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INTEGRATING BIOFUELS INTO THE DART MODEL: ANALYSING THE EFFECTS OF THE EU 10% BIOFUEL TARGET[1]

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Abstract

Biofuels and other forms of bioenergy have received increased attention in recent times: They have partly been acclaimed as an instrument to contribute to rural development, energy security and to fight global warming but have been increasingly come under attack for their potential to contribute to rising food prices. It has thus become clear that bioenergy cannot be evaluated independently of the rest of the economy and that national and international feedback effects are important. In this paper we describe how the CGE model DART is extended to include first-generation biofuel production technologies. DART can now be used to assess the efficiency of combined climate and bioenergy policies. As a first example the effects of a 10% biofuel target in the EU are analysed.

Keywords

biofuels, CGE model, EU climate policy

1 Introduction

In the past years bioenergy in general and biofuels in particular have received increased attention because they were believed to tackle various problems at once: First, it was hoped that biofuels contribute to greenhouse gas emission reductions thus mitigating climate change. They were seen as an option to reduce emissions in the steadily growing transport sector, where other renewable energy sources are not yet widely available. Second, they were seen as a means of increasing energy security and thus reducing the dependence on energy imports from politically unstable regions. Third, bioenergy was hoped to provide new income sources to rural areas and to promote rural development. These hopes that bioenergy would contribute to solve all three problems have been dampened over time, though, and biofuels have partly fallen in disgrace due to dramatically rising food prices in 2007/2008. The recent developments have clearly demonstrated that the growing bioenergy industry cannot be evaluated independently from the rest of the economy since national and international feedback effects play an important role.

Hence, a general equilibrium model is an appropriate tool in order to get a better understanding of the market impacts of biofuel support policies. We have thus extended the DART model to include the most important first-generation biofuels, i.e. bioethanol and biodiesel. The aim of this paper is to describe the chosen approach and methodology as well as underlying data and assumptions. We present first simulation results focussing on the EU 10% biofuel target and its effects on agricultural markets and prices. The set-up is as follows: The next section starts out with a general introduction of the DART model and continues by explaining in detail the way in which bioenergy production technologies have been incorporated and calibrated. Section 3 presents first results of a 10% biofuel quota scenario in Europe. Section 4 concludes.

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2 Bioenergy modelling in CGE models – An application of DART

2.1 Methodology and research questions

The international scope of CGE models is crucial in order to account for international feedback effects due to globalized agricultural markets and growing biofuel trade. Furthermore, the advantage of a general equilibrium setting is to account for relevant intersectoral linkages, the most important being the interplay of energy and agricultural markets. The general scope comes with a neglect of sectoral detail. Also, it is sometimes rather difficult to disentangle the effects observed and to point out chains of causation because all activities are intertwined. Nevertheless, the CGE approach is very appropriate due to its ability to address the following questions: What role can bioenergy play in an effective and efficient climate policy? What are the economic costs of the European 10% biofuel target? What is the latter's impact on energy and agricultural markets? More concretely, how do agricultural prices and production react in response to it?

2.2 A general introduction to DART

We address these questions with the DART (Dynamic Applied Regional Trade) model, a multi-region, multi-sector recursive dynamic CGE model of the world economy. For the simulation of bioenergy policies, it is calibrated to an aggregation of 19 regions that include current and potential future bioenergy production hotspots (e.g. Brazil, Malaysia and Indonesia) as well as the main bioenergy consuming regions (e.g. different EU regions, USA). As shown in table 1, each model region consists of 21 sectors including 7 energy sectors and 11 agricultural sectors with the most important energy crops.

