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Endogenous technical change linked to international mobility of primary factors in climate change scenarios: global welfare implications using the GTAP model

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Abstract

Recent econometric literature suggests that the level of the economic activity and economic productivity are linked to changes in temperature. The relationship is non-linear, inverted U-shaped and generalizable to both developing and developed countries. An optimum level of temperature seems to be associated with an optimum level of productivity. Starting from this our research question is to evaluate ex-ante the welfare (GDP) implications for the global economy induced by an increase in the international mobility of primary factors (labor and capital) associated with climate impacts on economic productivity. To achieve this goal we use a neo-classical Computable General Equilibrium model, GTAP. Compared to the standard GTAP we only modify the supply of labor and capital to allow for the international mobility of primary factors. Results show that in case of an asymmetric climate impact between regions international mobility of primary factors (capital and labor) can transform a climate cost in a climate opportunity. Importantly, a stronger negative climate impact can increase the climate opportunity provided by the international mobility of primary factors. The explanation behind these results is the movement of labor and capital prices which drive the relocation of primary factors toward the most productive regions.

1. Introduction

Recent econometric literature (Burke et al., 2015) suggests that the level of the economic activity and economic productivity are linked to changes in temperature. The relationship is non-linear, inverted U-shaped and generalizable to both developing and developed countries. An optimum level of temperature seems to be associated with an optimum level of productivity. By implying substantial changes in temperature climate change could re-shape the level and the distribution of economic productivity across the globe and trigger economic losses much bigger than those predicted by most of the Integrated Assessment Models (IAMs) so far (Burke et al., 2015; Sterner, 2015). Using the estimated relationship between productivity and temperature, the GDP and population projections in Shared Socioeconomic Pathways (SSP) 5 scenario (O'Neill et al., 2015) and the temperature increase in RCP 8.5 (van Vuuren et al., 2011), Burke et al. find that climate change could reduce global output by 23% in 2100 compared to a world without climate change. If societies continue to function as they have in the recent past, climate change is expected to reduce considerably not only the global economic output but also to amplify existing global economic inequalities. This is essentially due to the asymmetric physical impacts of climate change.

As said, this could happen if societies continue to function as they have in the recent past. The recent past is supposed to be about 50 years which is the time span in the analysis of Burke et al. (2015) from 1960 to 2010. Clearly the role of adaptation and mitigation are crucial to avoid incurring big economic losses. In this study we focus on adaptation and in particular on the political and/or technological conditions which could improve adaptation through the global market mechanism. These political and/or technological conditions are the international mobility of primary factors (labor and capital). The global market mechanism is the price signal which should drive the geographical movement of labor and capital. The two primary factors follow the endogenous price signals triggered by the physical climate impact and re-locate in regions where the remunerations of primary factors are higher. The fundamental condition for this mechanism to take place is the existence of a global market for primary factors. *Our research question is to evaluate ex-ante the welfare (GDP) implications for the global economy induced by an increase in the international mobility of primary factors (labor and capital) associated with climate impacts on economic productivity.* We also address the regional welfare and the inequality between regions by looking at the changes in the relative prices.

In a sense we try to shed some light on the potential determinants of the challenges to adaptation in the SSP scenarios which are characterized by a high degree of uncertainty and under a continuous revision process (O'Neill et al., 2015). "Socioeconomic challenges to adaptation are defined as societal or environmental conditions that, by making adaptation more difficult, increase the risks associated with any given projection of climate change" (Rothman et al., 2014; O'Neill et al., 2014). It is important to stress that SSPs narratives describe challenges to mitigation and to adaptation which refer to characteristics of society, not to the amount of climate change or the stringency of the mitigation policy (factors that are not included in SSPs). As a consequence the determinants of the challenges are socioeconomic and environmental (but not climatic) (O'Neill et al., 2015).

By using expert elicitations Schweizer and O'Neill (2014) identify 13 main elements which are important for the definition of the challenges to adaptation and mitigation. Among these 13 elements *quality of governance* and *innovation capacity* are detected as particularly relevant for adaptation and disaggregating them in their different dimensions is also worthwhile for future research. In this study we identify international mobility of labor and capital as a potential key dimension of *quality of governance* and *innovation capacity* which are in turn key determinants of the challenge to adaptation. The increased international mobility of labor and capital can be considered as both a shift in the policy and technological framework. For example relaxing barriers to the international mobility of labor can be seen as a shift in the policy framework. Reduced

transport costs for capital as a consequence of the growth of the Information & Technology can be seen as a shift in the technological framework.

In order to improve the quality of the scenarios and to search for policy relevant features, other analytical tools in addition to IAMs should be used (Schweizer and O'Neill, 2014). Currently, the IAMs are the most widespread tool to carry out the economic assessment of losses induced by Climate Change at the global level because they are able to capture the feedbacks between climate and economy in a consistent framework. The RICE (Nordhaus, 2011), PAGE (Hope, 2011), FUND (Anthoff and Tol, 2012) and WITCH (Bosetti et al, 2006) models are good examples. Even if these tools are probably the most suitable for assessing the economic impacts of climate change at the global level, unfortunately they cannot consider some economic and social channels which could be interesting to look at. One of these is the above mentioned international mobility of labor and capital. This channel is fundamental to answer our research question and we have to include it in the modelling framework. To achieve this goal we use a neo-classical Computable General Equilibrium (CGE) model, GTAP (Hertel, 1997). The CGE models are also a global widespread tool used for the economic assessment of climate change impacts (Bosello et al, 2012; Ciscar et al, 2011; Darwin and Tol, 2001). Compared to the IAMs, CGE models usually do not take into account the feedbacks between climate and economy but they are able to introduce more flexibility in the economic system in terms of goods mobility (trade), capital flows and labor movements at the international level. This is exactly what we need to implement in our experiment.

The type of adaptation we want to capture by using the neo-classical CGE model is very specific. This is market-driven adaptation. The concept of market driven adaptation is somewhat similar to that one of autonomous adaptation adopted by IPCC¹. Autonomous adaptation does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. In our study the market-driven adaptation has even a more restrictive but poorly investigated connotation because it implies the spatial reaction of labor and capital at the international level following the price signals the two factors can detect in their respective markets.

