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Biofuels, Climate Policy, and the European Vehicle Fleet

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Abstract

We examine the effect of biofuels mandates and climate policy on the European vehicle fleet, in particular the prospects for diesel and gasoline vehicles. Our analysis is based on a dynamic computable general equilibrium model of the world economy which explicitly incorporates current generation biofuels, accounts for stock turnover of the vehicle fleets, disaggregates gasoline and diesel cars, and represents an advanced E85 vehicle. We find that the European vehicle fleet is robust to proposed biofuels mandates owing to an existing fuel tax and tariffs structure that favours diesel vehicles. Harmonising excise duties on diesel and gasoline or lowering tariffs on biofuel imports, however, is shown to reverse the trend toward more diesel vehicles and significantly alters the efficiency costs and environmental effectiveness of renewable fuel policies.

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1.0 Introduction

Diesel vehicles have strongly entered the European car market especially in the last decade, accounting now for over 50 per cent of new vehicle registrations (European Automobile Manufacturers' Association, 2008). The likely reason for the strong penetration of diesel vehicles is a fuel tax structure that favours diesel. However, Europe is now seeing a number of new policy developments that could change the cost and relative prices of fuels. Of particular interest are new renewable fuels mandates. The proposed energy and climate package from the European Commission that would extend the Emission Trading Scheme (ETS) over the next 20 years calls for an increase in renewable fuels. According to the European Commission (2008a) proposal to introduce biofuels mandates, 5.75 per cent by 2010 and 10 per cent beyond 2020 of renewable fuels (in volume terms) have to be blended into conventional fuels. This new initiative will interact with an existing tariff and tax structure that encourages domestic biofuel production and favours diesel imports. The overall outcome of proposed fuel policies on the European car market is not immediately clear. At issue with the renewable fuels requirement are the cost and availability of biodiesel, as currently produced biodiesel and ethanol use different plant feedstocks that lead to different cost and supply of the fuels. In particular, estimates (International Energy Agency, 2004) suggest that biodiesel produced from crops like rapeseed may be relatively expensive and its supply limited compared with ethanol. However, diesel combustion is more efficient and the fuel is subject to lower excise taxes, possibly offsetting the higher cost of biodiesel.

In this context, the paper presented here analyses the effects of biofuels mandates set out in the European Commission (2008a) proposal on the European vehicle fleet, in particular considering the prospects for diesel and gasoline vehicles. We also quantitatively assess the efficiency costs and environmental effectiveness of the proposed renewable fuel policies, taking into account their interaction with the current (and future) structure of fuel taxes and import tariffs on renewable fuels in Europe. While biofuels mandates are likely to reduce carbon dioxide emissions from the transportation sector, a key question from a climate change mitigation policy perspective is whether such policies can be an effective instrument for reducing overall carbon dioxide emissions when accounting for sectoral and global leakage effects.

To analyse these complex interrelationships in a consistent framework, we employ the MIT Emissions Prediction and Policy Analysis (EPPA) model, a large-scale recursive-dynamic computable general equilibrium (CGE) model of the world economy with international trade among regions (Paltsev *et al.*, 2005, 2009). Our starting point is the EPPA-ROIL version of the model that provides greater disaggregation of the petroleum, refining, and liquid fuel sectors compared to the standard model (Choumert *et al.*, 2006).[1]

To investigate the implications of renewable fuel policies on the European vehicle market, we augment the EPPA model along the following dimensions. We add an explicit representation of current technologies for biofuels production as these technologies are

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[1] See Chan *et al.* (2010) for an application of the EPPA-ROIL model to investigate the effects of climate policy on Canada's oil sand industry.

likely to contribute to meeting near-term targets and to shape the transition to second-generation cellulosic technologies. We also represent explicitly the production of different crops processed into biofuels. We account explicitly for CO_2 emissions from growing crops and from conversion into bio-energy. On the downstream side of the fuels market, we treat separately diesel and gasoline vehicles and include the asymmetry in the European fuel tax system as well as differences in the fuel efficiency. Based on the consumption of fuel per unit of distance and on the share of diesel vehicles in the stock of cars, we construct two private transportation functions, which use as inputs, fuel (diesel or gasoline), services, and rent of vehicles. The rental value of the fleet is imputed from historical sales of cars and appropriate depreciation and interest rates. We also treat stock turnover of vehicles to allow a better representation of the inertia of the vehicle fleet as it affects the penetration of new technologies. Finally, we introduce a backstop technology modelling E85 vehicles which, given their availability, may be widely commercialised in the near term.

The analysis begins in Section 2 where we describe our strategy for implementing first-generation biofuels production and representing in more detail the private transportation sector in EPPA. In Section 3 we simulate the impact of proposed renewable fuel policies on the European vehicle fleet and investigate their economic and environmental effectiveness. While we investigate the implications of biofuel mandates alone, a second objective here is to explore the extent to which the impacts of renewable fuel policies on the European vehicle fleet depend on the current structure of fuel taxes and import tariffs. Our primary strategy then is to complement biofuels mandates with either harmonising excise duties on gasoline and diesel or lowering tariffs on biodiesel and ethanol imports. Section 4 explores the robustness of our results with respect to key cost and technology assumptions. In Section 5 we discuss the outcome of the scenarios and offer some conclusions.

2.0 Analytical Framework

2.1 Background on the MIT EPPA model

Our tool for analysis is the MIT Emissions Prediction and Policy Analysis (EPPA) model which is described in Paltsev *et al.* (2005). EPPA has previously been applied, among others, to investigate the economic viability of hydrogen transportation in several different tax and carbon stabilisation policy scenarios (Sandoval *et al.*, 2009) and the prospect for plug-in hybrid electric vehicles (Karplus *et al.*, 2010) in the USA and Japan. EPPA is a recursive-dynamic multi-regional computable general equilibrium model of the world economy. It is built on Social Accounting Matrix (SAM) from the GTAP data set, which accommodates a consistent representation of energy markets in physical units as well as detailed accounts of regional production and bilateral trade flows (Hertel, 1997; Dimaranan and McDougall, 2002). Additional data for greenhouse gas (carbon dioxide, CO_2; methane, CH_4; hydrofluorocarbons, HFCs; nitrous oxide, N_2O; perfluorocarbons, PFCs; and sulphur hexafluoride, SF_6) emissions is based on United States Environmental Protection Agency inventory data and projects.

The regional and sectoral breakdown of the model is shown in Table 1. Much of the sectoral detail in the EPPA model is focused on providing a more accurate representation

Table 1

Regions and Sectors in the Augmented EPPA Model

Country or Region	*Sectors*	*Specificity beyond the standard EPPA model*
Developed	**Non-energy**	
United States (USA)	Agriculture (AGRI)	**Crop for biofuel feedstock**
Canada (CAN)	Services (SERV)	Grain
Japan (JPN)	Energy-Intensive Products (EINT)	Wheat
European Union (EUR)	Other Industries Products (OTHR)	Sugar cane
Australia & New Zealand (ANZ)	Industrial Transportation (TRAN)	Sugar beet
Former Soviet Union (FSU)	Household Transportation (HTRN)	Soybean
Eastern Europe (EET)		Rapeseed
	Energy	Palm fruit
Developing	Coal	
India (IND)	Crude oil	**Disaggregated refined oil sector**
China (CHN)	Refined oil	
Indonesia (IDZ)	Natural gas	Gasoline
Higher Income East Asia (ASI)	Electric: fossil	Heavy fuel oil
Mexico (MEX)	Electric: hydro	Petroleum coke
Central & South America (CSAM)	Electric: nuclear	Other petroleum products
Middle East (MES)	Electric: solar and wind	Liquid petroleum gas
Africa (AFR)	Electric: biomass	
Rest of World (ROW)	Electric: gas combined cycle	
	Electric: gas with CCS	
	Electric: coal with CCS	
	Oil from shale	
	Synthetic gas	
	Liquids from biomass	**Biofuels**
		Ethanol
		Biodiesel

of energy production and use, as it may change over time or under policies that would limit greenhouse gas emissions. The base year of the EPPA model is 1997, and the model is solved recursively in 5-year intervals starting with the year 2000. The EPPA model represents production and consumption sectors as nested Constant Elasticity of Substitution (CES) production functions (or the Cobb–Douglas and Leontief special cases of the CES). The model is written in the GAMS software system and solved using the MPSGE modelling language (Rutherford, 1995, 1999) and the PATH solver (Dirkse and Ferris, 1995). The EPPA model has been used in a wide variety of policy applications (for example, United States Climate Change Science Program, 2007; Paltsev *et al.*, 2009).