Table 1: DART regions and sectors

Countries and regions			
EU and other Annex B		**Non-Annex B**	
DEU	Germany	BRA	Brazil
GBR	UK, Ireland	LAM	Rest Latin America
FRA	France	IND	India
SCA	Denmark, Sweden, Finland	CPA	China, Hong-Kong
BEN	Belgium, Netherlands, Luxemburg	MAI	Indonesia, Malaysia
MED	Greece, Italy, Portugal, Spain, Malta	PAS	Rest of Pacific Asia
REU	Rest of EU27	CPA	China, Hong-Kong
USA	United States of America	MEA	Middle East & North Africa
OCD	Rest industrialized OECD	AFR	Sub-Saharan Africa
FSU	Former Soviet Union		
Production sectors/commodities			
Energy sectors		**Agricultural sectors**	
COL	Coal extraction	WHT	Wheat
GAS	Natural gas production & distribution	COR*	Corn
CRU	Crude oil	GRO	Other cereal grains
GSL*	Motor gasoline	OSD	Oilseeds
DIS*	Motor diesel	VOL	Vegetable oils and fats
OIL	Other refined oil products	C_B	Sugar cane, sugar beet
ELY	Electricity	SGR	Sugar
Other production sectors		MLK	Raw milk
ETS	Energy intensive sectors covered by EU ETS	MET	Meat
CRP	Chemical products	AGR	Rest of agriculture & food products
OTH	Other Manufactures & Services	FRS	Forestry

* These sectors where disaggregated from the original GTAP6 database

The economy in each region is modelled as a competitive economy with flexible prices and market clearing and three types of agents: a representative consumer, a representative producer in each sector and regional governments. All regions are connected through bilateral trade flows. The DART model is **recursive-dynamic**, meaning that it solves for a sequence of static one-period equilibria for future time periods connected through capital accumulation. The major exogenous driving forces of the model dynamics are change in the labour force, the rate of labour productivity growth, change in human capital, the fixed savings rate, the gross rate of return on capital, and thus the endogenous rate of capital accumulation. The static model is calibrated to the GTAP6 (DIMARANAN, 2006) database that represents production and trade data for 2001. The elasticities of substitution for the energy goods coal, gas, and crude oil are calibrated in such a way as to reproduce the emission projections of the IEA (IEA, 2007). For a more detailed description of the standard DART model, see KLEPPER et al. (2003).

2.3 DART with bioenergy technologies

We decided to explicitly model the consumption of motor gasoline and motor diesel, so that biofuels can substitute for these. Furthermore, we decided to explicitly model corn production and consumption since corn is an important feedstock for the production of bioethanol. All three sectors – gasoline, diesel and corn – are part of more aggregated sectors in the GTAP6 database. Using additional data from national statistics and the IEA (MWV, 2006, IEA 2003 & 2006) as well as from the CAPRI model (WITZKE and BRITZ, 2005) on trade, input and consumption shares we disaggregated gasoline and diesel from the GTAP sector "refined oil products" and corn from "cereal grains neglected". For more detail see KRETSCHMER et al. (2008).

Once the necessary data have been generated, bioenergy technologies are modelled as so-called 'latent technologies'. A latent technology is inactive in the base year due to higher costs than traditional technologies but its production may take off due to changes of relative prices and cost structures following market forces and/or policy changes. The approach of latent technologies is often used in the context of carbon-free backstop technologies that are activated at a certain price and has a number of advantages (see KRETSCHMER and PETERSON, forthcoming). The approach also fits to the market situation of biofuels where at the beginning of this millennium the technology for producing biofuels existed, but basically no biofuels were produced yet, at least not without governmental support (the exception being Brazil).

The production of biofuels depends on several factors. On the one hand, these are the direct factors influencing the cost of biofuels such as prices of agricultural feedstock inputs and tax exemptions and indirect factors such as blending targets or other political support measures. On the other hand, the production of biofuels is related to the corresponding fossil fuel prices. To take these into account, we use the appropriate cost shares for each biofuel technology and region in DART and incorporate so-called mark ups to account for the difference between production costs and prices. The cost shares are calculated for seven different technologies; biodiesel based on (i) vegetable oil, (ii) soy, (iii) palm, (iv) rape seeds and bioethanol based on (v) sugar cane or sugar beet, (vi) sugar cane (Brazil) and (vii) wheat or corn (see table 2). These include the following inputs: the feedstock, electricity, and a value-added composite of capital and labour. The different cost structures for biofuels were defined with the help of the meó Consulting Team, a consultancy that has built up potential expertise in the bioenergy industry (personal communication with meó, 2007). The technologies are assumed to be available in the countries where we observe some production until the year 2005 (cf. table 3).

