Modelling the competition for land between traditional agriculture and Bio-fuel production

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Introduction

Since the industrial revolution, human actions have driven rapid growth in greenhouse gas emissions, to the point where we have modified the Earth's atmospheric composition and are changing the climate. This poses a significant threat to our economic development, prosperity and wellbeing. As fossil fuel burning accounts for 90% of all anthropogenic emissions, global mitigation efforts will mainly involve policies to target the production and consumption of fossil fuels. Introducing a carbon price on fossil fuel consumption, either in the form of a direct tax, or via a permit price under a cap and trade scheme, is widely considered to be an essential component of any cost-effective policy to decarbonise the economy. However, imposing a carbon price incurs ancillary costs to economic activities and can potentially reduce economic outputs.

It is important to recognise that not all the burden of mitigation need to be assumed by reducing industrial emissions. Some mitigation can be achieved by producing Bio-fuels that can substitute fossil fuels and sequestering carbon to generate 'negative' emissions. However, the growth of Bio-fuels implies a new competitor for land that would be otherwise used for traditional agricultural activities, in particular, food production. The Food and Agriculture Organization of the United Nations (FAO) estimates that the global food production must increase by 60% by 2050 in order to keep up with the pace of population growth. Therefore, the production of Bio-fuels for global climate mitigation will be primarily a compromise between the benefits of reducing global climate change and the costs of feeding the growing world population. Finding an optimal global balance between the uses of land for growth of Bio-fuels and production of food requires us to quantify the associated trade-offs.

In this paper, we apply the dynamic version of the GTAP Bio-fuel model (GDyn-Bio) to investigate the climate and socioeconomic implications of Bio-fuel production in the context of global carbon mitigation. The GDyn-Bio model describes the treatment of energy substitution, the role of Bio-fuel by products, specification of bilateral trade, the determination of land cover changes in response to increased Bio-fuel feedstock production, and changes in crop yields. Furthermore, the model modifies the GTAP framework to incorporate different types of land (Agro Ecological Zones, AEZ), and it has a detail accounting for four greenhouse gas emissions (CO_2, N_2O, CH_4 and F-gases). These features make the model a suitable tool to study the policy contention surrounding Bio-fuels.

Methods and hypothesis

Competition over land for Food and Bio-fuels

We start the modelling exercise with a baseline scenario representing a world in 19 regions (Table 1) in which economic activities progress along pathways that assume no climate change mitigation policies are implemented. Under this baseline scenario the production of Bio-fuels will be minimal. Then, we simulate a mitigation policy scenario in which a trajectory of global carbon price is imposed. The carbon price starts at US$ 5 per ton of CO2-e in 2015 and increases by 4% per year. Then, we repeat this exercise with a baseline and global carbon mitigation scenarios that assumes agricultural optimization. The imposition of carbon price will set off the development of Bio-fuels world-wide. The inter-comparison and trajectories from the model realisations will allow us to test several hypotheses.

Assuming that agricultural productivity and technologies remain unchanged, then the production of Bio-fuels will directly compete with the production of commodities for land. We hypothesise that developed regions favoured by biogeography (e.g. regions that scatter across greater number of AEZs, or that contain AEZs that are associated with better yields) will be in better position to produce Bio-fuels. Also, developed regions will be able to import food from other regions where labour is cheaper. Regions that are in disadvantage to produce Bio-fuels, will perceive an increase in food prices and labour. Then, an increase in the price of food will impact on exports' price and labour, so developed regions that were importing 'cheap' food may decide not to produce Bio-fuels and continuing with traditional agriculture. Note that socio-cultural motivations to produce one or the other commodities were not taken into consideration.

Given that in the mitigation scenario the production and export of Bio-fuels will be subject to carbon price, we could expect that regions that start producing Bio-fuels may decide to go back to traditional agriculture and pay the tax because a higher demand from imported commodities may trigger an increase in the costs of commodities and labour.

