., 2013; CNIS,2011; CNIS, 2010). See also the regulatory and voluntary instruments undertaken by the Chinese government to reinforce buildings' energy efficiency (Climate Group, 2011, MOHURD, 2011) like for instance the "Design Standard for energy efficiency of public buildings (GB50189-2005)", the "Standard for lighting design in buildings (GB50034-2004)", the "Evaluation standard for green building (GB/T 50378-2006)", or the Leadership in Energy and Environmental Design (LEED) scheme (see Chen and Lee, 2013 for details).

local measures in sectors faced with behavioral biases (imperfect foresights of future energy prices for instance) and technical inertias. The modeling exercise helps to identify some key challenges for their design regarding long-term sustainability objectives.

In fact, sectoral measures should not be only “no regret options”, but should also anticipate the future of energy resources and hence reduce the vulnerability of the economy to energy system changes on the short-term as well as on the long-term. A key result of Section 3 is that short-term market prices are a biased signal to inform future energy conditions, which make them insufficient to accelerate technical change towards low-oil dependency of the Chinese economy in due time. As a corollary, given the inertias in sectors like buildings and transportation, it seems necessary to implement the measures in these sectors as early as possible, i.e. to anticipate the changes of economic conditions to foster the diffusion of energy efficiency in due time and not to wait until the emergence of a clear price signal.

Furthermore, in line with the “green growth policies” announced (and launched for some of them) in the 12^{th} Five Year Plan, sectoral measures should not be limited to energy efficiency, but also include infrastructure policies that affect the structure of socio-economic interactions and its exposure to energy and climate constraints (Li and Wang, 2012; Waisman et al., 2014). This is particularly true for the high energy and carbon intensive transportation sector. Given the weak price sensitivity of this crucial sector, specific measures to control mobility are therefore necessary, especially in the Chinese urban areas that are growing very quickly and characterized by rapidly increasing motorization rates. The results of section 4 have highlighted the necessity of very high carbon price to curb transport related emissions and the induced drastic slowdown of economic growth after 2050. But the core of these costs can be avoided provided that the deployment of infrastructures favoring sustainable cities and low-transport production systems starts in the early phase of the climate policy (Waisman et al., 2013a; Li, 2011). Early investments in critical infrastructures could *(i)* avoid long-term technological and behavioral lock-ins into high carbon emissions pathways, and *(ii)* allow for gaining development and environment co-benefits (Shukla and Dhar, 2011).

To go further into the assessment of these policies, the model could be improved to represent infrastructure networks and behaviors associated to the building and transport sectors. This means in particular incorporating an explicit representation of mechanisms related to urban dynamics and production structure, including the logistics organization. The role of crucial sectoral measures would thus explicitly captured.

Finally, the results of section 4 have also highlighted significant short-term socio-economic tensions when a global mitigation policy is implemented. This is due to the necessary steep increase of the carbon price at the beginning of the policy in order to have a signal strong enough to redirect investment choices towards low-oil/carbon patterns. These short-term transition costs obviously go along with significant unemployment issues, which can create high social and political obstacles for the implementation of a climate policy. Therefore, in order to promote an inclusive growth with green policies in a context of global mitigation action, the Chinese government could consider the implementation of fiscal reforms based on the carbon tax revenue recycling (Lu et al., 2010). "Carbon revenues" could be used for instance to lower labor costs, which would offset the short-term increase of energy prices and foster employment during the carbon transition. This would enhance income, consumption and living standards, and hence increase the social and political acceptability of global mitigation policies.

5.3 Complementary global policies

In this paper we have pointed out non-pricing global measures as crucial dimension of sustainable pathways for the Chinese economy. Indeed, sensitivity tests on globalization processes helped identifying basic mechanisms that link globalization and macroeconomic trajectories under energy and climate constraints.

In absence of any climate policy, moving towards more regionalized trade where local firms are less exposed to international competition has two major effects. On the short-term, we observe a significant reduction of the Chinese exportations inducing a drop of the GDP. Whereas at a longer term horizon, the reduction of trade volumes goes with a decoupling between consumption patterns and transport, which has the advantage of reducing transport-related energy and carbon uses and being thus beneficial for the Chinese economy. Regarding capital flows, fragmented markets releases capital for local investments in China since it is a net capital exporter. This improves the resilience of this oil-importing economy to rising oil prices. However, the fragmentation of global capital markets affects the pace and direction of technical change, which make the Chinese economy more hurt by a global carbon pricing policy than in a continued globalized world. Conversely, China is less affected when good markets are regionalized due to *(i)* the less sensitivity of exportations to price variations induced by carbon pricing on the one hand, and to *(ii)* the lower reliance on international transport reducing the oil dependency of the economy on the other hand.

To go further into this analysis of globalization patterns under energy and climate constraints, the model could be improved by representing explicitly all determinants of capital allocation. This would help analyzing the conditions of investments' allocation in accordance with energy sustainability objectives. Indeed, the redirection of investment yet needs specific devices. Hourcade and Shukla (2013) building upon Hourcade et al. (2012) show the crucial role of organizing a "low-carbon finance" able to generate a sufficient amount of capital and to direct them towards the funding of low carbon infrastructures.

5.4 Towards a policy mix to tackle long-term energy sustainability issues

The Chinese "green growth policies" announced in the 12th Five Year Plan state implicitly that china has to maximize synergies between competitiveness, energy security and environmental sustainability. The above analysis identifies challenges that require a policy mix that resorts to a plurality of complementary instruments. This mix of policy instruments to tackle the twofold challenges posed by resource scarcity and climate change must be designed to benefit from potential synergies between both objectives. The analysis of the medium-term effect of a carbon pricing policy in Section 4 has showed the potentials for co-benefits of carbon control measures. It can act as a hedging strategy against the scarcity of oil reserves and ensures an environmentally friendly society. In addition, the articulation and the time sequencing of policy instruments must be a key concern when designing the policy mix to ensure a sustained action throughout the century. On the one hand, price instruments have an immediate effect and the implementation of fiscal reforms - based on the recycling of carbon tax revenues- generates their co-benefices on the short-term. On the other hand, policies targeting long-lived infrastructure involve a gap between their implementation and their ultimate effects. This is why, in particular, early investments in transport infrastructures to support climate action are required to ensure that they generate benefits in the middle of the century. They then become crucial to control transport-related emissions due to the increasing access to oil-based mobility. Therefore, in order to help funding low-carbon infrastructures early enough, global processes for the establishment of a "low-carbon finance" should be strongly encouraged.

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