Should a vehicle fuel economy standard be combined with an economy-wide greenhouse gas emissions constraint? Implications for energy and climate policy in the United States*

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ABSTRACT

The United States has adopted fuel economy standards that require increases in the on-road efficiency of new passenger vehicles, with the goal of reducing petroleum use and (more recently) greenhouse gas (GHG) emissions. Understanding the cost and effectiveness of fuel economy standards, alone and in combination with economy-wide policies that constrain GHG emissions, is essential to inform coordinated design of future climate and energy policy. We use a computable general equilibrium model, the MIT Emissions Prediction and Policy Analysis (EPPA) model, to investigate the effect of combining a fuel economy standard with an economy-wide GHG emissions constraint in the United States. First, a fuel economy standard is shown to be at least six to fourteen times less cost effective than a price instrument (fuel tax) when targeting an identical reduction in cumulative gasoline use. Second, when combined with a cap-and-trade (CAT) policy, a binding fuel economy standard increases the cost of meeting the GHG emissions constraint by forcing expensive reductions in passenger vehicle gasoline use, displacing more cost-effective abatement opportunities. Third, the impact of adding a fuel economy standard to the CAT policy depends on the availability and cost of abatement opportunities in transport—if advanced biofuels provide a cost-competitive, low carbon alternative to gasoline, the fuel economy standard does not bind and the use of low carbon fuels in passenger vehicles makes a significantly larger contribution to GHG emissions abatement relative to the case when biofuels are not available. This analysis underscores the potentially large costs of a fuel economy standard relative to alternative policies aimed at reducing petroleum use and GHG emissions. It further emphasizes the need to consider sensitivity to vehicle technology and alternative fuel availability and costs as well as economy-wide responses when forecasting the energy, environmental, and economic outcomes of policy combinations.

1. Introduction

How to treat passenger vehicles as part of national climate and energy policy is under discussion in many countries. Globally, passenger vehicles are driven around seven trillion miles every year and account for around 20% of manmade carbon dioxide (CO_2) emissions in the United States, 12% in Europe, and about 5% of emissions worldwide (EPA, 2010a; GMID, 2010; IEA, 2010). As vehicle ownership and use increases in many developing countries, identifying effective policy approaches will have not only national, but global, importance.

Households in the United States in particular are largely dependent on privately-owned vehicles for personal mobility. A U.S. household spends around 10% of its annual income on vehicle transport (BEA, 2012), and the majority of U.S. households own two or more vehicles (Davis et al., 2011).[1] Annual growth in the number of private vehicles in the U.S. has averaged about 2.3% per year since 1970, while miles-traveled per vehicle has trended slowly upward at 0.4% per year over the same period (Davis et al., 2011). Although the U.S. household transport income share and the household vehicle stock growth rate has declined in recent years (BEA, 2012; Davis et al., 2011), the prospect of continued growth in vehicle ownership and travel demand has prompted increasing concern about the externalities associated with passenger vehicles. In 2010, light-duty vehicles accounted for about 45% of total U.S. petroleum use and petroleum-based fuels supplied over 90% of the energy required by vehicles (Davis et al., 2011). Recent U.S. federal energy legislation has targeted reductions in petroleum use, given concerns over the vulnerability of the U.S. to global oil price shocks and its associated national security implications (EISA, 2007; Energy Policy Act of 2005).

This analysis focuses on two policies intended to address the linked goals of reducing petroleum use and GHG emissions in the United States.

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[1] This percentage is much lower for households that do not own a vehicle.

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These policies include an economy-wide cap-and-trade (CAT) policy and a vehicle fuel economy standard (FES) policy. Although policies are often designed separately in the course of the political process, when implemented they will interact, affecting energy and environmental outcomes as well as total policy cost. Studies have shown that a policy requiring sector- or technology-specific contributions to economy-wide abatement can increase the cost of complying with an economy-wide cap on GHG or CO_2 emissions (see for example Morris et al., 2010; Rathmann, 2007; De Jonghe et al., 2009; Bennear and Stavins, 2007; Böhringer and Rosendahl, 2009). Here we investigate the consequences of combining policies that have the distinct but closely-linked primary goals of mitigating climate change (through a cap on fossil CO_2 emissions) and addressing energy security concerns (through a national fuel economy standard that regulates the efficiency of new passenger vehicles). Lessons from this analysis are relevant for policymaking efforts in other countries and regions.