The focus of our analysis are 4 commodities (paddy rice, soybeans, wheat & coarse grains, this is mostly corn) that account for > 75% of the calories that humans directly or indirectly consume (Cassman, 1999), in addition to the production of Bio-fuels. We maintain control of the forestry industry based on the assumption that the forestry industry will grow to keep pace with the other commodities. Forest productivity is an exogenous variable in our model calculated as a weighted average of the other land industries. We calibrated GDP and oil price based on labour and population from 2004 to 2010, values from 2010 to 2100 are calculated by the model.

Table 1. Regional aggregation of GDyn-Bio

Code in Gdyn-Bio	Regions
USA	United States of America
EU27	Albania, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Rest of EFTA, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom
BRAZIL	Brazil
CAN	Canada
JAPAN	Japan
CHIHKG	China & Hong Kong
INDIA	India
C_C_Amer	Mexico, Costa Rica, Guatemala , Nicaragua, Panama , Rest of Central America, Rest of Caribbean Regions
S_o_Amer	Argentina, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Rest of South America
E_Asia	Korea, Taiwan, Rest of East Asia
Mala_Indo	Malasia & Indonesia
R_SE_Asia	Cambodia, Lao People's Democratic Republic, Myanmar, Philippines, Singapore, Thailand, Vietnam, Rest of Southeast Asia
R_S_Asia	Bangladesh, Pakistan, Sri Lanka, Rest of South Asia
Russia	Russia
Oth_CEE_CIS	Albania, Belarus, Croatia, Ukraine, Rest of Eastern Europe, Kazakhstan, Kyrgyzstan, Rest of Former Soviet Union, Armenia, Azerbaijan, Georgia, Turkey
Oth_Europe	Switzerland, Norway
MEAS_NAfr	Bahrain, Islamic Republic of Iran, Israel, Kazakhstan, Kuwait, Oman, Qatar, Saudi Arabia, Turkey, United Arab Emirates, Rest of West Asia
S_S_AFR	Nigeria, Senegal, Ethiopia, Madagascar, Malawi, Mauritius, Mozambique, Tanzania, Uganda, Zambia, Zimbabwe, Rest of Eastern Africa, Botswana, South Africa, Rest of South African Customs Union, Rest of Western Africa, Rest of Central Africa, Rest of South Central Africa
Oceania	Australia, New Zealand, Rest of Oceania

Scenarios design

Our baseline is calibrated to the 'business-as-usual' scenario with no global carbon mitigation. The population estimates are taken from the medium variant of the United Nations' World Population Prospects (United Nations, 2013), with a global population of 10.6 billion people in 2100. Productivity of the agricultural sectors, such as paddy rice, soybeans, wheat & coarse grains is assumed to keep on increasing but with a decaying annual growth rate which drops gradually from 0.5% in 2015 to 0.2% in 2100. The annual growth rates of regional input productivities are iteratively derived such that regional Gross Domestic Products (GDP) will continue the momentum of growth, with world GDP reaching 150 trillion in constant 2004 dollars (2004 US$). These productivity shocks are applied uniformly across all non-agricultural sectors. Assuming no exhaustion or expansion of current reserves, the supply of fossil fuels will continue the trend of growth through more capital, labour and immediate inputs. The demand for fossil fuels will ease due to the improvement of energy efficiency and the use of bio-fuels. As a result, global GHG emissions will stabilize at 157 gigatonnes (Gt) of CO2-e in 2100. In the context of this study, CO2-e accounts for the emissions of CO_2, N_2O and CH_4. For the reference, the CO2-e emissions for the baseline scenario are slightly higher than in the Intergovernmental Panel on Climate Change (IPCC) projections under the RCP8.5 scenario;

however, we consider our baseline realistic and in line with the recent literature (see for example Raupach et al. (2014)).