The EPPA model also includes many low-carbon technologies that were either not developed or pre-competitive in 1997, but could enter the market in the future under favourable cost conditions. For example, these technologies may be too expensive relative to pre-existing technologies. Bottom-up engineering detail is used to specify these so-called 'backstop' technologies (McFarland *et al.*, 2004). The competitiveness of these technologies depends on the evolution of endogenously determined prices for all inputs. These input prices in turn depend on the depletion of resources, policy, and other forces driving economic growth such as savings, investment, and productivity of labour. In the model, the supply of biofuels from various feedstocks is represented by such 'backstop' technologies, and is described in detail in Section 2.2.

Given our focus on transportation and fuel supply, we use a specific version of the EPPA, the EPPA-ROIL model, that relies on additional data further to disaggregate GTAP data for transportation to include household transportation (Paltsev *et al.*, 2005) and for the refining sector to include various types of fuels: gasoline, diesel, liquid petroleum products, heavy fuel oil, petroleum coke, and other petroleum products (Choumert *et al.*, 2006). To be able to address the research questions formulated above, we have to augment the existing EPPA-ROIL model structure significantly. We provide a brief summary of each of the model extensions below. More detail on the implementation can be found in Gitiaux *et al.* (2009).

2.2 First-generation biofuels

The standard EPPA model includes a 'second generation' cellulosic biofuels technology that in the long run and under climate policy would crowd out the current generation of biofuels (Reilly and Paltsev, 2007; Gurgel *et al.*, 2008). An implicit representation of current generation biofuels is incorporated only to the extent that those fuels are contained in highly aggregated agricultural products (AGRI) used as intermediate inputs in the fuel sector. As current biofuel technologies are likely to contribute to meeting near-term mandates, and may therefore be pivotal in shaping the transition to second-generation biofuels, a more explicit representation of these technologies is clearly needed.

As shown in Table 1, we add seven new production activities, indexed by j ($j =$ grain, wheat, sugar cane, sugar beet, soybean, rapeseed, and palm fruit), in the agricultural sector that represent production of the crops used as a feedstock for biofuel production. Crop and biofuel production are modelled using CES functions according to the nesting structure shown in panel (a) and (b) in Figure 1, respectively. CES functions are globally defined by share and elasticity parameters. σ denotes the elasticity of substitution between inputs at a given nest; vertical lines in the input nest signify a Leontief or fixed coefficient production structure where the elasticity of substitution is zero. As is customary in applied general equilibrium analysis, we calibrate share parameters based on base year prices and quantities (see, for example, Robinson, 1991; and Rutherford, 1999).

We utilise data from GTAP input–output tables to disaggregate the agricultural sector and determine output and input shares for crop production of grain, wheat, oilseed, and sugar crops. For further disaggregation of oilseeds into soybean, rapeseed, and palm fruit, and sugar crops into sugar beet and sugar cane beyond the level of detail available in GTAP data, we rely on data from the Food and Agriculture Organization of the United Nations (2008). We split production based on acreage shares of each respective crop in a given region leaving inputs shares unchanged. Land productivity is assumed to improve over time according to an exogenous trend (1 per cent per year in developed regions and 1.5–2 per cent in Central and South America (CSAM), Indonesia (IDZ), India (IND), China (CHN), and Africa (AFR)).[2]

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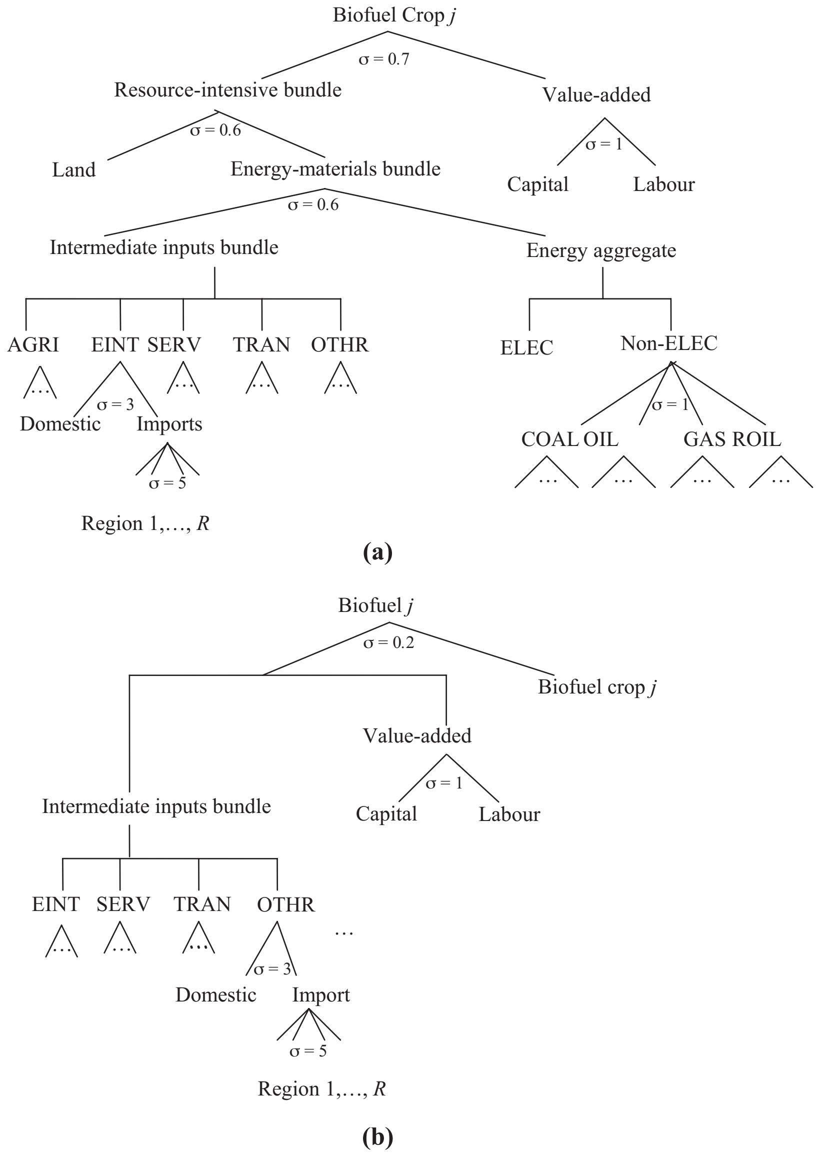
[2] Note, however, that land productivity (that is, crop yields) varies endogenously over time and across the different scenarios as determined by relative price changes and by the elasticity of substitution between land and the energy-material bundle, and indirectly with the capital-labour bundle.