Mark ups for bioenergy were calculated based on the quality difference between bioenergy and the corresponding fossil energy source and the difference between bioenergy and conventional energy prices, which have been collected from IEA (2006) and other sources[4]. The quality ratios used are 0.65 for bioethanol and 0.91 for biodiesel. Due to distinct prices, mark ups differ across regions. For bioethanol they vary between 1.7 in Scandinavia and 2.4 in the United States and for biodiesel between 2.8 in Benelux and 3.3 in Germany.

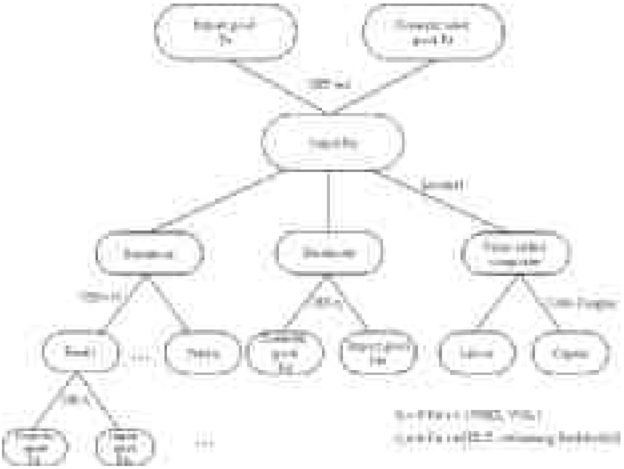
Table 2: Cost shares of bioenergy production

	Biodiesel from				Bioethanol from		
	veg. oil	soy	palm	rape	sugar cane/beet	Sugar cane BRA	wheat/ corn
feedstock	0.80	0.76	0.73	0.79	0.62	0.59	0.62
electricity	0.04	0.04	0.05	0.04	0.15	0.17	0.15
capital	0.15	0.19	0.21	0.16	0.20	0.22	0.20
labour	0.01	0.01	0.01	0.01	0.03	0.02	0.03

Figure 1 displays the nesting structure for the production of the latent bioenergy technologies in DART. The feedstock input is represented by the intermediate input nest and can either be derived from domestic production or be imported. Note that the input factor land is not represented explicitly in the nesting structure. It is implicitly contained in the production of the agricultural inputs used. We have so far presented the production side of biofuels. The crucial elements on the consumption side are that biodiesel and bioethanol perfectly substitute for conventional diesel and gasoline, respectively, which is possible after the disaggregation of diesel and gasoline from the aggregated GTAP sector “refined oil products“. Relative prices between bio- and fossil fuels thus determine which will be demanded.

In order to get a more comprehensive overview of various approaches of modelling bioenergy in CGE models the interested reader is referred to KRETSCHMER and PETERSON (forthcoming) that provide a survey on this issue.

Figure 1: Nesting structure biofuel production



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[4] Data on Brazilian ethanol prices are obtained from UNICA (2008), monthly and annual US prices (FOB prices Omaha, Nebraska) obtained from http://www.neo.ne.gov/statshtml/66.html.

2.4 Calibrating DART with biofuels

After having introduced the latent technologies for the production of biofuels in the different DART regions we calibrate the model to match the production and trade structure that we observe in reality. Without any biofuel support policy only Brazil is able to produce biofuels competitively. Here, we adjusted the cost advantage of bioethanol relative to conventional motor gasoline such that the market penetration in 2005 is around 40%, the actually observed share in that year. In the other DART regions we imposed a subsidy on the production of biofuels whose level is determined endogenously such that the share of biofuel in total fuel consumption matches the data shown in table 4. This subsidy represents policies such as tax exemptions, quotas and explicit subsidies that have led to the current production of biofuels.

Table 3: Shares of biofuel in total fuel consumption in 2005

	Biodiesel (oil seeds and vegetable oils)	Bioethanol			
		SUM	wheat	sugar beet/cane	corn
DEU	6.9	0.7	0.3	0.1	0.3
FRA	1.8	1.8	0.45	0.9	0.45
GBR	0.3	0.1	0.1	-	-
SCA	0.7	2.1		2.1	-
BEN	0.1	0.1	0.05	-	0.05
MED	0.5	0.5	0.25	-	0.25
REU	0.5	0.5	0.499	0.001	-
USA	0.3	2.6	-	-	2.6
BRA	0.1	40.0	-	40.0	-
OECD	0.05	0.4	-	0.2	0.2
CPA	-	1.7	1.7	-	-
IND	0.6	1.7	-	1.7	-

Source: OECD/FAO 2008, personal communication with meó Consulting Team; regions not in the table are assumed to have biofuel shares of approximately zero.