An economy-wide cap-and-trade (CAT) policy is considered an economically efficient mechanism for achieving emissions reductions at least cost. The 2009 Waxman–Markey Act, which included a CAT policy, became the first comprehensive climate policy legislation to pass the U.S. House of Representatives (ACES, 2009). Although never passed into law, a CAT policy may be proposed again in the future.

Unlike a CAT policy, fuel economy standards have been implemented in the United States for several decades. Passed in 1975 in the wake of 1973 Arab Oil Embargo, the Corporate Average Fuel Economy (CAFE) Standards mandated increases in the on-road fuel economy of cars and light-duty trucks starting in 1978 (Shiau et al., 2009). These standards were tightened sharply through the early 1980s but remained constant over much of the 1990s and were not increased again until 2005 for light trucks and 2011 for cars.[2] In 2010, following classification by the Environmental Protection Agency (EPA) of CO_2 and other GHGs as pollutants under the Clean Air Act, the agency became involved in setting per mile emissions standards. Per-mile CO_2 emissions standards were harmonized with a more stringent version of the CAFE standard, and mandated an increase in the combined average per mile CO_2 emissions to 250 g/mile (which corresponds to a fuel economy target of 35.5 miles/gal if the per-mile emissions target is met through improvements in fuel efficiency alone) over the period 2012 to 2016.[3] In late 2011, a new fuel economy standard for model years 2017 to 2025 was announced, requiring a 5% annual increase in fuel economy for passenger cars, and a 3.5% annual increase for light trucks for model years 2017 to 2021 followed by a 5% increase per year for model years 2022 to 2025 (EPA, 2011). For model year 2025, this translates into a CO_2 emissions target of 144 g/mile for passenger cars and 203 g/mile for light trucks, for a combined new fleet average of 163 g/mile.

Multiple policy instruments focused on distinct but related goals are often evaluated in separate analyses. However, integrated assessment is essential to understand the potentially large impacts caused by policy interaction on the targeted outcomes as well as the economic cost. Often policies are sold to the public as addressing multiple goals, for instance, both energy security and climate change. Policymakers need to understand the cost effectiveness of policies with respect to each goal when policies are implemented *in combination*, since non-linear technology cost curves and differences in policy coverage result in an impact that is unlikely to be additive.

This paper focuses on the impact of a representative fuel economy standard (FES), modeled based on current and potential future U.S. CAFE targets, alone and in combination with an economy-wide cap-and-trade system. To evaluate the impact of these policies, a model is needed that captures endogenously transitions in vehicle technology and fuels as well as macroeconomic feedbacks and the resulting costs associated with policies. The second section describes the details of the model and the representation of policies. The third section provides results for the FES implemented alone and in combination with a CAT policy. The fourth section summarizes the conclusions of this study and associated policy implications.

2. Model description

The model used in this analysis is a specialized version of the MIT Emissions Prediction and Policy Analysis (EPPA) model that includes a technology-rich representation of the passenger vehicle transport sector. The EPPA model is a recursive–dynamic general equilibrium model of the world economy developed by the Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology (Paltsev et al., 2005). The EPPA model is built using the Global Trade Analysis Project (GTAP) dataset (Dimaranan and McDougall, 2002; Hertel, 1997). For use in the EPPA model, the GTAP dataset is aggregated into 16 regions and 24 sectors with several advanced technology sectors that are not explicitly represented in the GTAP data (Table 1). Additional data for greenhouse gases (carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulfur hexafluoride, SF_6) are based on the United States Environmental Protection Agency inventory data and projects.

2.1. The passenger vehicle transport sector in the EPPA5-HTRN model

To simulate the costs and impacts of policies, models must include both broad sectoral coverage and price feedbacks as well as an appropriate amount of system detail that resolves key variables and the

Table 1
Sectors and regions in the EPPA model.