Figure 1

Production Structure for (a) Crop and (b) Biofuel Production. Vertical Lines Signify a Fixed Coefficient Production Structure



Because the relatively small amounts of biofuel production that occurred in the base year data are not explicitly represented in the GTAP data set, we assume that first-generation biofuel technologies enter the market after the year 2000. Furthermore, we assume that ethanol (produced from biofuel *j* = grain, wheat, sugar cane, sugar beet) is a perfect substitute for gasoline, and that biodiesel (produced from biofuel *j* = soybean, rapeseed, palm fruit) is a perfect substitute for conventional diesel. For calibrating production functions, we base benchmark value shares on engineering cost data.[3] For ethanol from grains including wheat, we follow bottom-up estimates from Shapouri and Gallagher (2003) and Tiffany and Edman (2003). For ethanol from sugar plants, we use information available from the US Department of Agriculture (2006) and the International Energy Agency (2008). Finally, for biodiesel from oilseed, we use data from Fortenbery (2005) and Hass *et al.* (2005). Based on these studies, we determine for each feedstock category and for a given reference region the 2000–5 average cost of production and individual cost components. For all technologies except for biodiesel from oilseeds, for which the LAM region is the reference, we take the USA as the reference region.

We extend our cost estimates to other regions following the approach used in Gurgel *et al.* (2008) whereby conversion technologies across regions are the same as in the respective reference region, but feedstock cost shares can vary regionally according to differences in crop prices. Crop price data is taken from the Food and Agriculture Organization of the United Nations (2008).

To characterise relative costs of different types of technology, we follow the approach described in Paltsev *et al.* (2004) by identifying separately a multiplicative mark-up factor that describes the costs of each advanced biofuel technology relative to the existing technology against which it competes.[4] Mark-up factors are uniform across regions, and are calculated based on bottom-up cost estimates taken from the respective studies listed above relative to the 2000–5 price average of gasoline or diesel in the respective reference region.[5]

Finally, elasticity of substitution parameters shown in Figure 1 are based on estimates from Dimaranan and McDougall (2002), Choumert *et al.* (2006), and Reilly and Paltsev (2009). The parameterisation employed in the base case is shown below each respective nest in the figure.

2.3 The private transportation sector

We improve the representation of the private transportation sector in the standard EPPA model in three ways: (1) we explicitly treat vehicle fleet turnover; (2) we disaggregate diesel and gasoline vehicles; and (3) we allow introduction of E85 vehicles. All these changes are implemented for the USA and EUR regions only.

2.3.1 Modelling the vehicle fleet turnover

A commonly adopted approach in CGE models is to consider private purchases of vehicles through a flow of current consumption (see, for example, Paltsev *et al.*, 2004).

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[3] The explicit technologies for production thus capture expansion of the industry beyond that amount implicitly included in the base data set.

[4] The mark-up factor for biodiesel from palm oil is computed relative to the price of soy oil for the USA taken from the US Department of Agriculture (2008). In addition, biodiesel standards in Europe require products from soybean and palm oil to be further transformed before being injected in engines. Following Moser *et al.* (2007), we estimate the cost of these additional process steps at $0.05 per litre of biodiesel produced, and increase mark-ups accordingly.

[5] Table 3 in Gitiaux *et al.* (2009) reports region- and technology-specific biomass input shares and mark-up factors used in the model.

Such a representation, however, underestimates inertia in own-supplied transportation as vehicle fleets typically have a lifetime of around 15 years (European Automobile Manufacturers' Association, 2006). Our improved approach treats vehicles as capital goods that depreciate while providing a flow of services over their lifetime.

We represent the vehicle fleet as a vintaged capital stock, similar to the representation of industrial sectors in EPPA (see Paltsev *et al.*, 2004). Each vintage is represented as a fixed coefficient production function. Purchasers of vehicles can choose the fuel efficiency and other characteristics of new vehicles, but once they are part of the fleet, these characteristics are frozen. We further assume that there is no possibility to retrofit existing vehicles, that is, we represent 100 per cent of the vehicle fleet as vintage.

We impute the base year rental value of the stock of cars in private transportation based on data from the European Automobile Manufacturers Association (2006) on historical sales, and assumptions about appropriate depreciation and interest rates. Using data from the European Automobile Manufacturers' Association data on the distribution of 2006 car stock by age in the EU15 and new cars registrations since 1979, we deduce a lifetime function that characterises the European stock of cars with a mean lifetime of about 15 years and an average age of about 8 years. An exponential fit of this function produces a depreciation rate of about 8 per cent. We assume a constant depreciation rate that accounts for the average life of a vehicle. In addition, we assume that the real rate of interest is 5 per cent to be consistent with the treatment of other industrial assets in EPPA.

2.3.2 Disaggregation of gasoline fleet and diesel fleet

We follow the specification in Paltsev *et al.* (2004) according to which households choose between purchased transport and the services of household-owned vehicles. Spending on transportation is assumed to be a constant fraction of the household budget, based on work by Schafer (1998) and Schafer and Victor (2000). Own-supplied transportation uses inputs from the other industries (purchase of cars), from the services sector (maintenance and insurance costs), and from the refinery sector (fuel costs). We separately identify own-supplied transportation from diesel and gasoline vehicles.

Our disaggregation of diesel and gasoline vehicles requires, first, separating total expenditures on fuel by the private transportation sector (Paltsev *et al.*, 2004) into expenditures on diesel and gasoline. We derive the energy used by the diesel fleet based on data on physical energy consumption of refined oil products, fuel efficiency of gasoline and diesel engines (European Automobile Manufacturers' Association, 2008), and the stock of diesel passenger cars (see Bensaid, 2005; and the European Commission, 2008b). Next, we combine this with relative fuel prices (International Energy Agency, 2008a) to obtain the value of diesel expenditures in the private transportation. Second, we need to calculate the share of the monetary value of the private transportation services (as in Paltsev *et al.*, 2004) that is attributed to the gasoline and diesel fleet. As these numbers are not readily available, we estimate them as the fraction of miles driven by diesel vehicles relative to the total miles driven by the whole fleet. Our estimation relies on the assumption that one mile driven with a diesel car provides the same mobility service as one mile driven with a gasoline car. These shares are obtained by using again our fuel efficiency numbers and estimates of physical energy consumption of gasoline and diesel for the whole fleet. The resulting cost shares are reported in Table 4 in Gitiaux *et al.* (2009).

GTAP data do not differentiate taxes on diesel and gasoline. We use data from the International Energy Agency (2008a) to determine the *ad-valorem* tax on gasoline in the base year and to establish revenue raised by these excise duties. The excise duty on diesel is then adjusted to keep the revenue from fuel taxes equal to the revenue accounted for in the original GTAP data.

Finally, to pin down elasticity parameters we draw on econometric estimates in a literature survey in Paltsev *et al.* (2004). Estimates for short-run and long-run elasticities between fuel and other inputs are in the ranges 0.2–0.5 and 0.6–0.8, respectively. For the transportation services provided by new vehicles, we use the long-run elasticity of substitution that is assumed to capture the ability to respond to higher fuel prices by purchasing more efficient vehicles. With the vintaging structure, the aggregate short-run elasticity will reflect a weighted average of old vintages with zero substitution elasticity and the new vintage with high elasticity. Persistently high prices will then gradually lead to a vehicle fleet with greater efficiency. Vintaging captures structurally the observed difference between short- and long-run elasticities.