A further important issue is the inclusion of trade in biofuels. EU member states may rely on imported biofuels (if certified) to meet the 10% quota, which is a very likely scenario given a limited biofuel production potential within Europe. It is thus very important to model trade in biofuels but nevertheless difficult due to limited data availability and limitations of the latent technology approach. For bioethanol, there are some trade data available. The largest trade flows are exports from Brazil to Europe and the US. Furthermore, there is some internal EU trade. The problem with the approach of modelling biofuels as latent technologies is that it is difficult to calibrate the model to a certain trade structure that is not fully developed yet but will potentially evolve rapidly. Since our main focus is on analysing EU biofuel policy and since in the near future major exports from any other region are not very likely we assume that bioethanol trade only takes place between Brazil and the industrialized countries.

There are no data on biodiesel trade. World production is much lower than for ethanol with Germany being the largest producer in the world and the EU being responsible for more than 60% of global production. Some trade takes place within the EU. In 2007, the US exported B99 to the EU. This was, however, only possible due to high subsidies in the US. Argentina is a potential exporter of biodiesel and Brazil has a biodiesel program in place but no exports yet. In Asia there are small biodiesel production capacities but currently probably no exports to the EU. However, it is believed that Malaysia and Indonesia could develop a significant export potential (meó Consulting Team, personal communication, 2008). We therefore include small initial shares of biodiesel exports for our model region MAI in order to account for the possibility of future exports. Vegetable oils used for the production of biodiesel can of course be traded. Furthermore, we implemented the import tariffs for biofuels as listed in OECD/FAO (2008).

3 Analysing the EU climate package and the 10% biofuel target

To show global leadership and to foster the international negotiations for a long term international climate regime the EU agreed in March 2007 on legally binding EU climate policy targets that go beyond the Kyoto targets. The two key targets are a reduction of at least 20% (relative to 1990) in greenhouse gases by 2020 – rising to 30% if there is an international agreement committing other developed countries to "comparable emission reductions and economically more advanced developing countries to contributing adequately according to their responsibilities and respective capabilities" and a 20% share of renewable energies in EU energy consumption by 2020 (see EC 2008a). To reach these targets the European Commission put forward an integrated climate policy package adopted by the Council in April 2009 including a directive that contains these two targets and additionally a 10% minimum target for the market share of biofuels by 2020 (EUROPEAN UNION 2008a,b).

3.1 Scenarios

As a first application of the extended DART model we analyse the economic effects of a 10% quota on biofuels until the year 2020. In order to simulate a policy target share for biofuels, a quota is imposed on the Armington supply so that the quota requirement may either be met by domestic production or by imported biofuel. We here consider the following three scenarios:

[REF]: Constant share of biofuels in total fuel consumption at the level of 2005 achieved by a subsidy on domestic production of biofuels; EU reaches 20% reduction target in CO_2 emissions relative to 1990 as announced in the EU climate package; emission trading among the sectors covered by the European emissions trading scheme (ETS); emission targets for the non-ETS sectors are reached by means of a uniform national carbon tax; targets for ETS and non-ETS sectors are derived from national allocation plans and the EU climate package; no use of CDM and JI.[5]

[10Q]: same as [REF] plus a 10% quota on biofuel use in each EU country/region by 2020; quota may be met by domestically produced and imported biofuels.

[10QNT]: Corresponds to [10Q] with the difference that only domestically produced biofuels count towards the 10% EU quota.

For the sensitivity analysis in section 6.3, some scenarios are suffixed by SENSUP and SENSDO in order to denote scenario runs with increased and decreased mark ups, respectively. Details about the implementation of the EU climate package and the targets for the ETS and non-ETS sectors can be found in PETERSON and KLEPPER (2008).