The paper is organized as follows. In section 2 we briefly explain the theoretical structure of the standard GTAP model and the changes we have introduced with respect to it. In section 3 we describe the experiment design. Section 4 presents the general results for the global welfare and also for inequality across regions through the examination of the relative prices. In section 5 we discuss these results and their potential interaction with other socio-economic drivers in the global economy. Section 6 concludes and offers some insights for further development of this work. In the Appendix at the end of paper we carry out a sensitivity analysis on the parameter regulating the international mobility of labor and capital.

2. Theoretical structure

We use a standard neo-classical CGE, the GTAP model which is calibrated to the GTAP 9 database (Aguiar et al., 2016), a series of Social Accounting Matrixes (SAMs) for the base year 2011. The behavioral parameters of the model are derived on the basis of econometric estimations or using the economic theory (Hertel, 1997; Jomini et al., 1991). The representative agents are households and firms. The representative household maximizes utility under the budget constraint in each region and the representative firm maximizes profits under the technological constraint in each region and sector. Perfect competition holds in the markets and the agents have perfect information on the market prices. The neoclassical structure implies that investments are saving driven.

¹ <https://www.ipcc.ch/pdf/glossary/ar4-wg2.pdf>

It is worth noting that the economic system is supposed to be in equilibrium in the base year. After a shock in the economic system relative market prices adjust in such a way demand equals supply and the system reaches the new equilibrium. The shocks can be socio-political, technological and environmental. In the present framework we do not introduce any intertemporal dynamics and any stationary condition on the evolution of capital. The potential role played by technological progress or accumulation of capital and labor over the years will be discussed in section 5.

With respect to the standard GTAP model we only modify the supply of labor and capital. In the standard GTAP model the regional supply of labor and capital is exogenous and geographically immobile. As a result, workers and capital cannot move outside the region they belong to in response to the shock. We use a Constant Elasticity of Transformation (CET) function to endogenously model the regional supply of labor and capital. In other words we are introducing two additional maximization programs for the agents capital and labor. The two agents maximize their respective global income flows (from labor and capital) under the international mobility constraint.

The First Order Conditions of the two maximization programs are the regional supply functions and the equation determining the world price of the endowment (shadow price), Eqs. [1]-[4], where QL, QK, PL and PK represent, respectively, the quantity of supplied labor, capital and the associated prices. Globe and r are, respectively, the global aggregate index and the regional index. The elasticity of substitution in the CET function (σ) allows us to set different scenarios for the international mobility of these two primary factors. A value of zero means no mobility, a negative value means international mobility between regions. Raising the absolute value increases the international mobility. We set a value of minus ten for both labor and capital to model the international mobility.

$$QL_r = QL_{GLOBE} \left(\frac{PL_{GLOBE}}{PL_r} \right)^{\sigma_L} \quad \text{with } \sigma_L \leq 0 \quad [1]$$

$$\sum_r QL_r PL_r = QL_{GLOBE} PL_{GLOBE} \quad [2]$$

$$QK_r = QK_{GLOBE} \left(\frac{PK_{GLOBE}}{PK_r} \right)^{\sigma_K} \quad \text{with } \sigma_K \leq 0 \quad [3]$$

$$\sum_r QK_r PK_r = QK_{GLOBE} PK_{GLOBE} \quad [4]$$

By changing the behavioral parameter σ we are assuming that policy maker is able to improve the *quality of governance* and the *innovation capacity* and consequently the international mobility of labor and capital. From a modelling point of view this is equivalent to create a global market for labor and capital where labor and capital can take advantage of the price signals to re-locate according to their respective maximization programs which First Order Conditions are illustrated in Eqs [1]-[4].

For the simulations we have used the Gempack software (Harrison et al., 2014). A multi-step Gragg solution method has been implemented to solve the non-linear system of First Order Condition equations. In the macro-economic closure we have assumed that investments are saving-driven and the net investments funds are allocated across regions to maintain the existing composition of global investments².

² This is equivalent to set the parameter Rordelta equal to zero in the Gempack code.

3. Experiment design

We conduct a comparative static experiment. We use the CGE model as a laboratory where we can control some political and technological conditions, notably the international mobility of capital and labor. We also assume that we can translate the changes in temperature in changes in economic productivity. First we implement the climatic shocks and then for the same climatic shocks we modify the international mobility of primary factors. This is the typical *ex-ante* analysis and makes possible to isolate and explain the contribution of a given environmental, technological or political variable in the economic system (*what if*).

In the CGE model the changes in temperature are represented by uniform per cent changes in the productivity of primary factors (capital, labor, land and natural resources). These shocks are exogenous and are supposed to represent permanent variations of temperature and related productivity in the long run. The underlying hypothesis is that climate shocks evenly impact the usage of labor and capital in the different economic sectors of the region. Maybe this is not very realistic but in absence of better information it represents a reasonable simplification. In addition further differentiating the impact by sector would not be very relevant for the research question of this work.

We simulate two types of climate impact **intensity** (**low** and **high**), two types of climate impact **distribution** across the globe (**symmetric** and **asymmetric**) and two types of **international mobility** for labor and capital (**no mobility** and **mobility**). Regions are ten: Oceania, East Asia, South East Asia, South Asia, North America, Latin America, Europe, Middle East and North Africa (MENA), Sub Saharan Africa (SSA) and Rest of the World. Sectors are three: agriculture, industry and services.

Table 1 indicates the exogenous shocks in the low/high intensity and symmetric/asymmetric case. In the low intensity case we arbitrary assume a productivity loss by 10% at the global level; in the high intensity case this loss is doubled. The shocks are not empirically estimated. They are theoretical and represent just a basis to understand the economic implications of the experiment. Only for the distribution of the impacts in the asymmetric case, we have tried to follow previous studies (Burke et al., 2015). The existence of the optimal temperature implies that some regions located in the Northern latitude could get closer to the optimum because of the temperature increase and experience productivity gains. Other regions could move away from the optimum and experience substantial productivity losses. However the specific geographical distribution is not very relevant for the general comprehension of our experiment.