2.3.3 Introducing E85 vehicles

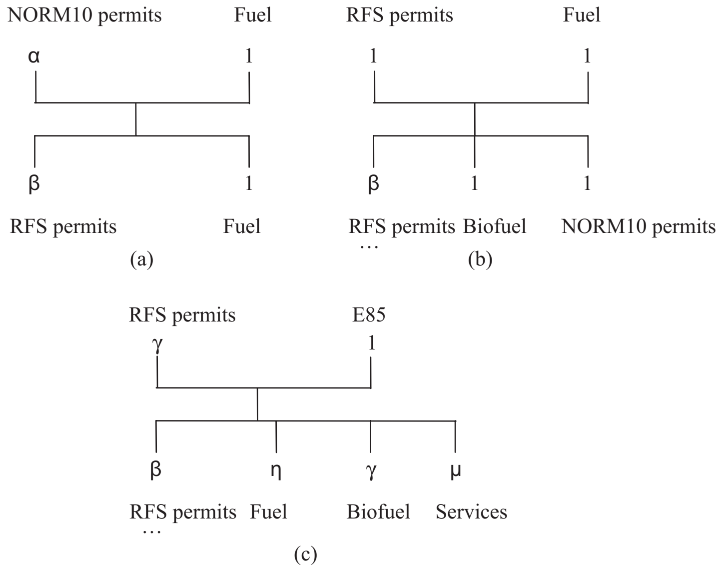
Blending more than 10 per cent of biofuels into conventional fuels may damage vehicles that are not designed to utilise them. Thus, fuel standards limit the blending percentage. In the USA the 10 per cent limit is often referred to as the blending wall, because it would limit biofuel use in absent vehicles that could use a greater percentage. In Brazil, flex-fuel vehicles that can run on any mix of ethanol accounted for 84 per cent of new sales at the beginning of 2009 according to Associacoa Nacional dos Fabricantes de Veiculos Automotores (2009). In the USA, E85 vehicles that can run on blends of up to 85 per cent ethanol have been introduced in response to fuel-economy compliance credits offered by the Department of Transportation since 2001 (National Highway Traffic Safety Administration, 2001). In 2007, almost 5 per cent of the 17 million new light-duty vehicles sold in the USA were E85 vehicles.

In EPPA, we introduce E85 vehicles as an advanced technology that enters the market after the year 2000 and that is largely based on the same input shares as the conventional gasoline technology. However, it is estimated that technology-specific characteristics (including a stainless fuel tank and a special sensor to adjust engine spark timing) add \$200 to the vehicle cost (Keefe *et al.*, 2007). That extra cost translates to a mark-up of 1.015 on the capital input share in the E85 fleet production function. The main advantage of including E85 vehicles explicitly is that the vintaging of the vehicle fleet limits the use of ethanol based on the 10 per cent blending wall on conventional vehicles and the growth of the stock of E85 vehicles available.

There are also additional costs associated with distribution of E85 fuel. For example, adding an E85 pump at a service station is estimated to cost approximately \$200,000 (Keefe *et al.*, 2007). The International Energy Agency (2004) estimates that the total infrastructure changes needed for the transport, storage, and distribution of E85 add about \$0.06 per gallon to the price of ethanol. We add this additional cost for selling E85 to the services input in the production function of E85 vehicles.

Figure 2

Implementation of Renewable Fuels Standards. Renewable Fuel Permits are Modelled as either Leontief Joint Inputs or Outputs in Production, where the Values of Fixed Coefficients are shown next to the Respective Input Names. (a) Conventional Fuel Production; (b) Blending of Biofuels into Conventional Refinery Products; (c) Production Function of E85 Fuel



2.4 Implementing fuel standards

To implement Renewable Fuel Standards (RFSs), we follow the permit approach adopted by Morris *et al.* (2010) for modelling renewable electricity standards. We implement the RFS by requiring that for each unit of conventional fuel produced, β units of renewable fuel permits (to which we refer as RFS permits) have to be used as a Leontief input to production. Firms that produce one unit of renewable fuel receive one unit of RFS permits. This approach captures the redistribution of funds between conventional refiners and biofuels producers, as fuel sellers must pay a premium (the permit price) to renewable fuel producers. To capture the 10 per cent blending wall and E85 fuel production, we introduce a second set of permits (which we refer to as NORM10 permits) and two blending processes that complement the conventional refinery sector. The structure of the permit approach is represented in Figure 2.

The first blending process allows up to 10 per cent (in volume terms) of biofuel products to be combined with conventional fuel that is mandated to surrender β RFS permits. The 10 per cent blending constraint is implemented by requiring that each unit of blended fuel produced has to use one unit of NORM10 permits, and $\alpha = 0.1$ units of NORM10 permits are produced jointly with each unit of conventional refinery product. The E85 blending process is a fixed coefficient production function blending $\gamma = 0.85$ biofuels and $\eta = 0.15$ conventional fuel. Use of E85 is more expensive because of the extra distribution costs (as reflected by required services inputs with a fixed coefficient

Table 2
Overview of Scenarios

Scenario	*Biofuels mandates according to European Commission proposal (2008)*	*Import tariffs on ethanol and biodiesel*	*Excise duties on diesel and gasoline*
BAU	No	Current tariffs	Current fuel taxes
MAND	Yes	Current tariffs	Current fuel taxes[a]
MAND_TARIFF	Yes	No tariffs	Current fuel taxes[a]
MAND_TAX	Yes	Current tariffs	Harmonised tax rates

Note: [a]Benchmark diesel and gasoline tax rates are scaled uniformly to keep total tax and tariffs revenue neutral.

$\mu = 0.15$; see Section 2.33 for a discussion of our cost assumptions) and higher vehicle costs.

Thus, a fuel mandate of $\beta < 10$ per cent can be met using the 10 per cent blending process up to the level needed to meet the target, and even if biofuels are economic without the mandate, they are limited to not more than 10 per cent unless they overcome the extra cost of using E85. A fuel mandate of $\beta > 10$ per cent requires use of the E85 blending process, and at high enough β's E85 will crowd out the 10 per cent blending process.

3.0 Policy Scenarios and Numerical Results

3.1 Policy scenarios

We consider four scenarios to investigate the economic and environmental implications of biofuels mandates and interactions with European fuel tax and tariff policy, with a particular focus on the relative penetration of diesel and gasoline vehicles, fuel prices, CO_2 emissions, and overall economic costs. Table 2 summarises the main characteristics of the scenarios. The study starts with a Business-As-Usual (BAU) scenario which assumes that mandates for renewable fuels are absent and that all tariffs and taxes are held at their current level.

The MAND scenario simulates the European Commission (2008a) proposal to introduce mandates on renewable fuels requiring blending of at least 5.75 per cent by 2010 and 10 per cent by 2020 (in volume terms) into conventional fuels. The following two scenarios include the biofuels requirements of the MAND scenario but consider changes in either tariff or tax policy. The MAND_TARIFF scenario removes European tariffs on ethanol and biodiesel imports. The MAND_TAX scenario harmonises European excise duties on diesel and gasoline fuels, and sets an equal *ad-valorem* tax rate on all liquid fuels at the gas station. In all scenarios, we require revenue neutrality by endogenising fuel taxes to keep total tax and tariff revenues constant at the BAU level. In the MAND and MAND_TARIFF scenario, we uniformly scale fuel taxes but preserve the differentiated tax structure. In the MAND_TAX scenario, the harmonised tax rate on diesel and gasoline is calculated endogenously to satisfy the revenue-neutrality requirement.[6] We assume that both tax and tariff policies are implemented from 2010 onwards jointly with biofuels mandates.[7]

3.2 Impacts on the European vehicle fleet

In the BAU case, diesel vehicles continue to penetrate the European vehicle fleet and account for 34 per cent of all vehicles by 2030 (Figure 3a). This growth is driven by a tax system that maintains the price of diesel ($5.63 per gallon by 2030) at the gas station below the price of gasoline ($6.30 per gallon by 2030, Table 3) and by the general increase in oil prices that favours the most efficient motorisation.