3.2 Simulation Results

When presenting the results we focus on three different issues: changes in the biofuel sectors, effects on the agriculture sectors and finally the overall welfare implications of the biofuel target. Also, we focus on the year 2020. We start with the effects on biofuel production and consumption. Figure 2 represents the total value of biofuel production in the year 2020 in selected regions.

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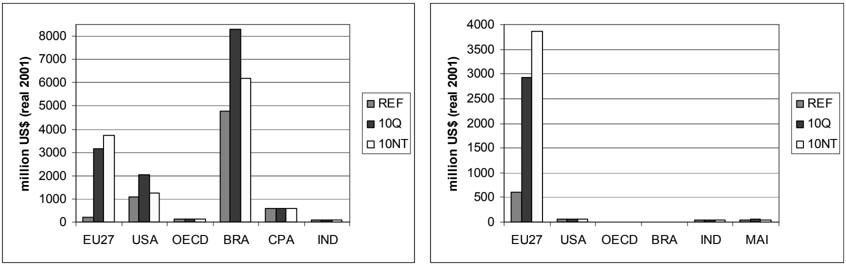
[5] Clean development mechanism (CDM) and joint implementation (JI).

Figure 2: *Bioethanol* (left panel) and *biodiesel* (right panel) production in 2020



Today's world leaders in ethanol and biodiesel production, being Brazil and the EU, respectively, remain the biggest producers over the projection period. The no-trade scenario leads to substantial ethanol production losses in Brazil compared to the [10Q] scenario. The EU makes up for this loss in imports mostly by expanding biodiesel production, but also by increasing ethanol production. Due to the 10% quota, the EU actually becomes the second biggest ethanol producer by the end of the projection period, overtaking the US. This would surely change once the US Energy Independence and Security Act of 2007 is taken into account that calls for 36 billion gallons of biofuels out of total transport fuels by the year 2022. As concerns biodiesel production, the EU remains well ahead of all other regions. Looking at bioethanol and biodiesel consumption quotas for the three scenarios shows that EU climate targets alone do not increase the production and consumption of biofuels. In the reference scenario with 20% emissions reductions EU biofuel shares never exceed the actually observed biofuel shares of the year 2005 that were imposed as a constraint on biofuel production[6].

Figure 3: Biofuel net exports in 2020

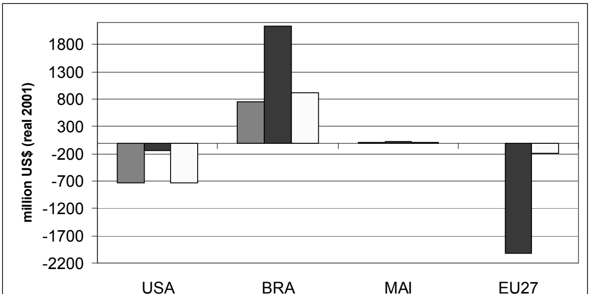


Figure 3 shows the trade balances for selected regions. The largest trade flows are ethanol from Brazil to the US in the reference and to the EU in the [10Q] scenario with exports shifting back to the US in the no-trade scenario[7]. Having a closer look at the imports of biofuels in the different EU countries reveals that biodiesel import shares remain low across scenarios (due to the limited export potential of Malaysia/Indonesia) while the shares of ethanol imports vary greatly across Europe (see KRETSCHMER et al., 2008, for detail).

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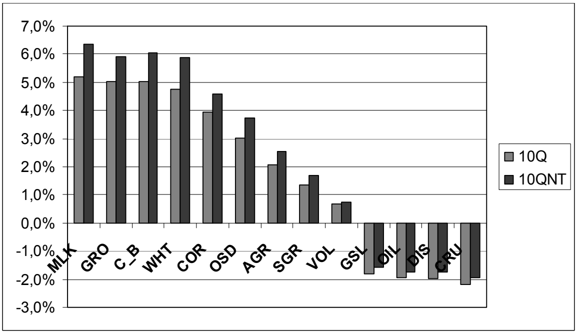
[6] This also holds for the other DART regions with the exception of ethanol in Brazil, where the mark-up had initially been adjusted so as to replicate observed 2005 shares and where production does increase steadily over the projection period without any policy support.

[7] Note that biofuel trade in the EU27 in the no-trade scenario is slightly larger than zero since even without subsidies bioethanol from Brazil can compete with conventional fuels.