The ‘carbon-tax’ scenario (hereafter ‘CTAX’) follows the same parameters as in the baseline but with global carbon mitigation. A carbon tax is set to start at around US$ 5 per ton of CO2-e in 2016 and increases gradually from 0.2% rate in 2015 to 5.4% by 2100. Note that GDyn-Bio assumes that users’ first response to achieve CO2 mitigation is to reduce energy consumption, so we would expect a decline in energy consumption as a first response when comparing the baseline with the CTAX scenario.

The ‘agricultural optimization’ scenario (hereafter ‘AO’) is the same as the baseline, with no global carbon mitigation, but with a uniform annual increase in agricultural production of 0.2% from 2015 to 2100. In this scenario we expect greater agricultural production than in baseline and greater emissions in regions with strong economies. The last scenario is the ‘carbon-tax & agricultural optimization’ (hereafter ‘CTAX_AO’) that is a combination of CTAX and AO. This scenario aims at understanding the impact of an increase in agricultural production (same as in AO) with global carbon mitigation (same as in CTAX). The research question behind the generation of the last two scenarios is to know if the agricultural optimization would diminish competition between production of Bio-fuels and food.

Results

Impacts of mitigation on the economy

Here we compare and present the global GDP projections for the four scenarios. The projections for GDP show no change until the carbon tax is applied in 2015, then GDP projections start to diverge between scenarios with and without global carbon mitigation (Figure 1). The scenarios that assumed an agricultural optimization present GDP values around 10% higher than their counterparts. Global projections in GDP are projected to decrease for the carbon mitigation scenarios when compared with their respective baselines. This is, the GDP in the CTAX scenario is projected to decline by around 4%, relative to the baseline, while the CTAX_AO scenario is projected to decline by 3% relative to the AO scenario (Figure 1).

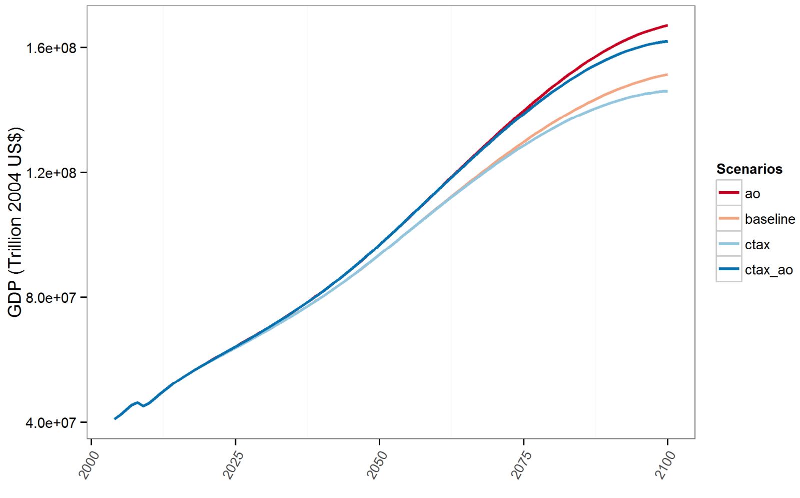

Figure 1: Global GDP projections under the 4 socio-economic scenarios

GHG emissions

The modelled scenarios projected global CO2-e emissions in 2100 that ranges from 86 Gt to 158 Gt (Figure 2). The baseline and AO scenarios, characterised by no global carbon mitigation, present almost an identical trend for the CO2-e emissions. For these scenarios with no global carbon mitigation the trend in CO2-e gradually increases until 2030 to reach about 70 Gt, then it reaches a twofold increase and by 2100. The CTAX and CTAX_AO scenarios, whit global carbon mitigation, track below 75 Gt by 2050, then they slightly diverge. The CTAX_AO scenario presents higher CO2-e than CTAX, peaking to 96 Gt in 2080 and stabilising at 89 Gt by 2100. The CTAX scenario shows a peak in emissions in 2080 of 92 Gt and stabilises at 86 Gt by 2100 (Figure 2).