The share of diesel vehicles drifts upward gradually, due to sales of new diesel cars that stabilise around 33–35 per cent of the new registrations after 2020 (Figure 3b). A factor behind the gradual levelling off of the diesel share of new vehicles beyond 2020 is that the diesel price is growing somewhat faster than the gasoline price (as shown in Table 3). The diesel price, exclusive of excise duties, reaches $1.92 per gallon by 2030, compared with a gasoline price of $1.64 per gallon. Therefore, prices inclusive of taxes gradually converge: the gasoline price at the pump is only 12 per cent higher in 2030 than the diesel price, while it is one-third more expensive in the benchmark year. The limited ability of the European refineries to respond to the growing demand for diesel increases the pressure on the supply of diesel. The refinery sector is modelled as a multi-output production sector where the ability to shift the product share is limited by a low elasticity of transformation between refinery outputs.[8]

The MAND scenario results in somewhat greater penetration of diesel vehicles as they account for 35 per cent of the passenger cars driven in 2030. The differentiated tariffs system on biofuels, favouring biodiesel over ethanol, makes biodiesel imports a somewhat less expensive way to meet the mandate than either domestic ethanol or imported sugar cane ethanol.[9] The differential tariff structure maintains the gap between

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[6] The revenue-neutrality assumption is necessary because government spending does not enter the household utility function, and we did not want to confound welfare impacts from changes in the size of government spending with welfare impacts from the policies under scrutiny here. How much government spends and whether it spends it effectively is an important consideration but beyond the scope of this paper. Our assumption of revenue neutrality remains neutral on this issue — whatever value there is in public spending, it is held constant, and so we concern ourselves only with the welfare generated by resources allocated to the private sector.

[7] Note that the objective of this paper is not to quantify the efficiency implications of fuel tax harmonisation alone. The focus is, rather, to assess the implications of the biofuels mandates set out in the European Commission (2008a) proposal, taking into account important interactions with fuel tax and tariff policy. From standard neoclassical economic theory, it follows that removing the fuel tax distortion without imposing additional regulatory standards in the form of a biofuel mandate would lead to welfare gains larger than with any combined policy. Thus, if policy goals are solely to improve economic efficiency without the objective to promote biofuels and reduce carbon dioxide emissions from the transportation sector, a pure fuel tax reform would be preferable.

[8] Following Choumert *et al.* (2006), the EPPA-ROIL model uses a multi-output production function to model the disaggregated refinery sector, and assumes a relatively low elasticity of transformation of 0.2. Indeed, in the past 20 years, the increasingly stringent fuel specifications (sulphur content, quality, volatility, and so on) have considerably reduced the already limited flexibility of refinery processes. An existing refinery generally has to invest heavily in a new unit, such as a conversion unit, to process residual fuel oil further, in order to meet a change in the demand mix of products.

[9] A table showing the composition of liquid fuels distributed at European gas stations in the different scenarios is available on request from the authors.

Figure 3

Share of Diesel Vehicles in (a) European Stock of Cars and (b) in European New Registrations

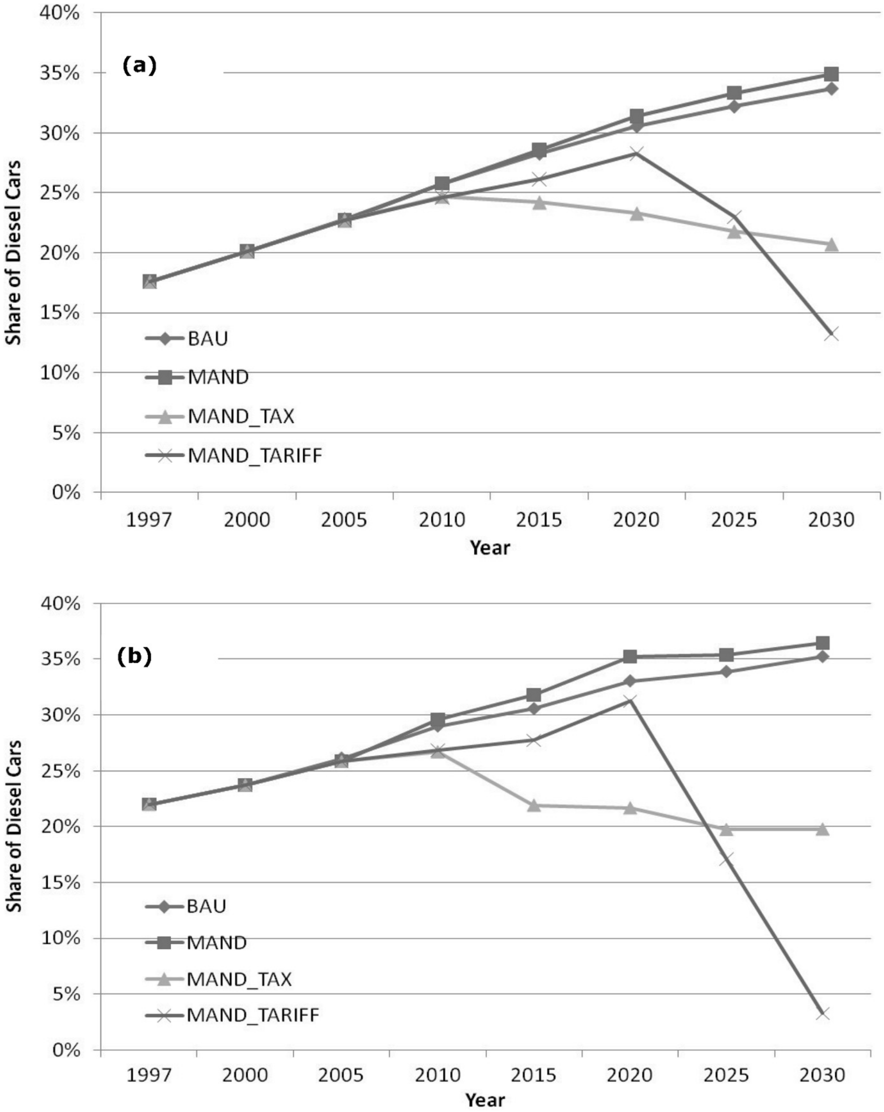
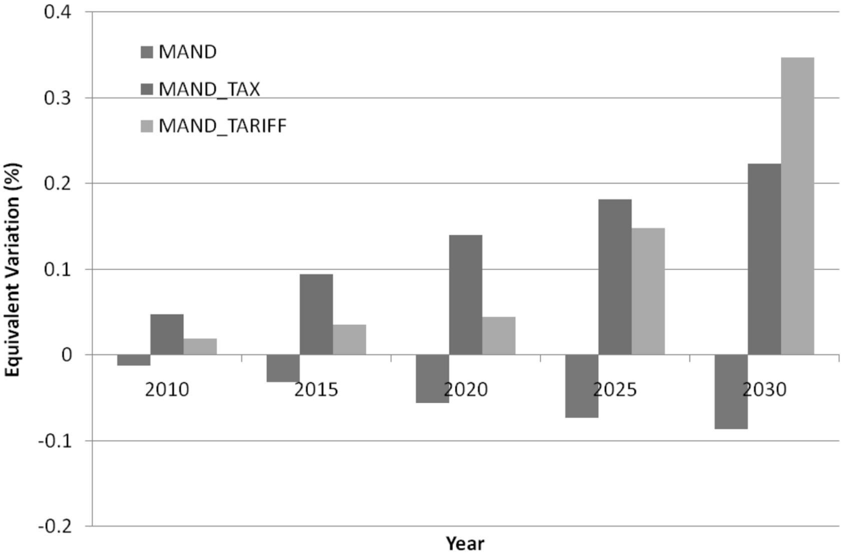