Figure 4: EU27 price effects, in % deviation from the 2020 reference value



The question that we address now is the impact of the expanding biofuel production on prices and production especially in the agricultural sectors. Biofuel production was blamed by many to be among the principal reasons underlying the massive increases in feedstock prices of 2007/2008. Even in our reference scenario without additional biofuel production agricultural prices increase substantially from the base year 2001 to 2020. European and world price increases range from 100-160%. The additional price increases due to enhanced biofuel production have to be assessed in this light. Figure 4 presents the effects on prices of imposing a biofuel quota for selected DART sectors in the year 2020 compared to the reference scenario. Agricultural sectors are obviously most affected and we thus focus on them in our presentation of results. Though not massive compared to the overall increases over time, the effects are significant, reaching around 6% for some sectors and scenarios. This supports the view that an increase of biofuel production potentially contributes to higher grain and food prices. Somewhat surprisingly perhaps, the milk sector is affected most indicating that the rise in agricultural product prices drives up input (cattle feed) costs in the milk sector considerably. Unsurprisingly, the no-trade scenario [10QNT] leads to even higher price effects since the need to fulfil the 10% with domestically produced biofuel only raises demand for agricultural inputs further. Prices in the fossil fuel sectors are negatively affected, which is readily explained by reduced demand for conventional sources of energy.

Figure 5: EU27 sectoral production 2020 in % deviation from the 2020 reference value

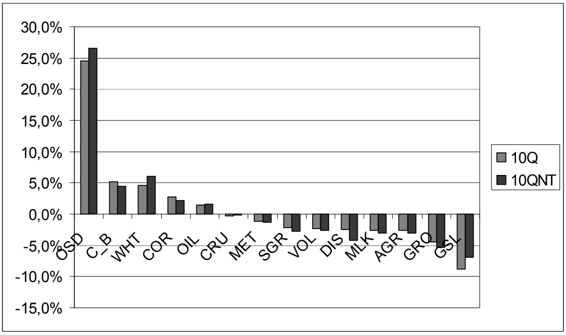
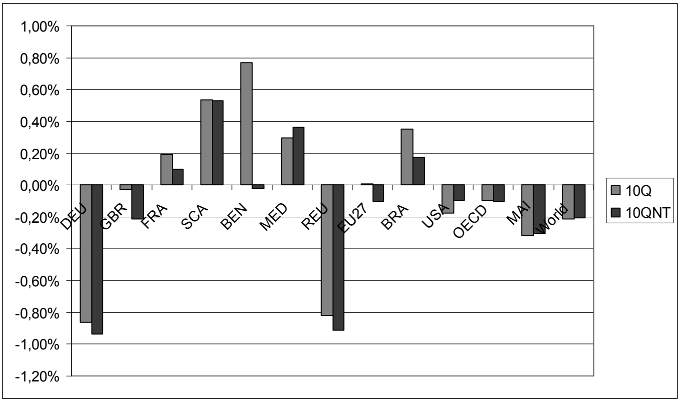


Figure 5 displays production effects. As expected, production of all bioenergy feedstocks increases. While production of corn, wheat and sugar beet increase only moderately by 3 to 5%, the overwhelming effect is found in the oilseeds sector (OSD) that increases by more than 25%. This highlights the fact that the EU relies most heavily on biodiesel produced from oilseeds in order to meet the 10% target. The increase in oilseed or more generally bioenergy feedstock production crowds out other agricultural activities, most notably milk and other grains. Furthermore, one notices that conventional diesel and gasoline production decrease considerably. The pattern across the different quota scenarios is as expected. The no-trade scenario leads to a greater expansion of production compared to the [10Q] scenario because of higher domestic biofuel production.

Figure 6: Welfare effects in the year 2020 relative to the reference scenario



The macroeconomic effects resulting from our scenarios summarize overall impacts. Figure 6 above displays the welfare effects measured in terms of equivalent variation. Welfare effects for the EU as a whole are somewhat ambiguous with hardly any effect found for the [10Q] scenario and negative effects for the no-trade scenario. The effects for single countries/regions are partly quite considerable, with Germany and REU (mostly Eastern Europe) being very much negatively affected while the Scandinavian and Mediterranean countries reap considerable welfare gains. The Benelux region relies heavily on imports, which explains the sharp drop in welfare from the [10Q] to the no-trade scenario. Brazil is the only non-EU region that actually displays any welfare gains, which is not surprising given its increased export market due to the imposition of a 10%. The no-trade scenario consequently shows a substantial reduction in its welfare gains.