Table 1: climate impacts on productivity of primary factors (land, natural resources, labor and capital)

	Low sym	Low asym	High sym	High asym
Oceania	-10	-25	-20	-45
East Asia	-10	-30	-20	-55
South East Asia	-10	-40	-20	-75
South Asia	-10	-40	-20	-75
North America	-10	0	-20	4
Latin America	-10	-25	-20	-60
Europe	-10	14.66	-20	22.78
MENA	-10	-30	-20	-70
SSA	-10	-40	-20	-75
Rest of World	-10	0	-20	4
Globe	-10	-10	-20	-20

4. Results

4.1 Global and regional welfare (GDP)

Table 2 shows the results on GDP for the symmetric/asymmetric case in the low intensity impact scenario with no international mobility and with international mobility. Table 3 shows the results on GDP for the symmetric/asymmetric case in the high intensity impact scenario with no international mobility and with international mobility.

Table 2: GDP % changes (low intensity scenario)

	Sym No Mob	Asym No Mob	Sym Mob	Asym Mob
Oceania	-9.99	-24.91	-9.76	-51.41
East Asia	-9.98	-29.73	-9.80	-56.25
South East Asia	-9.99	-39.81	-10.27	-68.12
South Asia	-9.93	-39.42	-10.76	-60.56
North America	-10.02	-0.10	-10.30	13.62
Latin America	-9.97	-24.87	-10.25	-51.78
Europe	-10.08	14.79	-9.80	93.00
MENA	-10.00	-29.94	-9.65	-55.35
SSA	-9.97	-39.62	-9.77	-69.63
Rest of World	-9.95	0.11	-9.76	14.48
Globe	-10.01	-9.88	-9.99	2.14

Table 3: GDP % changes (high intensity scenario)

	Sym No Mob	Asym No Mob	Sym Mob	Asym Mob
Oceania	-19.98	-44.91	-19.55	-76.05
East Asia	-19.96	-54.59	-19.62	-81.19
South East Asia	-19.98	-74.77	-20.51	-91.09
South Asia	-19.87	-73.95	-21.42	-85.5
North America	-20.03	3.79	-20.61	32.4
Latin America	-19.94	-59.73	-20.5	-86.98
Europe	-20.17	22.96	-19.61	139.82
MENA	-20.01	-69.84	-19.32	-90.01
SSA	-19.94	-74.46	-19.53	-92.67
Rest of World	-19.92	4.17	-19.54	30.2
Globe	-20.03	-19.83	-19.99	7.28

The observation of the results in Table 2 and 3 allows us to carry out the following two *Propositions*.

Proposition 1: *in case of an asymmetric climate impact international mobility of primary factors (capital and labor) can transform a climate cost in a climate opportunity.*

Explanation of *Proposition 1* is straightforward. We can immediately notice that in presence of symmetric climate impacts the international mobility of primary factors has no relevant effect on the global welfare. This is not the case when climate impacts are asymmetric. In this case labor and capital move from the most negatively affected regions to the regions experiencing productivity gains or no productivity loss. This takes place because labor and capital follow the price signals, that is the higher remuneration in not affected or positively affected regions. Remunerations are higher in the latter regions because the global demand for goods produced in these regions has increased given the goods can be produced at a lower cost. The

increased demand for goods by households translates in an increased demand for primary factors by firms. If the factors are geographically immobile, the regional supply is fixed and the increased demand by the firms will boost the prices of labor and capital. When the geographical mobility option is activated regional supply is no more fixe and a certain amount of labor and capital will move in order to get a higher remuneration. As a consequence, the productivity loss in the most negatively affected regions will affect a smaller amount of labor and capital while the productivity gain will affect a bigger amount of labor and capital. The technical change is endogenous because a fraction of labor and capital becomes more productive following the price signals determined endogenously in the labor and capital markets at the global level.

Proposition 2: *in case of an asymmetric climate impact the higher intensity of the climate impact can increase the climate opportunity provided by the international mobility of primary factors.*

This result sounds paradoxical but the underlying explanation is also clear like in Proposition 1. When the productivity loss is stronger, the market price signals on capital and labor remunerations are also stronger. In general the outflows of labor and capital stop when the reductions in the supply of labor and capital compensate the reduction in the demand of labor and capital due to the fact the global consumers substitute the goods produced in the most negatively affected regions with goods produced in the not affected (or positively) affected regions. When the negative shocks on productivity are stronger, bigger reductions in the supply of labor and capital are needed to reach the equilibrium point and to stop the outflows of primary factors. This means on the other side that a bigger amount of labor and capital will increase its productivity by migrating in the regions not affected or positively affected by climate change. The observation of Table 4 makes this clear.

Table 4: % changes in capital and labor supply in the asymmetric case with international mobility

	Capital Low Intensity	Capital High Intensity	Labor Low Intensity	Labor High Intensity
Oceania	-37.65	-59.47	-35.38	-56.81
East Asia	-39.38	-60.51	-38.14	-59.61
South East Asia	-50.75	-69.42	-47.28	-64.64
South Asia	-38.24	-50.01	-36.16	-46.88
North America	12.91	27.86	14.49	28.25
Latin America	-37.53	-69.67	-36.55	-69.06
Europe	67.28	96.02	70.76	98.61
MENA	-41.08	-73.78	-35.63	-63.91
SSA	-55.73	-78.17	-49.82	-71.05
Rest of World	14.56	26.92	16.04	27.75

4.2 Inequality across regions: relative prices

The good point in using the General Equilibrium approach for policy simulations is the possibility to explore all the dimensions of the economic system in a consistent framework. The changes in the relative prices of labor, capital and goods represent important dimensions to characterize the new equilibrium and structure of the economic system. They give interesting insights on inequality across regions because refer to unit prices while the previous section referred to the aggregate regional and global GDP. Clearly this is not an issue for global GDP as the global population is fixed but has some implications for regional GDP as this measure should be cleaned by the inflows/outflows of capital and labor. The best way to achieve this goal is looking at the changes in the relative prices and the CGE model is probably the most suitable tool to do it.

Tables 5, 6 and 7 show % changes in the relative price of labor, capital and final goods. The first distinction we have to do is still between the asymmetric and symmetric case. When the climate shocks are symmetric the effects on relative prices of primary factors are always small with and without international mobility. On the other hand the relative prices of goods increase around 11% and 25% in the symmetric low intensity and symmetric high intensity case, respectively, no matter the assumption about international mobility we do. The effects are homogenous across regions. What happens in the economic system?