Sectors	Regions
Non-energy	*Developed*
Agriculture	USA
Forestry	Canada
Energy-intensive products	Japan
Other industry products	Europe
Industrial transportation	Australia and Oceania
Household transportation	Russia
Food	Eastern Europe
Services	*Developing*
Energy	India
Coal	China
Crude oil	Indonesia
Refined oil	Rest of East Asia
Natural gas	Mexico
Electricity generation technologies	Central and South America
Fossil	Middle East
Hydro	Africa
Nuclear	Rest of Europe and Central Asia
Solar and wind	Dynamic Asia
Biomass	
Natural Gas Combined Cycle (NGCC)	
NGCC with CO_2 Capture and Storage (CCS)	
Advanced coal with CCS	
Synthetic gas from coal	
Hydrogen from coal	
Hydrogen from gas	
Oil from shale	
Liquid fuel from biomass	

Note: Detail on aggregation of sectors from the GTAP sectors and the addition of advanced technologies are provided in Paltsev et al. (2005). Details on the disaggregation of industrial and household transportation sectors are documented in Paltsev et al. (2004).

[2] In addition to passenger vehicles, the light-duty vehicle fleet is comprised of cars and light-trucks owned by commercial businesses and government. U.S. federal regulations consider a light-duty truck to be any motor vehicle having a gross vehicle weight rating (curb weight plus payload) of no more than 8500 pounds (3855.5 kg). Light trucks include minivans, pickup trucks, and sport-utility vehicles (SUVs).

[3] The original vehicle fuel economy target under the Energy Independence and Security Act of 2007 was 35 mpg by 2020. The 35.5 mpg target is the improvement required if the corresponding per mile CO_2-equivalent emissions target (250 g/mile) is met by improvements in fuel economy alone. Emissions of CO_2 account for over 95% of vehicle-related GHG emissions.

relationships among them as they evolve over time. Few models used for policy analysis attempt to address both needs, whether for the case of passenger vehicles or for other sectors, and indeed the type of detail required depends on the research question of interest. The developments undertaken in the EPPA model to enable this work build on previous efforts to develop model versions that simultaneously forecast economic and physical system characteristics by supplementing economic accounts with physical system data. For instance, McFarland et al. (2004) adopt a similar approach, implementing technological detail for carbon capture and storage technology in a top–down macroeconomic model. Another example is Schafer and Jacoby (2006), which examines the response of the transportation sector to economy-wide climate policy by coupling a top–down macroeconomic model with bottom–up mode share forecasting and vehicle technology models.

In this work, several features were incorporated into the EPPA model to explicitly represent passenger vehicle transport sector detail. These features include an empirically-based parameterization of the relationship between income growth and demand for vehicle-miles traveled, a representation of fleet turnover, and opportunities for fuel use and emissions abatement. These model developments, which constitute the *EPPA5-HTRN* version of the model, are described in detail in Karplus (2011), and build on previous disaggregation of the household transportation sector in the EPPA model described in Paltsev et al. (2004). The structure of the passenger vehicle transport sector in *EPPA5-HTRN* that includes these developments is shown in Fig. 1.

The main innovation in the *EPPA5-HTRN* model is the use of disaggregated empirical economic and engineering data to develop additional model structure and introduce detailed supplemental physical accounting in the passenger vehicle sector. First, to capture the relationship between income growth and VMT demand, econometric estimates were used in the calibration of the income elasticities (Hanly et al., 2002), which were implemented using a Stone–Geary utility function, a method for allowing income elasticities to vary from unity within the Linear Expenditure System (LES) (Markusen and Rutherford, 1995). The income elasticity in the United States was calibrated to reflect the long-run estimate of 0.73 given in Hanly et al. (2002), but after 2035 this elasticity is set to diminish by 0.05 in each five-year period to simulate saturation of household vehicle ownership by further reducing the size of the household vehicle transport expenditure share. More details on model parameterization can be found in Karplus (2011). Second, data on the physical characteristics of the fleet (number of vehicles, vehicle-miles traveled (VMT), and fuel use by both new vehicles (zero to five-year-old) and used vehicles (older than five years), as well as economic characteristics (the levelized cost of vehicle ownership, comprised of capital, fuel, and services components) were used to parameterize the passenger vehicle transport sector in the benchmark year and vehicle fleet turnover dynamics over time in all model regions (Bandivadekar et al., 2008; GMID, 2010; Karplus, 2011). Engineering-cost data on vehicle technologies were used to parameterize elasticities that determine substitution between fuel and vehicle efficiency capital (EPA, 2010b). Third, plug-in hybrid electric vehicles (PHEVs), as a representative alternative fuel vehicle, were introduced into the model, along with a substitution elasticity between the fuel and vehicle efficiency capital (similar to the ICE vehicle) that represents fuel consumption reduction opportunities specific to the PHEV (Karplus et al., 2010). The detailed structure of the powertrain-fuel bundle for new vehicles, which shows substitution between the PHEV and ICE-only vehicle, as well as opportunities to reduce the fuel consumption of each vehicle type through substitution between fuel and vehicle powertrain efficiency capital, is shown in Fig. 1b.