The result that the 10% biofuel quota does on average only lead to insignificant welfare changes in Europe is surprising. Obviously, the additional economic inefficiencies of the quota are offset by other developments, which become obvious when looking at the carbon prices in the ETS but also in the sectors not covered by the ETS. Additional biofuel targets decrease the pressure to reduce emissions and thus lower carbon prices. While prices in the ETS are only slightly affected, decreases in the carbon taxes outside the ETS are more considerable. As a result ETS prices and non-ETS carbon prices move closer together, highlighting the inefficiencies of the targets in the separated carbon markets with different carbon prices. There is a clear correspondence between the regions where carbon taxes fall most strongly and those with the largest welfare gains from the biofuel targets. These effects may change, though, with different carbon targets such as full EU emissions trading. The welfare effects at hand can partly also be explained by the fact that a quota subsidizes cheap Brazilian ethanol which can compete with conventional fuels. Also, inefficiencies of the EU's Common Agricultural Policy (CAP) such as export subsidies are likely to be dampened with increased domestic demand for EU agricultural output. Finally, figure 6 shows that *globally* the additional constraint of the 10% biofuel target does lead to welfare losses.

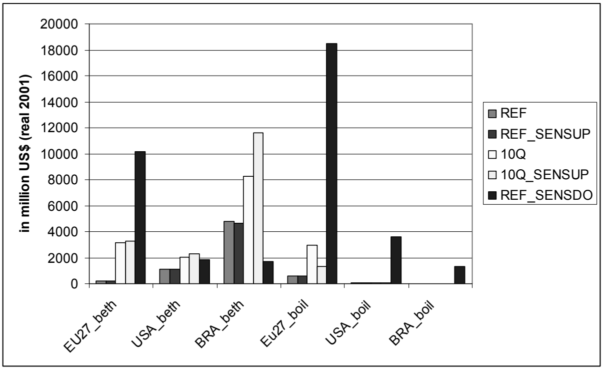
3.3 Sensitivity Analysis

As a first sensitivity analysis we vary the original level of the mark ups on bioenergy production. On the one hand, technological improvement can decrease mark ups. On the other hand, our mark ups for 2005 are only estimations based on weak assumptions for some countries and strongly depend on input prices. We thus run the [REF] and [10Q] scenarios with mark ups increased and decreased by 50% for both biodiesel and bioethanol in all countries except for Brazilian ethanol production[8] assuming that biofuels are either more expensive (suffix SENSUP) or cheaper (suffix SENSDO) than in the reference scenario.

Figure 7 displays bioethanol production for selected regions as well as biodiesel production for the EU in the year 2020. Production in the [REF_SENSUP] scenario, the reference scenario with increased mark ups, hardly changes since the EU, the USA, the OECD and China (CPA) only fulfil their respective benchmark shares of the year 2005 in both reference scenarios. Comparing the results of the quota scenarios [10Q] and [10Q_SENSUP] reveals as expected that Europe relies more heavily on imported biofuel in order to meets its quota with increased mark ups, which is represented by large production increases in Brazil and a considerable drop in European biodiesel production. Additionally, the increase in mark ups seems to bring about a shift in the relative cost and price structures underlying ethanol and biodiesel production that leads to a slight expansion of EU ethanol production despite the increased mark up.

In the case of decreased mark ups we only represented the results for the reference scenario and selected regions, since it turns out that the enhanced competitiveness of biofuels alone is sufficient to meet the 10% biofuel quota, at least in our setting of EU climate policy. Especially EU biofuel production increases considerably, but also US and Brazilian biodiesel production realize large gains. These expansions divert resources away from ethanol production in Brazil and also – though to a much less dramatic extent – in the US.