At the regional scale, the increase in CO2-e emissions from 2015 to 2100 will not be uniform. For example, USA and China & Hong Kong present a threefold increase in emission by 2100 under the scenarios with no global carbon mitigation (baseline and AO), while other regions, like India and Europe present a twofold increase, and others almost no change (Figure 3). The gap between 2015-2100 in CO2-e emission under the scenario with global carbon mitigation is less marked than in the scenarios with no carbon mitigation and, for example, CO2-e emissions for China & Hong Kong are projected to be lower than USA's by 2100 (Figure 3).

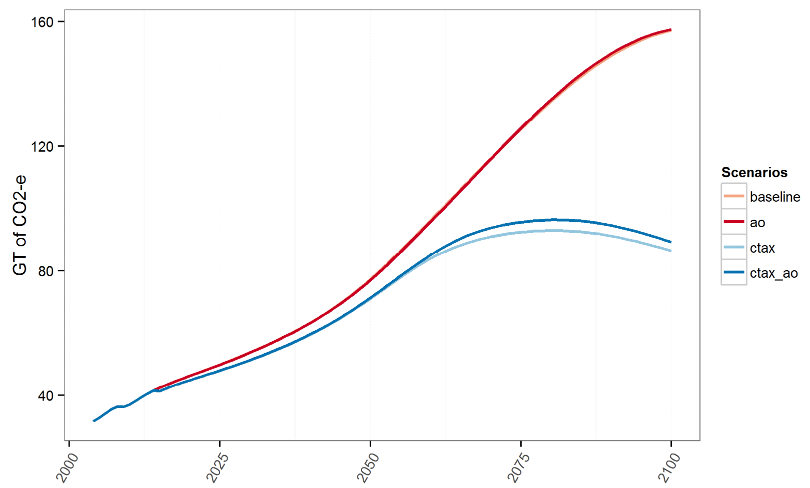

Figure 2: Global emissions of CO2-e projected to 2100 under the 4 socio-economic scenarios

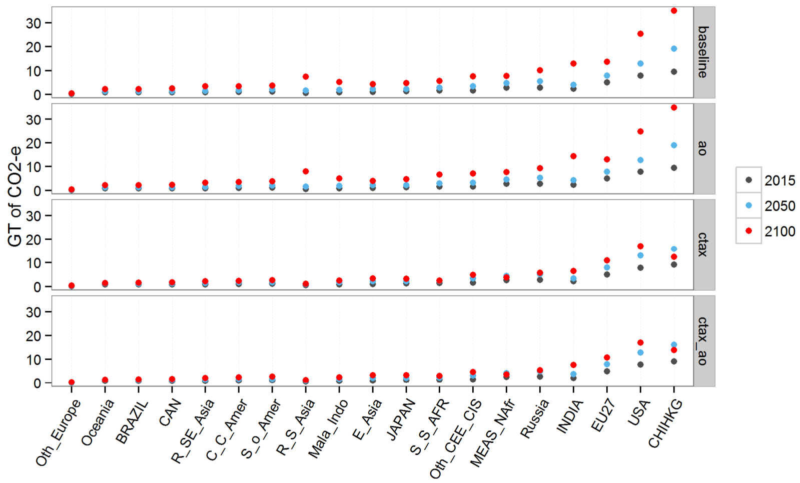

Figure 3: Regional projections for CO2-e emissions to 2015, 2050 and 2100 under the 4 socio-economic scenarios.

Production of food

Agricultural production of paddy rice, soybeans, wheat & coarse grains are projected to respond differently under the 4 scenarios. In general, the scenarios with agricultural optimization (AO and CTAX_AO) present, by 2100, around 20% more production relative to the baseline (Figure 4). However, the analysed commodities have a contrasting respond to the carbon tax. For example, production of soybeans and coarse grains present no response to carbon tax, there are no differences between the baselines scenarios and the carbon tax scenarios. The projected production of paddy rice shows a negative response towards the end of the century and the production of wheat, in contrast, presents a positive response to the carbon tax (Figure 4).