The uniform decrease in productivity determines a reduction in the supply of goods. For a given level of the real demand (the amount of capital and labor representing the resources of the household) the price of goods will rise. Clearly the price of goods will increase more when the productivity loss will be bigger (high intensity case). But why are the effects on the price of primary factors so small? The reason is that the climate shocks are geographically uniform and, as a consequence the effects on the price of goods will be geographically uniform too. This implies that the representative consumer in each region will continue to buy similar shares of the domestic and imported goods and no international substitution between domestic and imported goods will take place. Therefore the representative firm in each region will keep its demand of primary factors unchanged. Finally the relative prices of labor and capital will not move substantially and the assumption about mobility of primary factors will become irrelevant.

In the asymmetric case the scenario changes dramatically. The effects on relative prices of primary factors are now considerable and very different according to the assumption about international mobility of primary factors. The % changes are very similar between labor and capital. This is not surprising and depends on the fact that the shocks are uniformly applied to both the primary factors. The relative prices of final goods are not only differentiated by the intensity of the climate impact but also differentiated by region and degree of international factors mobility. How is the economic system behaving in this scenario?

To understand the economic chain in this scenario we start from the no international mobility assumption for primary factors and analyze the results of two regions, Europe and Sub Saharan Africa (SSA), which represent well the two extremes of the asymmetric climate impact (positive and negative). These two extremes are useful to explain the general economic dynamics in the CGE. In the SSA the negative productivity shock determines a reduction in the supply of goods. For a given level of the real demand (the amount of capital and labor representing the resources of the household) the price of goods will rise. As before, the price of goods will increase more when the productivity loss will be bigger (high intensity case). Conversely, in Europe the positive productivity shock determines an increase in the supply of goods. For a given level of the real demand the price of goods will reduce. But what happens to the global demand for goods in the case of a no more uniform price change across regions? Because the effects on the price of the final goods are now different the representative consumer in each region will substitute the domestic and imported product. For instance Europe will increase the demand for domestic product and decrease that of imported product and the opposite will happen for Africa. Therefore the demand for the European goods will strongly increase and more than offset the increase in the supply determining a price increase in goods (9.08% and 23.02% in the low and high intensity impact, respectively). The demand of firms for primary factors will increase too and the price of primary factors will rise by 23% and 47%. In the SSA demand will reduce but not enough to compensate the reduction in the supply of goods and the price will go up by 21.29% and 60.13% (recall that the absolute value of the productivity shock in the SSA is between 2.7 and 3.2 times bigger depending on the intensity than that of Europe). The smaller demand from consumers will mean smaller demand of firms for primary factors and, as a consequence, the price of labor and capital will reduce strongly, in a range between 26 and 27% in the low intensity case and between 57% and 59% in the high intensity case.

When the assumption about international mobility of primary factors is introduced the scenario changes again considerably. Let's start from the last outcome, the different changes in the price of primary factors.

When the climate shocks were geographically symmetric no significant divergence was observed across regions in the relative prices of capital and labor. Now we have these strong divergences and relaxing the political and technological barriers to mobility provokes huge inflows and outflows of capital and labor. Clearly, labor and capital move toward Europe and out of Africa. Not surprisingly, the opening of the global market for labor and capital makes the divergences in the primary factors price between regions much less pronounced. Interestingly the huge inflow of labor and capital in Europe still determines an increase in the relative prices of primary factor (around 5% and 6%) while in Africa the reductions are much less strong (around 6% and 13%) compared to the no international mobility assumption. On the other hand the opening of the global markets for labor and capital causes stronger divergences across regions for the price of goods, especially in the high intensity case (-5.34% in Europe and +117% in SSA). This is due to the fact that the outflows of labor and capital from Africa combined with the negative productivity shock will decrease the supply more than the demand. In Europe the opposite will happen. The inflows of labor and capital combined with positive productivity shock will increase supply more than demand.

Some political implications can be drawn from the examination of the relative prices. First of all when capital and labor are geographically immobile the asymmetric nature of climate impacts strongly exacerbates the inequality across regions both in primary factors market and goods market. For instance in Europe the price of labor and capital rise more than the price of goods. In SSA not only the price of labor and capital decreases but the increase in the goods prices is more than that of Europe.

When barriers to labor and capital mobility are relaxed price inequality between regions decreases in the primary factors market but increases in the goods market. However, taking one of the most negatively affected regions SSA as an example and considering international mobility of primary factors, goods price is 1.5 or 2 times bigger comparing relative prices with and without international mobility of primary factors while the reduction in the price of capital and labor is about 4 times smaller.

Another politically relevant result is that the opening of labor and capital market at the global level causes an increase in the relative price of the primary factors even in those regions experiencing a huge inflow of primary factors, like Europe. One could expect that the arrival of many foreign workers reduce the wages but when we consider the international macro-economic context in which this arrival takes place we discover that increase in the goods demand from domestic and foreign consumers more than offset the inflow of foreign workers.

Table 5: % changes in relative wages

	Sym No Mob LI	Sym Mob LI	Sym No Mob HI	Sym Mob HI	Asym No Mob LI	Asym Mob LI	Asym No Mob HI	Asym Mob HI
Oceania	-0.03	-0.13	-0.08	-0.29	-12.68	-4.60	-24.39	-9.34
EastAsia	-0.01	-0.13	-0.02	-0.29	-16.17	-5.02	-32.94	-9.95
SEAsia	-0.29	-0.18	-0.62	-0.40	-25.66	-6.52	-54.17	-11.14
SouthAsia	-0.86	-0.25	-1.85	-0.55	-24.45	-4.72	-48.57	-7.44
NAmerica	-0.27	-0.19	-0.61	-0.42	9.50	1.02	26.58	1.08
LatinAmer	-0.32	-0.19	-0.71	-0.43	-13.45	-4.77	-42.74	-12.32
Europe	-0.01	-0.12	-0.02	-0.26	23.55	5.14	47.70	5.60
MENA	0.14	-0.11	0.32	-0.24	-15.87	-4.64	-46.69	-10.95
SSA	0.11	-0.12	0.23	-0.27	-26.04	-6.98	-57.05	-12.90
Row	-0.02	-0.13	-0.04	-0.29	10.25	1.15	27.96	1.04