Table 3

Price of Fuel at the Gas Station by 2030 ($/gal)

	BAU	*MAND*	*MAND_TAX*	*MAND_TARIFF*
Diesel exclusive of duties ($/gal)	1.92	1.94	1.87	1.96
Gasoline exclusive of duties ($/gal)	1.64	1.67	1.79	1.52
Diesel inclusive of duties ($/gal)	5.63	5.70	6.31	5.74
Gasoline inclusive of duties ($/gal)	6.30	6.39	6.06	5.84

Figure 4
European Welfare Changes Relative to the BAU Scenario



the diesel price and the gasoline price at the gas station: by 2030, one gallon of diesel is estimated to cost $5.70 and one gallon of gasoline $6.39.

The marked trend of penetration of diesel vehicles hinges decisively on the current tax and tariff regime in Europe. Changes in tax and/or tariffs can reverse this trend as is evident from the MAND_TAX and MAND_TARIFF scenarios. The MAND_TAX scenario leads to a share of diesel vehicles that falls to 21 per cent by 2030. The MAND_TARIFF scenario has less effect in the near term, but beyond 2020 the diesel vehicle share falls sharply due to the rising price of conventional gasoline that makes sugar ethanol sufficiently competitive to offset additional costs that are involved in the deployment of E85 fuels and vehicles. The mandatory fuel standards become non-binding, the E85 fuel blend is produced, and E85 vehicles crowd out diesel vehicles whose sales fall to zero by 2030.

In the MAND_TARIFF scenario, the shift towards a gasoline-ethanol blend, which is more heavily taxed, leads to lower tax rates on both fuels to satisfy the revenue neutrality condition. By 2030, excise duties on both gasoline and diesel decrease by 4.7 per cent compared to the MAND scenario and prices of fuels inclusive of duties drop as shown in Table 3, which reduces even further the competitiveness of diesel vehicles.

3.3 Welfare and emissions impacts of European fuel policies

We find that the renewable fuels requirement alone (MAND scenario) would incur overall economic costs[10] of 0.09 per cent by 2030 relative to the BAU case (Figure 4). This is hardly surprising, since it increases fuel prices at the pump. We find, however,

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[10] We measure economic costs in equivalent variation as a percentage of full income, where full income is the value of consumption and leisure.

that if combined with an appropriate tariff and fuel tax policy, biofuels mandates can be welfare enhancing. Jointly harmonising tax rates on fuels in the MAND_TAX scenario improves welfare by 0.35 per cent in 2030. The reason for this is that existing fuel taxes distort fuel choices. The lower tax-inclusive price of diesel leads consumers to choose more expensive diesel vehicles over gasoline vehicles, but because the lower price is due to the tax rate, there are no real cost savings from using the diesel fuel when European consumers are seen as a group. Equating excise taxes on gasoline and diesel removes the deadweight loss associated with differential fuel price taxation, and we find here that this effect more than offsets the cost of biofuels mandates. Welfare gains from harmonising fuel taxes are substantial relative to the costs of biofuel policy, and are increasing over time, because the tax reform impacts on a large and growing stock of diesel cars that has evolved in the BAU case under a fiscal environment that favours diesel vehicles. Lowering tariffs on biofuels in the MAND_TARIFF scenario increases welfare as it provides access to lower-cost ethanol. As is the case with a combined policy of fuel tax harmonisation, the absence of trade barriers overcompensates costs of biofuels mandates, producing a welfare gain of 0.34 per cent in 2030.[11]

In a context of climate change mitigation policy, these welfare changes can also be evaluated in terms of the resulting reductions in carbon dioxide emissions. In our calculations, we assume that carbon dioxide released in the atmosphere by the consumption of biofuels has been previously captured during the harvest of feedstock, so the net emissions from biofuels are zero. However, energy is used to grow the crop and produce the biofuels, and there are emissions associated with that use of energy. While we account for process emissions from biofuels production, note that we do not consider direct and indirect land-use emissions which are beyond the scope of this paper.[12] Estimates for land use emissions vary widely but, as shown by Melillo *et al.* (2009) and Taheripour *et al.* (2010), they can significantly undermine any emissions reduction benefits.

Focusing first on the emissions from the European private vehicle fleet, the renewable fuel requirement reduces carbon dioxide emissions by 8.2 per cent (MAND scenario)

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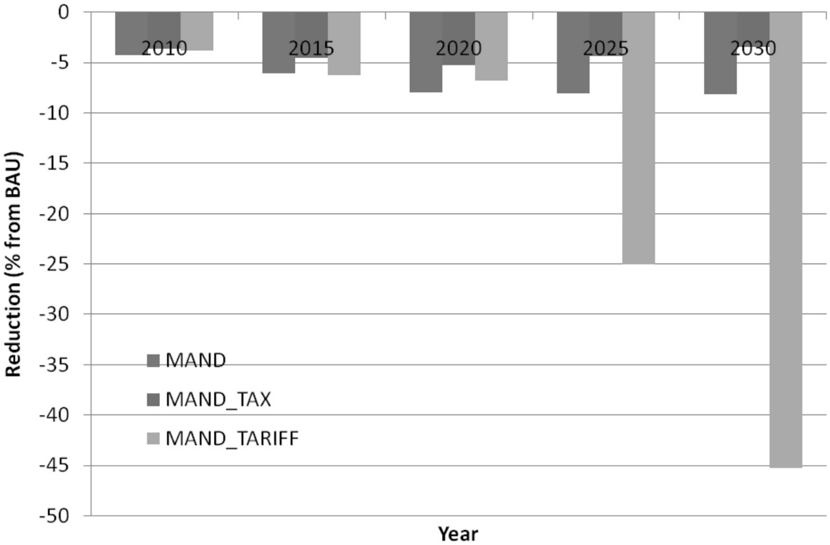
[11] Harmonising tax rates on an *ad-valorem* basis does not equalise marginal costs related to pricing externalities that are not proportional to the fuel price; for example, carbon dioxide emissions, congestion, or noise. In the context of emissions reductions, our approach thus implies that the welfare costs of achieving a given abatement level could be reduced if the carbon content of gasoline and diesel fuels were taxed directly and at an equal rate. In terms of the impacts on the competitiveness of diesel versus gasoline cars, note that the carbon content per dollar of private transportation for a gasoline car is 11 per cent higher than for a diesel car (based on own calculations using the underlying model data). A carbon tax scenario would therefore favour the diesel technology and dampen the downsizing of the diesel fleet relative to what is observed in the MAND_TAX scenario. This moderating effect would be further reinforced by the fact that the pre-tax price for diesel is higher than for gasoline. Overall, we find that alternative assumptions on how to harmonise fuel taxes yield identical qualitative results, and produce quantitatively negligible differences in terms of the penetration of diesel and gasoline cars in Europe. We want to emphasise that the purpose of the tax harmonisation scenario is to show that a mandate on biofuels leads to an inefficient level of biodiesel production if the current fuel tax structure is maintained. While this result can be equally demonstrated by harmonising tax rates on either an *ad-valorem* or an absolute basis, it is important to bear in mind that alternative assumptions affect the cost effectiveness of carbon dioxide emissions reduction targets.