The representation of technology and its endogenous response to underlying cost conditions is essential for analyzing policies, which

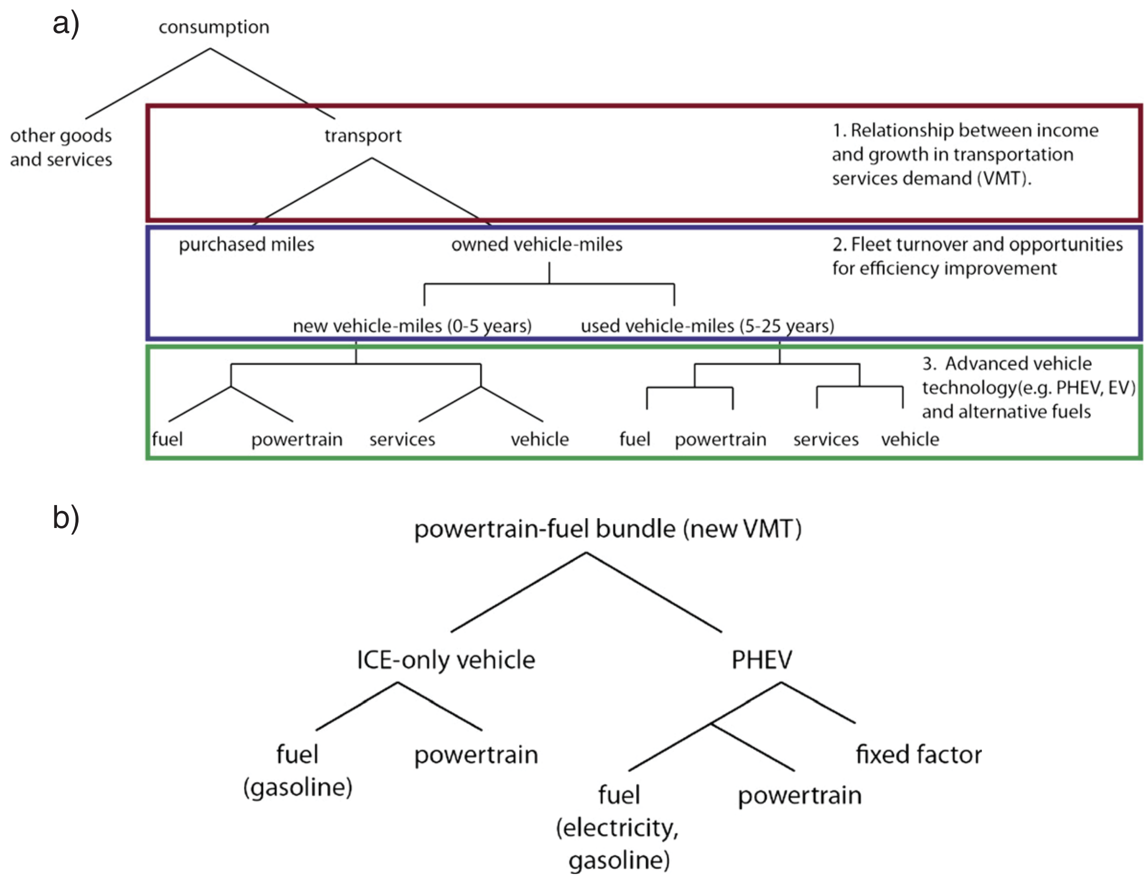


Fig. 1. Representation of a) the passenger vehicle transport sector incorporated into the representative consumer's utility function in the MIT EPPA model, and b) the detailed structure of the powertrain-fuel bundle.