Table 6: % changes in relative prices of capital

	Sym No Mob LI	Sym Mob LI	Sym No Mob HI	Sym Mob HI	Asym No Mob LI	Asym Mob LI	Asym No Mob HI	Asym Mob HI
Oceania	0.02	-0.07	0.03	-0.15	-12.75	-3.53	-24.31	-9.25
EastAsia	-0.06	-0.08	-0.13	-0.18	-16.27	-3.80	-33.12	-9.49
SEAsia	-0.33	-0.13	-0.72	-0.29	-26.37	-5.78	-55.77	-11.77
SouthAsia	-0.87	-0.20	-1.89	-0.43	-24.87	-3.63	-49.47	-7.33
NAmerica	-0.21	-0.12	-0.46	-0.28	9.69	2.37	27.02	1.80
LatinAmer	-0.19	-0.12	-0.43	-0.27	-13.25	-3.51	-42.51	-11.85
Europe	-0.05	-0.07	-0.12	-0.15	23.25	6.47	47.07	6.24
MENA	0.07	-0.05	0.16	-0.12	-17.15	-4.08	-51.32	-13.12
SSA	-0.11	-0.08	-0.23	-0.18	-27.45	-6.78	-59.32	-14.70
Row	-0.04	-0.07	-0.08	-0.16	10.48	2.52	28.52	1.72

Table 7: % changes in relative prices of final goods

	Sym No Mob LI	Sym Mob LI	Sym No Mob HI	Sym Mob HI	Asym No Mob LI	Asym Mob LI	Asym No Mob HI	Asym Mob HI
Oceania	11.15	11.08	25.10	24.91	16.07	22.85	37.20	49.88
EastAsia	11.23	11.17	25.31	25.15	18.89	28.51	46.75	72.43
SEAsia	11.28	11.32	25.42	25.51	21.09	31.46	61.35	107.08
SouthAsia	11.24	11.42	25.33	25.74	25.37	35.03	85.35	138.57
NAmerica	10.93	11.00	24.54	24.72	10.31	2.96	23.74	0.82
LatinAmer	11.05	11.12	24.84	25.02	15.55	22.41	42.95	82.18
Europe	11.15	11.09	25.09	24.94	9.08	-3.07	23.02	-5.34
MENA	11.36	11.26	25.64	25.38	17.49	22.74	55.48	89.22
SSA	11.49	11.43	25.95	25.78	21.29	31.93	60.13	117.19
Row	11.25	11.19	25.36	25.22	10.97	3.85	25.29	3.86

5. Discussion of results

The two propositions in section 4.1 are the result of a comparative static exercise where no baseline scenario has been built. We have tried to be as general as possible in order to identify and explaining the economic dynamic behind the experiment. It turns out that the asymmetry and the intensity of the climate impact together with the international mobility of labor and capital can transform a climate cost in a climate opportunity. The apparent paradox is that a stronger negative intensity of the global climate impact can even amplify the benefits stemming from international mobility of the primary factors.

Clearly the above-mentioned economic dynamic will interact with other socio-economic drivers in the future. We identify 3 main socio-economic drivers:

- 1) demographic projections
- 2) capital accumulation
- 3) technological progress (substitution between labor and capital)

We will examine each one of these drivers separately and finally analyze them together. This will help us to disentangle the contribution of each driver and understand how this contribution could change in association

with the other drivers, the asymmetric climate impacts and the assumption about international mobility of primary factors.

We start from the population (UN, 2015). In general, the demographic projections are more reliable than economic forecasts because the generation of future mothers is already born and there is empirical evidence that the fertility rates tend to change slowly. We know that population in developed countries will be stationary or even declining in the next decades while the population in the developing countries will keep growing but probably at decreasing growth rates. This implies that the stock of labor will increase more in developing countries. Keeping unchanged the amount of capital and making no specific hypothesis on technological progress, this in turn means that the price of labor in developing countries will reduce and that of developed countries will remain stable. If we assume that climate impacts could be close to zero or even positive in the Northern latitude (Europe, North America and Russia) and negative elsewhere, the demographic patterns are likely to amplify the inequality of labor price across regions. In this case the international mobility of labor would have an additional reason to be promoted because the productivity gain coming from the relocation of workers will concern a higher number of persons from developing countries.

The second important driver is the capital accumulation. We can assume a catching-up process between developed and developing countries. GDP per capita tends to converge across regions and this is due to the stronger capital accumulation in the developing countries which start from a lower level of capital stock. To some extent this takes place also in the SSPs and it is consistent with neo-classical growth models (Solow, 1956; Cass, 1965; Koopman, 1965). In a sense the capital accumulation is similar to labor accumulation because we can expect a bigger increase in the capital stock of developing countries. Therefore the price of capital will decrease in developing countries more than that in developed countries. The reduction of the capital price in developing countries associated with climate impacts could enlarge the distance between capital prices across regions and increase the opportunity provided by the international mobility of capital.

What happens when we consider both population projections and capital accumulation. In general we can assume that capital accumulation is bigger than labor accumulation. To maintain an average of 1% or 2% annual GDP growth rate in the next decades for developing countries as a reference and making no assumption on technological progress, capital accumulation must be greater than the current demographic projections. We have tried to replicate these facts in a very stylized exercise. We have used the standard GTAP model with the same regional and sectoral aggregation illustrated in Section 3. As in section 4.2 we take Europe and Sub Saharan Africa as the two representative regions. In a very rough way we increase the capital stock and labor stock in SSA region by respectively 40% and 5% and we assume Europe in a stationary situation for both capital and population. We assume no international mobility of labor and capital and we just look at the changes in the primary factors price to understand the potential for global welfare gain deriving from the re-location of labor and capital. The results for this very simple exercise show that the price of capital decreases in the SSA while the price of labor increases. The explanation for this opposite dynamic between labor and capital prices is that the increase in the capital and labor stock is not uniform. The growth in the capital supply is 40% in SSA but the growth of demand is an average between 40% and 5% (recall that the income of the representative household comes from the remuneration of primary factors). As a consequence the capital price will go down. The opposite will happen with labor. The reduction in capital price will be bigger than the increase of labor price in absolute value because the growth of capital is bigger than the growth of labor. Overall the labor price dynamic stemming from the growth of both primary factors could reduce the international asymmetry of relative wages coming from the climate impacts. Conversely the capital price dynamic stemming from the growth of both primary factors could increase the international asymmetry in the relative price of capital coming from climate impacts.