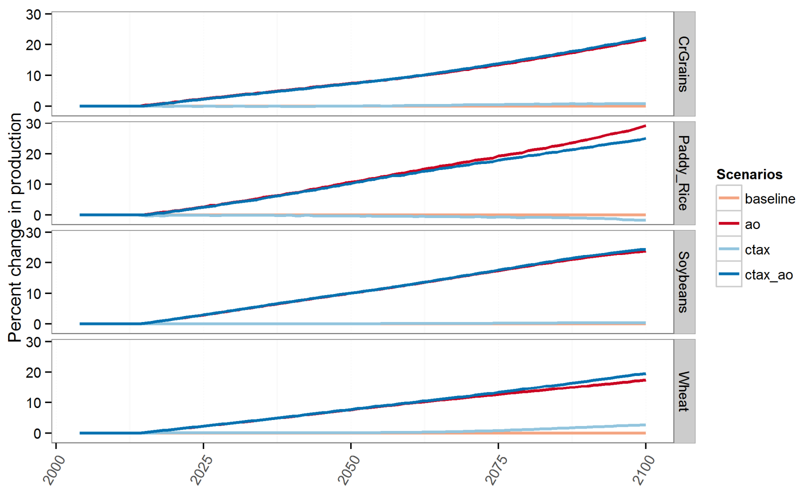

Figure 4: Projection of relative change in crop production for the socio-economic scenarios relative to baseline.

Production of Bio-fuels

We compare and present the global deviations from baseline in Bio-fuel production for the scenarios with and without carbon mitigation. The comparison is done by looking at the differences between, in one hand, the baseline *versus* the CTAX scenario, and in the other hand, the AO *versus* the CTAX_AO (Figure 5). Our projections show that the global production of Bio-fuel presents a negative response to global carbon mitigation in the first half of the century of about 1 billion of gallons regardless the assumption of agricultural optimization (Figure 5). However, this trend is reversed in 2060, where both scenarios with global carbon mitigation present greater production of Bio-fuel when compared to the baseline scenarios (baseline and AO), being the CTAX_AO the scenario with the greatest increase in Bio-fuel production, peaking 20 billion of gallons by 2100 (Figure 5).

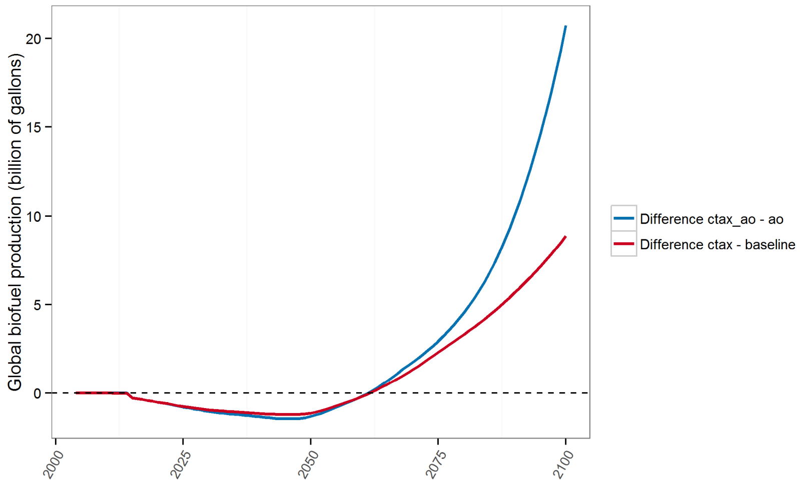

Figure 5: Projection of deviations from baseline in Bio-fuel production.