typically act—directly or indirectly—through the relative prices of fuels or vehicles. Here we consider a plug-in hybrid electric vehicle (PHEV), which is modeled as a substitute for the ICE-only vehicle that can run on gasoline in a downsized internal combustion engine (ICE) or on grid-supplied, battery-stored electricity. The PHEV itself is assumed to be 30% more expensive relative to a new internal combustion engine (ICE)-only vehicle, an assumption at the low end of the range of estimates from a recent literature review (Cheah and Heywood, 2010).[4] Vehicle characteristics and technology requirements are defined based on a mid-sized sedan, which relies on grid-supplied electricity for 60% of miles traveled and liquid fuels for the remaining 40%.[5] ICE fuel economy assumes operation in hybrid mode, while the battery is sized for an all-electric range of 40 miles. As the levelized price per mile of ICE vehicle ownership increases over time (with increasing fuel cost and the introduction of efficiency technology), the cost gap is allowed to narrow and may eventually favor adoption of the PHEV. PHEVs are assumed to use grid-supplied electricity for the first 30 miles of travel, beyond which they run on the existing liquid fuel supply (gasoline and gasohol blends). The electricity sector in EPPA is modeled as a combination of the mix of generation technologies in 2004 and any advanced low carbon electricity production methods that are introduced over time in response to changing underlying prices or policy.[6]

As mentioned briefly above, we also simulate the ability to reduce the fuel consumption of newly sold PHEVs by investing in efficiency improvements. For the PHEV, we develop a marginal abatement cost curve using the same procedure as was used for the ICE-only vehicle described above, but using the PHEV as the new more efficient "base" vehicle and including opportunities to reduce fuel consumption specific to the PHEV. For instance, mild hybridization of the ICE (e.g. adding a battery to store energy during breaking and using it to assist ICE operation) is included as a fuel consumption reduction opportunity for the ICE-only vehicle, but not for the PHEV, because the PHEV is assumed to have this capability (and it is reflected in the fuel efficiency of miles driven using the ICE). Opportunities to improve the efficiency of the PHEV include improvements such as vehicle light weighting, further engine downsizing, or the adoption of low rolling resistance tires, among others.

When initially adopted, the PHEV faces increasing returns to scale as parameterized in earlier work, to capture the intuition that early deployment is more costly per unit until large-scale production volumes have been reached, which also affects its relative cost (Karplus et al., 2010). The PHEV competes against an ICE-only vehicle, which as described above is parameterized to become more efficient in response to rising fuel prices. As ever larger volumes of PHEVs are introduced, cost of further scaling production will fall accordingly. The model chooses the least cost combination of PHEV adoption and ICE-only vehicle efficiency improvement that is capable of achieving compliance with the standard. The model captures the intuition that the cost and pace of PHEV deployment should depend on when these vehicles become economically viable, stringency of the fuel economy standard, and the rate at which costs decrease as production is scaled up. The results of this analysis are sensitive to the parameterization of these responses, and therefore we have taken steps to calibrate these responses based on the range of available empirical data (Karplus, 2011). We note that the deployment decisions taken under the two policy trajectories specified reflect a myopic decision-making assumption due to the recursive–dynamic model structure; a forward-looking model would likely suggest an earlier deployment time frame under a gradual path to reduce high costs associated with the stringency of the policy target in later periods. However, this myopic assumption may be realistic if policy targets are not defined far enough in advance, as lead times for introducing new vehicle technologies can be several years or more.

In our modeling strategy we essentially capture a single representative size class with average fuel economy for the both the new and used vehicle fleets. The characteristics of used vehicles, including their fuel economy, are a function of the surviving vehicles in each year, while improved vehicle efficiency is introduced largely through the sales of new vehicles. To capture the additional investment required to reduce fuel consumption, we have parameterized a substitution elasticity between vehicle efficiency capital and fuel that is based on an estimation of the costs of strategies for reducing fuel consumption in vehicles in response to the new standard.

2.2. Policy representation: Fuel economy standard (FES) and cap-and-trade (CAT) policy

The new model structure allows for a comparison of energy, environmental, and economic outcomes under policies implemented individually and in combination, relative to a No Policy baseline scenario. A CAT policy is imposed in the model as a constraint on economy-wide GHG emissions as described in previous work (Paltsev et al., 2009). The additional disaggregation in the *EPPA5-HTRN* model makes it possible to impose on-road efficiency (fuel economy) targets in the passenger vehicle transport sector.