Finally we try to examine the role of technological progress. It is difficult to do predictions on the evolution of this variable. It is also difficult to imagine how we should model the technological progress, in an

exogenous way or rather endogenously. And if endogenously what type of assumptions should we introduce (Acemoglu, 2009). Clearly the regional and sectoral asymmetry of the technological progress will be crucial to amplify or mitigate the asymmetry of climate change impacts. One key parameter to define how the technology will change in the future is the substitution between labor and capital (Piketti, 2014). We can easily assess the role of this parameter in the CGE framework. We multiply by 5 the value of this parameter for all regions in the standard GTAP model and we replicate the previous experiment for Europe and SSA, where we increased the capital and labor stock, by 40% and 5% respectively in the SSA. As usual we look at the relative price changes for labor and capital. When the substitution between labor and capital is increased the effects on European prices of capital and labor are still small but the two prices tend to converge in the SSA. In the SSA the labor and capital prices tend to converge toward a negative price because the decrease of capital price is bigger than the increased in the labor price in absolute terms and this is due to the bigger growth of capital compared to labor. Therefore the higher substitutability between labor and capital could amplify the benefits stemming from the international mobility of primary factors and the asymmetric climate impacts.

We should highlight that all these results refer to a situation in which the economy is in equilibrium in the base year. The overall picture could substantially change if we imagine an economy still doing its transition path.

6. Conclusions and further research

This work aims at shedding some light on the potential role played by international mobility of labor and capital for global welfare in the context of climate change scenarios. The work can be useful also to identify key dimensions of *quality of governance* and *innovation capacity* which are in turn key determinants of the challenge to adaptation in the SSP scenarios.

The two fundamental characteristics of the climate impacts are their geographical asymmetry and their intensity. The results show that the international mobility of labor and capital can transform a climate cost in a climate opportunity in case of asymmetric impacts. The apparent paradox is that a bigger negative intensity at the global level can even increase this opportunity. The explanation behind these results is the movement of labor and capital prices which drive the relocation of primary factors toward the most productive regions.

Further research will consist in integrating the exogenous productivity impacts in the CGE model through an endogenous damage function and carrying out a more extensive analysis of the asymmetry and intensity of the climate impacts. This requires the coupling between the macro-economic model and the climate models. The coupling with the climate models via the estimated econometric relation between temperature and productivity will be crucial to give more realism and more accuracy to the economic effects. In addition the coupling will make possible to include all the feedbacks between the economy and the climate, in particular the feedback of the level of the economic activity on the level of Co2 emissions and temperature, which is missing in this study. The integration requires a deeper investigation in the climate models and it is interesting to assess how the damage function could possibly interact with the intensity and asymmetry of the climate impacts.

Another line for further research would be to fully develop this comparative static exercise in a SSP scenario (O'Neill et al., 2015). SSP5 seems to be the most suitable as it assumes an increasing degree of international mobility and market integration in the global economy and little effort on mitigation. This development will make possible to evaluate the interaction between climate impacts, international mobility of primary factors and the three drivers we have discussed in section 5 for all regions in the world.

We have to point out that large uncertainty characterizes the climate impacts, especially for what concerns the intensity. However there is less uncertainty on the fact that these impacts will be asymmetric. As a final message, *this study highlights the importance to consider market adaptation in the form of a more integrated global market for labor and capital as a possible strategy option to deal with climate change*. We should acknowledge that the existence of this more integrated global market poses tremendous political challenges, especially for the international mobility of labor. The feasibility of the autonomous market adaptation via the international mobility of primary factors should be evaluated very carefully also by comparing it with other strategy options on mitigation efforts.

References

- Acemoglu D., 2009. First-Generation Models of Endogenous Growth. Introduction to Modern Economic Growth. Princeton: Princeton University Press. pp. 387–407.
- Aguiar A., Narayanan B, McDougall R., 2016. An Overview of the GTAP 9 Data Base, *Journal of Global Economic Analysis*, no. 1 181-208.
- Anthoff D., Tol R.S.J., 2012. Climate damages in the FUND model: A comment, *Ecological Economics*, 81: 42.
- Bosello F., Nicholls R.J., Richards J., Roson R., Tol R.S.J., 2012. Economic impacts of climate change in Europe: sea level rise, *Climatic Change*, No. 112(1), pp. 63-81.
- Bosetti V., Carraro C., Galeotti M., Massetti E., Tavoni M., 2006. WITCH. A World Induced Technical Change Hybrid Model, Working Papers 2006 46, Department of Economics, University of Venice Ca' Foscari.
- Burke M., Hsiang S. and Miguel E, 2015. Global non-linear effect of temperature on economic production, *Nature*, 527, 235–239.
- Cass D., 1965. Optimum Growth in an Aggregative Model of Capital Accumulation. *Review of Economic Studies*, 32, 233–240.
- Ciscar J.-C., Iglesias A., Feyen L., Szabó L., Van Regemorter D., Amelung B., Nicholls R., Watkiss P., Christensen O.B., Dankers R., Garrote L., Goodess C.M., Hunt A., Moreno A., Richards J., Soria A., 2011. Physical and economic consequences of climate change in Europe. Proceedings of the National Academy of Sciences of the United States of America, 108(7), pp. 2678-2683.
- Darwin R., Tol R., 2001. Estimates of the Economic Effects of Sea Level Rise, *Environmental & Resource Economics*, European Association of Environmental and Resource Economists, vol. 19(2), pages 113-129, June.
- Hertel, T.W. (Ed.), 1997. Global trade analysis: Modeling and applications, Cambridge and New York: Cambridge University Press.
- Harrison J., Horridge M, Jerie M, Pearson K., 2014. GEMPACK manual, GEMPACK Software, ISBN 978-1-921654-34-3.
- Hope, C.W., 2011. The social cost of CO2 from the PAGE09 model, Economics Discussion Papers 2011-39, Kiel Institute for the World Economy.
- Jomini P., Zeitsch J.F., McDougall R., Welsh A., Brown S., Hambley J., Kelly j., 1991. SALTER: A General Equilibrium Model of the World Economy, Vol. 1. Model Structure, Data Base, and Parameters. Canberra, Australia: Industry Commission.
- Koopmans T.C., 1965. On the Concept of Optimal Economic Growth. In The Econometric Approach to Development Planning. Amsterdam: North Holland, 1965.
- Nordhaus, W.D., 2011. Integrated Economic and Climate Modeling, Yale University Cowles Foundation for Research in Economics, Discussion Paper 1839.