[12] Increased demand for land to produce biofuel crops causes land conversion. If those conversions are from undisturbed land, the result can be significant carbon dioxide emissions.

Figure 5

Reduction of CO_2 Emissions from the Private European Transportation Sector



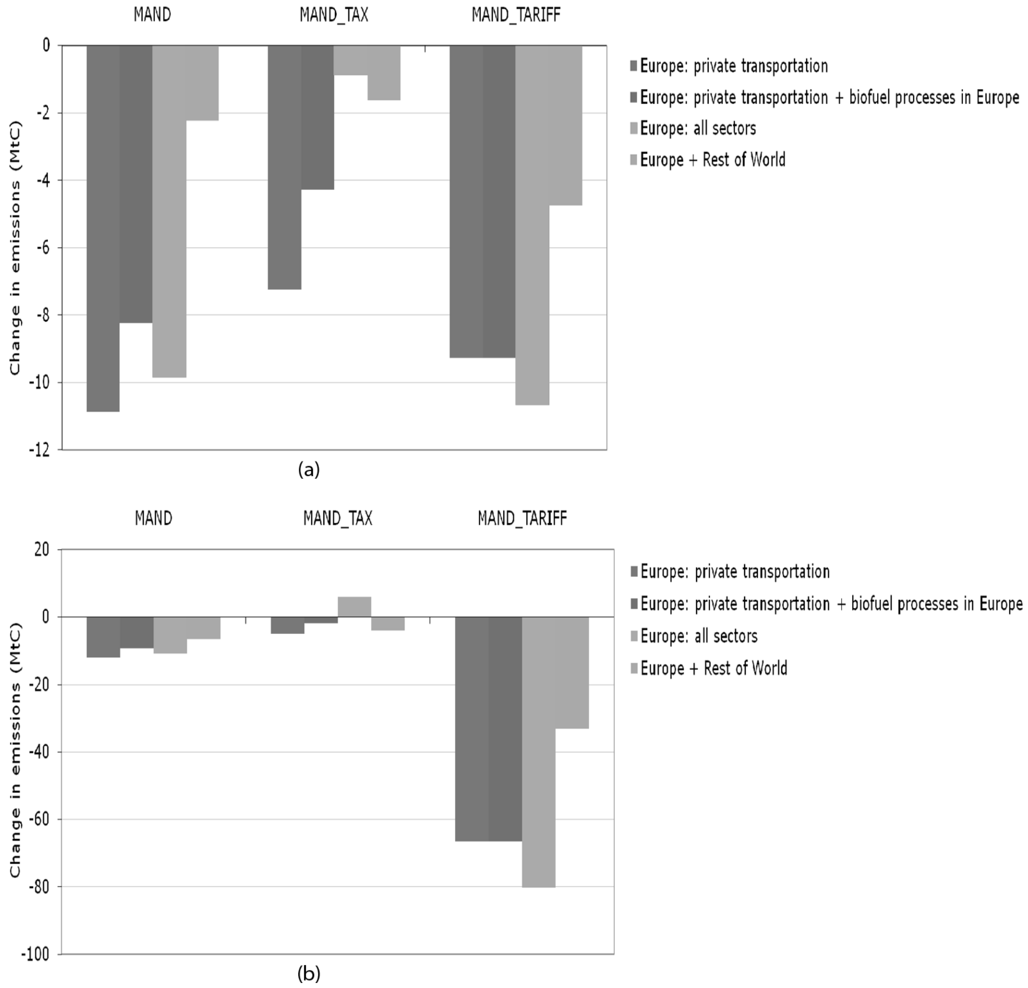
from the 2030 level without the requirement (Figure 5). The relaxation of tariff barriers on biodiesel and ethanol has a much stronger mitigation effect, reducing emissions from the European private transportation sector by 45.3 per cent in 2030. The harmonisation of fuel taxes in the MAND_TAX scenario has the opposite effect, dampening slightly the mitigation effect of renewable fuel requirements. By 2030 the European fleet emits only 3.4 per cent less CO_2 than in the BAU scenario. This results from the fact that the harmonised tax rates lead to increased purchases of gasoline vehicles that have a lower efficiency.

To explore leakage and life-cycle effects (not including indirect land-use change effects), Figure 6 shows for 2020 and 2030 the change in emissions (in million metric tons of carbon, MtC) for the private transportation sector in Europe, the change in private transportation emissions plus emissions from processing biofuels in Europe, the change in emissions from all sectors in Europe, and the change in global emissions.

In the MAND and MAND_TAX scenarios some of the reductions from private vehicles are offset within Europe by process emissions from biofuel production. In the MAND_TARIFF case, there is no difference because biofuels are imported, so there are no process emissions in Europe. European emissions outside the transportation and biofuels processing sectors are reduced in the MAND case, partially offsetting the process emission effect, and in the MAND_TARIFF case actually leading to greater emissions reductions because there are no biofuel process emissions. The main source of this effect is reduced European refinery emissions, because less conventional fuel is used. For the MAND_TAX scenario the decrease of diesel vehicles lowers the pressure on diesel supply and spurs an increase of diesel consumption by other sectors of the economy (agriculture, services, and industries), especially as the economy is growing

Figure 6

Reduction of CO_2 Emissions by the European Renewable Fuels Initiatives in (a) 2020 and (b) 2030



faster than in the BAU scenario. This additional demand for diesel reduces the emissions benefit further, and actually more than offsets the mitigation effect in 2030.

Looking at global emissions reductions shows that renewable initiatives alone or policies with combined changes in fuel tax or tariffs rates produce significant leakage effects. For the MAND and MAND_TARIFF cases, the main effect here is that reduced conventional fuel demand in Europe leads to lower prices for fuel outside of Europe and an increase in fuel use and emissions. Biofuels imports also have associated emissions, but the energy used in biofuels from ethanol is a relatively small factor because the sugar ethanol generally uses bagasse for process energy. Energy use is mainly associated with growing and harvesting the crop. In the MAND_TAX scenario, increased demand for gasoline in Europe drives up gasoline prices outside of Europe and favours a reduction of gasoline use and emissions: here accounting for leakage effects makes the MAND_TAX scenario almost as effective as the MAND scenario in terms of emissions reduction.

4.0 Sensitivity Analysis

To test the robustness of our results with regard to technology and cost assumptions, we use sensitivity analysis to examine how key elasticity and mark-up parameters affect the share of diesel vehicles in the European fleet. Of particular interest are the elasticity of transformation in the refinery sector and substitution elasticities between fuel and other inputs in the private transportation sector, as their parameterisation may affect differentially the diesel and gasoline fleets. Results are reported in Table 4.