A representative vehicle fuel economy standard was implemented in the model in order to simulate a policy constraint similar to the U.S. Corporate Average Fuel Economy (CAFE) standards. A fuel economy standard is represented in the EPPA model as a constraint on the quantity of fuel required to produce a fixed quantity of vehicle-miles traveled. The target level of fuel consumption is reached by imposing an endogenous subsidy on vehicle efficiency capital at a level that incentivizes market uptake of strategies that achieve the target at least cost. Opportunities to improve fuel economy are described by a parameter that relates cost of technology and abatement potential, which is used to estimate the elasticity of substitution between fuel and powertrain capital as inputs to household vehicle transport. The model also captures how total VMT will then respond when fuel economy has been forced to high levels by the constraint, also known as the rebound effect. The form of the utility function, the input shares, and the substitution elasticity between vehicle and powertrain capital determines how much the marginal cost per mile of travel responds to changes in the underlying fuel requirement and vehicle characteristics, which in turn determines the magnitude of the rebound effect.

The vehicle fuel consumption constraint equation is shown in Eq. (1). All future reductions are defined relative to the ratio of fuel Q_{f,t_0} to miles-traveled Q_{VMT,t_0} in the model benchmark year (t_0). Vehicle fuel economy as described in EPPA is based on the actual quantity of energy used and is expressed here as on-road (adjusted) fuel consumption in liters per 100 km (L/100 km).[7] Targets set by policymakers are typically reported in the literature and popular press using unadjusted fuel consumption (or fuel economy) figures. Unadjusted fuel consumption is the fuel requirement per unit distance measured by laboratory tests, while adjusted figures reflect actual energy consumption on the road. To obtain adjusted fuel consumption, we divide the unadjusted numbers by 0.8, which is an approximation of the combined effect of on-road adjustment factors applied by the EPA to city and highway test cycle estimates (EPA, 2006). All vehicle technologies are modeled by applying this adjustment factor to test-cycle rated fuel consumption (and so reflect on-road estimates). For the PHEV this adjustment factor

[4] Specifically, we choose as a relatively optimistic scenario the estimate from Plotkin and Singh (2009) for a PHEV40 in 2015, which gives a markup over conventional ICE car of US $6000.

[5] This mileage split is a function of travel patterns in the United States and battery all-electric range, as discussed in Karplus (2011). The mileage share driven on electricity is referred to as the PHEV utility factor (Gonder and Simpson, 2006).

[6] We do not model hourly pricing or separately represent base load, peaking, and shoulder generation, nor do we represent regional differences in the electricity mix across the U.S. that could affect the marginal emissions rates for the PHEV fleet.

[7] Fuel economy targets are expressed here in L/100 km in order to preserve linear scaling in terms of the fuel requirement per unit distance traveled. To obtain the equivalent miles per gallon for targets expressed in liters per 100 km, the target quantity should be divided into 235.

is applied only for miles traveled on ICE. The trajectory A_t is a fraction that defines allowable per-mile fuel consumption relative to its value in the model benchmark year in each future model period. The constraint requires that the on-road fuel consumption (FES_t) realized in each period for new (zero to five-year old) vehicles remain below the average required by the regulation in each model year. The constraint is assumed to be met by a combination of available measures to reduce new vehicle fuel consumption, and results in a reduction in fuel required per unit distance traveled. For instance a value of $A_t = 0.5$ in 2030 means that fuel consumption relative to the model benchmark year must decline by half. To translate from the model year standard into a constraint consistent with the model's five-year time step, we calculate the target based on the fuel consumption reduction required in vehicles sold across the five most recent model years, weighted by the age-specific contribution of each model year to VMT.[8] Age-specific miles-traveled per vehicle are reported in Davis et al. (2011).