O'Neill B.C., Kriegler E., Riahi K., Ebi K.L., Hallegatte S., Carter T.R., Mathur R., Vuuren D.P., 2014. A new scenario framework for climate change research: the concept of shared socioeconomic pathways, *Climatic Change*, 122, 387–400.

O'Neill B.C., Kriegler E., Ebi K.L., Kemp-Benedict E., Riahi K., Rothman D.S., van Ruijven B.J., van Vuuren D.P., Birkmann J., Kok K., Levy M., Solecki W., 2015. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century, *Global Environmental Change*, 42: 169-180.

Piketty T., 2014. *Capital in the Twenty-first Century*. Cambridge Massachusetts: The Belknap Press of Harvard University Press.

Rothman D.S., Romero-Lankao P., Schweizer V.J., Bee B.A., 2014. Challenges to adaptation: a fundamental concept for the shared socio-economic pathways and beyond, *Climatic Change*, 122, 495–507.

Schweizer V.J., O'Neill B.C., 2014. Systematic construction of global socioeconomic pathways using internally consistent element combinations, *Climatic Change*, 122, 431–445.

Solow R.M., 1956. A Contribution to the Theory of Economic Growth. *Quarterly Journal of Economics*, 70, 65–94.

Sterner T., 2015. Higher costs of climate change, *Nature*, 527, 177–178.

UN (United Nations), 2015. World Population Prospects. Available at: <https://esa.un.org/unpd/wpp/>

van Vuuren D.P., Edmonds J., Kainuma M., Riahi K., Thomson A., Hibbard K., Hurtt G.C., Kram T., Krey V., Lamarque J.-F., Masui T., Meinshausen M., Nakicenovic N., Smith S.J., Rose S.K., 2011. The representative concentration pathways: An overview, *Climatic Change*, 109 (1): 5-31.

Appendix: sensitivity analysis on σ parameter

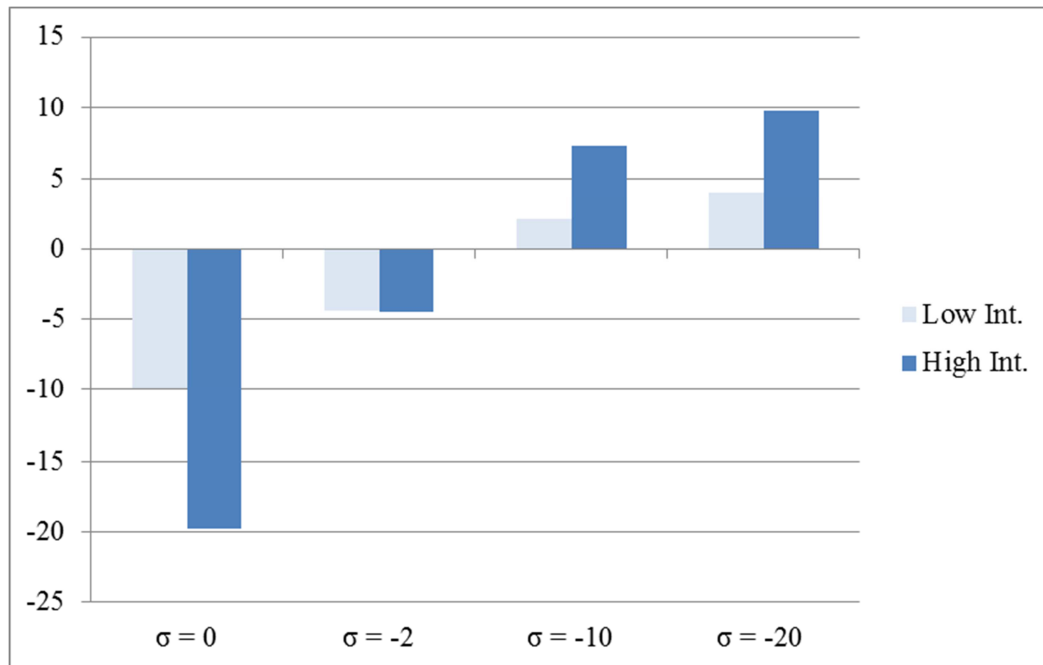
The key parameter of this analysis is clearly the elasticity of substitution (σ) in the CET function which determines the regional supply of labor and capital. In order to test the robustness of our conclusions, in particular the robustness of the two Propositions but also the robustness on the inequality across prices discussed in section 4.2, we carry out a sensitivity analysis on σ .

Graphs 1-4 finally confirm the main conclusions of this work. The parameter σ ranges from 0 to -20. In the previous sections we have used a value of zero and minus ten. We consider two additional cases: minus two and minus twenty. We can define these two additional cases as low mobility and high mobility of primary factors, respectively.