Preliminary discussion and conclusions

Economy and bio-fuel production

As calibrated in the baseline scenario the global projections for GDP continue the momentum of growth, with world GDP reaching 150 trillion in constant 2004 dollars (2004 US$). The CTAX scenario followed a similar trend in global GDP, diverging from baseline after 2060 to reach 146 trillion of US$ in 2100 (Figure 1). The reason for the delayed response in the decline in GDP is due to the substitution from energy to capital in the model. This approximates the uptake of low-hanging-fruit mitigation technologies that helps to effectively reduce emissions. However, the existing technologies are limited in their mitigation potential, and the economy will endure hardship if the carbon price rises continuously (Cai et al., 2015).

The projected CO2-e emissions for the baseline (150 Gt CO2-e) are high compared to the IPCC projections for the RCP8.5 that reach 120 Gt CO2-e by 2100 (Riahi et al., 2011). We found no differences between the CO2-e emissions from the baseline and the AO scenario because a high proportion of the emissions are coming from the energy sector. Other contributors to high CO2-e emissions will be an intensification of the agricultural sector, with an increase in the production of food, as well as Bio-fuels and increasing use of fertilizers. The projected CO2-e emissions for the scenarios with global carbon mitigation are close to the projection for the RCP6 scenario by 2100 (Thomson et al., 2011). The CTAX_AO scenario presents slightly higher emissions than the CTAX after 2060. The rationale behind this is that under the CTAX_AO scenario energy becomes less expensive than in the CTAX, so for the same dollar price people are able to utilise more energy, so to emit more. The lag effect can be linked to a rebound effect in the production of Bio-fuels under the carbon tax scenarios that, relative to the baselines, decreases in the first half of the century and takes-off towards a positive response after 2060 (Figure 5).

Food production is projected to increase following the demand by an increasing population. Our projections for the global carbon mitigation scenarios show that paddy rice would be the only commodity to lower production by 2100. Paddy rice cropping systems are a major source of CO_2 regardless the tillage system in place; however, for CH_4 and N_2O zero tillage would make a difference reducing the net emissions of these gases (Ahmad et al., 2009). GDyn-Bio does not differentiate between tillage systems, then, in the context of our study the production of paddy rice is heavily penalised for its emissions. In contrast, wheat production is projected to increase under the global carbon mitigation scenarios. That is linked to the relative low emission, low cost of production and high market price for this commodity.

References

Ahmad, S., Li, C., Dai, G., Zhan, M., Wang, J., Pan, S., Cao, C., 2009. Greenhouse gas emission from direct seeding paddy field under different rice tillage systems in central China. Soil Tillage Res. 106, 54–61. doi:10.1016/j.still.2009.09.005

Cai, Y., Newth, D., Finnigan, J., Gunasekera, D., 2015. A hybrid energy-economy model for global integrated assessment of climate change, carbon mitigation and energy transformation. Appl. Energy 148, 381–395. doi:10.1016/j.apenergy.2015.03.106

Cassman, K.G., 1999. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. Proc. Natl. Acad. Sci. 96, 5952–5959. doi:10.1073/pnas.96.11.5952

Raupach, M.R., Davis, S.J., Peters, G.P., Andrew, R.M., Canadell, J.G., Ciais, P., Friedlingstein, P., Jotzo, F., van Vuuren, D.P., Le Quéré, C., 2014. Sharing a quota on cumulative carbon emissions. Nat. Clim. Chang. 4, 873–879. doi:10.1038/nclimate2384

Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N., Rafaj, P., 2011. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. Clim. Change 109, 33–57. doi:10.1007/s10584-011-0149-y

Thomson, A., Calvin, K., Smith, S., Kyle, G., 2011. RCP4. 5: a pathway for stabilization of radiative forcing by 2100. Clim. Change.

United Nations, 2013. World Population Prospects The 2012 Revision [WWW Document]. United Nations. URL http://esa.un.org/unpd/wpp/documentation/pdf/wpp2012_volume-i_comprehensive-tables.pdf (accessed 4.9.15).