The overall insight borne out from these analyses is that across all scenarios considered, the diesel market share is relatively insensitive to different values of key parameters. The effects of varying the elasticity of substitution is of a second order compared to the rise in fuel prices that drives the demand for less fuel-intensive technology or for the cheapest fuel. Increasing transformation possibilities between refinery outputs relieves the pressure on the supply of diesel and allows a further expansion of the diesel fleet, but this effect remains small. The ability to switch between fuel and other inputs in the own-supplied transportation sector also does not significantly change the prospects for diesel

Table 4
Sensitivity of the Share of Diesel Vehicles in the European Fleet in 2030 (in per cent) with Respect to Key Technology and Cost Assumptions

Sector	*Elasticity of substitution between*	*Value*	*BAU*	*MAND*	*MAND_TAX*	*MAND_TARIFF*
Refined oil	Refinery outputs	0.0	33	33	20	13
		0.2*	34	35	21	13
		0.6	36	38	22	16
Private transportation	Fuel and other inputs: New cars	0.2	38	39	24	14
		0.6*	34	35	21	13
		1.0	30	31	16	15
	Fuel and other inputs: Vintage cars	0.0*	34	35	21	13
		0.3	32	33	18	12
		0.4	31	33	17	11
Technology	*Mark-up*	*Value*	*BAU*	*MAND*	*MAND_TAX*	*MAND_TARIFF*
Flex fuel E85 car	Distribution	1.025	34	35	21	10
		1.050*	34	35	21	13
		1.075	34	35	21	17
	Purchase	1.000	34	35	21	15
		1.015*	34	35	21	13
		1.030	34	35	21	13

Note: *Denotes the respective parameter value employed in the base case.

cars. As diesel vehicles are already more efficient than gasoline-based cars, additional improvements in technology and easier substitution between fuel and other inputs favours diesel, but this effect is partly dampened because diesel prices grow faster than gasoline prices, which encourages further substitution away from fuel (that is, purchase of vehicles with greater diesel engine efficiency). In all scenarios, over the 1997–2030 period, the efficiency of new diesel engines increases more (33 per cent in miles per gallon) than that of new gasoline engines (19 per cent in miles per gallon).

Among other sources of uncertainty in our modelling assumptions are the mark-ups related to costs for dispensing and for purchasing an E85 vehicle. According to the International Energy Agency (2006), uncertainties on the former are substantial, ranging from between $0.03 and $0.2 per gallon of ethanol. Information on the latter is unclear, particularly in the USA, where automakers are enticed to sell flex fuel engines because it produces a mileage credit under the Corporate Average Fuel Economy (CAFE) standards. Our sensitivity analysis suggests that different mark-up factors on the E85 vehicle do not change the effects of fuel policies on the diesel fleet (and on other key model variables) in all scenarios except for MAND_TARIFF. E85 is never sold, even without any additional costs entailed to its distribution infrastructures, unless tariffs on ethanol are eliminated. In the MAND_TARIFF scenario, the contraction of the diesel fleet remains a relatively robust pattern, even if E85 or flex fuel technology turns out to be more expensive than expected. Under renewable fuels mandates, inexpensive sugar ethanol, even when blended only up to 10 per cent with conventional gasoline, already reduces the cost of gasoline and makes the gasoline fleet more attractive.

Lastly, we also examine the importance of the revenue-neutrality assumption that underlies all counterfactual scenarios in order to provide a consistent basis for measuring welfare effects. We find that corresponding scenarios that do not require revenue neutrality result in qualitatively identical outcomes and show very small quantitative differences. For example, welfare losses in 2030 in the MAND scenario are slightly higher (−0.10 per cent) and welfare gains in MAND_TARIFF and MAND_TAX cases are slightly lower (0.29 per cent and 0.12 per cent, respectively).

5.0 Conclusions

Favoured by the fuel tax structure and by their efficiency, diesel vehicles have substantially entered the European car market in the last decade. We investigate the sustainability of such a penetration as Europe is moving toward mandatory standards on biofuels. Our analysis within a general equilibrium model of the economy provides several important insights. Under reference conditions (that is, in the absence of fuel and climate policy), diesel vehicles continue to penetrate the European fleet and account for 34 per cent of all vehicles by 2030 (compared to 25 per cent in 2010). This development is driven primarily by fuel prices that double over the next 20 years and that spur the emergence of more efficient engines and increases in the consumption of the least expensive fuel.

Different scenarios of fuel policy modify the prospect for the diesel fleet. We examine the potential implications of renewable fuels initiatives as proposed by the European

Commission (2008a) by implementing mandates on biofuels that require 10 per cent of ethanol and biodiesel after 2020. We find that despite the potentially limited production for biodiesel, the diesel fleet is robust to such a policy due to an existing tariffs structure that favours imports of biodiesel and that protects the domestic production of ethanol. However, combining biofuels mandates with a policy that harmonises excise duties on fuels or that eliminates tariffs on biofuels is shown to reverse the trend toward diesel vehicles. In the case of eliminating tariffs, diesel vehicles are reduced to 13 per cent of the stock of cars and to 3 per cent of new registrations by 2030.

Compliance costs of biofuels mandates can be more than offset if combined with a revenue-neutral reform that harmonises excise duties on fuels or eliminates import tariffs on biofuels. We estimate that proposed biofuels mandates alone would cost 0.09 per cent of welfare in 2030. The harmonisation of excise duties across fuels offsets these costs by reducing the distortionary effect of unequal taxation of fuels and actually leads to welfare gains of 0.22 per cent by 2030. The elimination of tariffs on biofuels generates a welfare gain of 0.34 per cent in 2030 as it makes accessible inexpensive sugar ethanol.

Finally, the environmental effectiveness of biofuels mandates depends crucially on the future stance of European fuel tax and tariffs policy. Without changes in the existing tax and tariff structure, the direct effect of biofuel standards is to reduce CO_2 emissions from the European private transportation sector by 8.2 per cent (-12.0 MtC) by 2030 relative to BAU. Accounting for emissions during the whole life cycle of biofuels produced in Europe dampens the mitigation effect of renewable mandates (-9.2 MtC in 2030). However, as demand for biofuels decreases production and emissions from European refineries, emissions from the production of biofuels are partially offset and the renewable fuel mandate brings about a reduction of total CO_2 emissions in Europe (-10.8 MtC in 2030). Harmonising fuel taxes slightly dampens the mitigation effect due to increased demand for gasoline-based vehicles that have a lower efficiency. Accounting for emissions from other sectors makes Europe an even large emitter under this case ($+6.0$ MtC in 2030) because reduced demand for diesel vehicles spurs diesel consumption in other sectors. On the other hand, the elimination of tariffs on biofuels imports significantly reduces European emissions (-80.2 MtC in 2030). Finally, leakage effects outside of Europe are substantial, particularly as imports of sugar ethanol constitute a large part of the fuel mix in Europe once import barriers are removed. By 2030, leakage effects from a biofuels mandate policy with or without an accompanying reduction in import tariffs reduces mitigation gains obtained from the European renewable initiative by about 40–60 per cent (compare Figure 6, 'Europe: all sectors' with 'Europe + Rest of World'). However, if biofuel mandates are complemented with a policy that harmonises fuel taxes, international leakage can be reduced effectively.

We have developed a model that examines in considerable detail the demand for and supply of fuel in Europe to study the role of biofuels mandates. The results show a complex interrelationship between the gasoline and diesel fleet, fuel tax and tariff policy, and fuel exports and imports. The interaction of biofuels mandates and fuel and tariff policy strongly affects the economic costs (or benefits) and the CO_2 emissions implications of the biofuel mandate. Accounting biofuels as nominally neutral in terms of CO_2 emissions within the private automobile fleet reduces fleet emissions, but there are many ways in which this direct effect on emissions is offset by process emissions domestically or abroad, or through other leakage effects domestically or abroad. Accurately accounting for biofuel CO_2 emissions would need to take into account these multiple indirect effects.

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