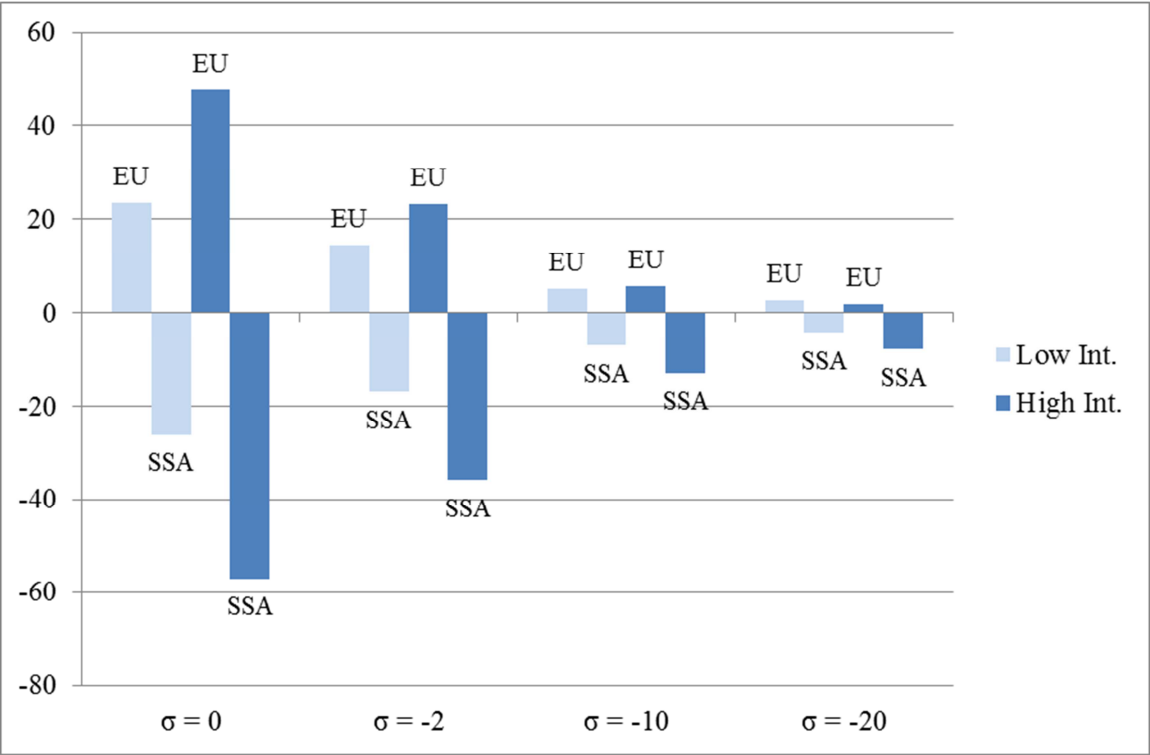
Graph 1 displays results for global GDP. Interestingly, in the low mobility case the world will still incur economic losses but in the low intensity case they will be cut by more than half and in the high intensity case by more than 75%. In the high mobility case and high intensity scenario the benefits could even reach 10% of global GDP.

Graphs 2-4 illustrate results for relative prices of labor, capital and goods. As usual we take SSA and Europe as representative of the most negatively affected regions and the not affected or positively affected regions. Not surprisingly, increasing the value of the elasticity σ results in a stronger convergence process for the price of labor and capital between Europe and SSA. Conversely, increasing the value of the elasticity σ results in a stronger divergence process for the price of goods between Europe and SSA.

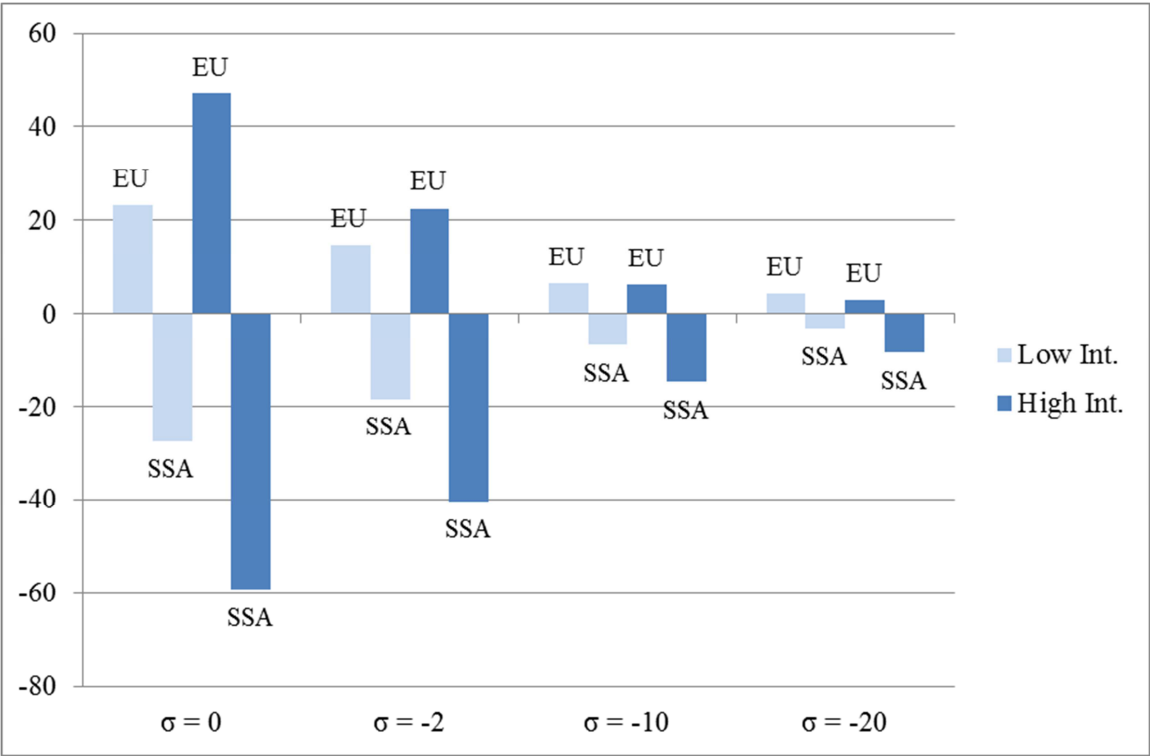
Graph 1: global GDP % changes (low intensity and high intensity scenarios with asymmetric impacts)



Graph 2: % changes in labor price between Europe and SSA (low intensity and high intensity scenarios with asymmetric impacts)



Graph 3: % changes in capital price between Europe and SSA (low intensity and high intensity scenarios with asymmetric impacts)



Graph 4: % changes in goods price between Europe and SSA (low intensity and high intensity scenarios with asymmetric impacts)