Figure 7: Biofuel production in 2020, sensitivity analysis



The mark ups have naturally also implications for welfare which are not shown here. A rise in mark ups implies more expensive biofuel production technologies, while a decrease implies less expensive production. Brazil reaps clear gains in the quota scenario with increased mark ups because its competitiveness increases further compared to other ethanol producers and demand for its exports rises. With decreased mark ups, this competitiveness effect vanishes but welfare remains higher than in the other two reference scenarios. We also see that under increased mark ups, the quota leads to clear overall welfare losses in Europe, which were slightly positive in the original quota scenario. Overall, the results are thus very sensitive to changing mark ups.

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[8] The ethanol mark up in Brazil is calibrated to replicate actually observed ethanol shares in 2005 and does not reflect any policy support measures.

4 Summary and conclusions

In this paper we have described how the multi-regional, multi-sectoral computable general equilibrium model DART has been extended to include first generation biofuels – that is biodiesel produced from oil seeds and vegetable oils and bioethanol from corn, sugar beet, sugar cane and wheat. As a first application we have analysed the economic effects of the 10% biofuel target for the EU. In all three scenarios we assume that the EU meets its climate target of a 20% reduction of carbon emissions relative to 1990 by means of the European emissions trading scheme (ETS) and by a uniform national carbon tax in the sectors not covered by the ETS. We then analyse two scenarios where additionally the 10% biofuel target is met. The scenarios differ in the extent of biofuel imports from Brazil (bioethanol) and Malaysia/Indonesia (biodiesel). In one of the scenarios, only domestically produced biofuel counts towards fulfilling the quota.

There are a number of interesting results, even though this study should be considered as preliminary. The first main result is that in our reference scenario the EU emission reduction target alone does not lead to increased production and consumption of biofuels in any EU country/region. Additional subsidies are necessary to go beyond the biofuel shares observed in 2005 and to reach the 10% biofuel target. Yet, this additional target does not much affect EU welfare on average though individual countries/regions do reap gains or suffer losses and global welfare decreases. The economic inefficiencies of such a quota are offset by decreasing inefficiencies in the separated carbon markets and regulated agricultural markets. This can be very different, though, once there is e.g. full EU emission trading. The second main result is that agricultural prices in the EU are significantly increased by introducing a 10% quota. Average EU agricultural sector prices in 2020 increase from 0.7-5.2% in the basic quota scenario and up to 6.4% in the no-trade scenario. World agricultural prices are affected less as expected and increase by up to 1.9% and 2.2% in 2020, respectively. These results are in the range of other CGE studies, see KRETSCHMER and PETERSON (forthcoming) for a survey. These increases in agricultural prices do not seem dramatic compared to e.g. overall European and world price increases in the range of 100-160% from 2001-2020 in our scenarios, but are not negligible either. Once additional biofuel targets in other countries are taken into account, one would surely see larger increases in world prices as well. The results obtained so far clearly support the view that it is important to account for the linkage of biofuel and agricultural markets. Further results indicate that restrictions on the trade of biofuels from abroad – e.g. by requiring that biofuels are certified – have the expected negative welfare impacts. In this context we highlight the importance of analysing possible future trade flows of biofuels in more detail, since this study only analysed bioethanol exports from Brazil and biodiesel exports from Malaysia/Indonesia. Also, there are clearly winners and losers of biofuel support. While the agricultural sector gains on average, fossil fuel sectors lose. Furthermore, sectors outside the ETS profit more from the reduced pressure on carbon prices than the sectors covered by the ETS.

Some limitations of the way bioenergy is modelled remain, as it is also discussed in KRETSCHMER and PETERSON (forthcoming). This includes the modelling of biofuel trade, the level of the mark ups that determine the future biofuel production structure and finally and most importantly the effects of land-use restrictions. Future research will aim for a better modelling of these issues and also include sensitivity analyses of further important parameters. A first sensitivity analysis with respect to the level of the mark up has shown that results may change substantially with respect to biofuel production and welfare. Another crucial parameter is the elasticity of substitution between land and other primary factors of production. Its level at least for Germany will be appropriately determined in the process of coupling DART to an agricultural sector model for Germany. A more detailed representation of land – for instance by including land-supply curves into DART – will be a special focus in the course of further research. Furthermore, we will undertake a more detailed analysis of the effects of different bioenergy targets worldwide analysing a much wider set of scenarios than in this study.

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