$$FES_t \leq A_t\left(Q_{f,t_0}/Q_{VMT,t_0}\right) \tag{1}$$

For purposes of this analysis, we consider two policy trajectories through 2050, with the objective of exploring the long-term implications of continuing policies that have been set recently for 2012 to 2016, or have been proposed for the period 2017 to 2025. The policy trajectories are shown in Fig. 2. We choose two representative FES policy pathways. The FES-sharp policy represents a halving of on-road adjusted fuel consumption by 2030 and remaining constant thereafter. The FES-gradual policy achieves the same cumulative reduction in passenger vehicle fuel use, but does so using steady incremental reductions in each compliance period through 2050. The sharp policy is approximately the same as the proposed combined standard for light duty vehicles through 2025, while the gradual policy is less stringent through 2025 but becomes more stringent over the 2025 to 2050 time frame (reaching 75 mpg on-road or 93.5 mpg unadjusted in 2050).

There are several limitations to our approach to representing fuel economy standards. First, we model the FES as a single target on all new vehicles sold, rather than a target that must be met by each manufacturer. However, we argue that this is realistic because recent CAFE standards allow trading of credits across manufacturers, resulting in a sales-weighted average target for the new vehicle fleet equivalent to the fuel economy target applied in our model. Second, since we do not model individual manufacturers explicitly, we also do not model the potential for oligopolistic behavior among automotive manufacturers in their response to the standards. Third, we do not represent the attribute-based component of the standard, which sets target fuel economy based on vehicle size. This additional detail is very difficult to model explicitly, given that the fleet-wide target fuel economy level will depend on the marginal costs and benefits of shifting across weight classes.

We also recognize that there are a number of features of the regulation that affect the outcomes of interest, but only some of which we are able to model. First, we do not model cars and light trucks separately, but instead assume a single representative vehicle that reflects the average characteristics of the light-duty vehicle fleet as a whole. While we do not explicitly consider the welfare costs of inducing a shift among vehicle segments in favor of smaller vehicles, we do consider opportunities (and the associated cost) of reducing vehicle weight through engine downsizing and the introduction of new materials in our estimates of the technology response. Second, we do not model flex-fuel credits, gas-guzzler taxes, or other provisions that could in practice affect the stringency of the fuel economy standard. Third, we do not model advanced technology credits that could incentivize more rapid deployment of alternative fuel vehicles, although we do capture the fact that emissions associated with alternative fuels are largely unconstrained by the regulation.

Economic cost throughout this analysis is measured in the form of equivalent variation (constant 2004 USD). It constitutes a measure of the economy-wide reduction in consumption due to the policy (relative to the reference scenario), including both direct and opportunity costs associated with investment in reducing new vehicle fuel consumption.

3. Results

The policy analysis is divided into several tasks. First, we analyze the FES policy implemented alone, and compare it to a tax that achieves the same cumulative reduction.[9] Second, we briefly focus on the role of passenger vehicles under a CAT policy. Third, we consider the impact of combining the two policies in terms of cost as well as gasoline use and GHG emissions reduction outcomes. Fourth, we analyze PHEV technology scenarios to understand its impact on these outcomes.

3.1. Analysis of a fuel economy standard

We begin by assessing the impact of the two FES policies paths described above in Section 2, both of which achieve a 20% cumulative reduction in gasoline use. The specific outcomes of interest are U.S. motor gasoline use, GHG emissions reductions, and policy cost relative to the No Policy reference case.

One way to measure the relative cost effectiveness of a fuel economy standard is to compare it to another policy instrument. In this case we choose the instrument that theory predicts will incentivize fuel use reductions at least cost—a tax on motor gasoline. Two tax cases are considered, one in which biofuels are available and another in which they are not. This sensitivity is important because a tax that increases the price of motor gasoline thereby reduces the relative price of available substitutes, which may play a large role in achieving the overall reduction target. Indeed, the tax required to achieve a 20% cumulative reduction in gasoline use is lower when biofuels are available. The resulting tax level (assuming biofuels are available) was an ad valorem rate of 45% (equivalent to \$0.83/gal in U.S. dollars in the model base year, 2004).[10] If biofuels are not available, the required tax is 75% (\$1.39/gal in 2004 U.S. dollars). To allow for consistency with the discount rate used in the EPPA model and to provide equal footing for the comparison of policy costs, policy costs are discounted at a rate of 4% per year and expressed in terms of net present cost in U.S. 2004 dollars.[11] When comparing the four policy trajectories (two FES policies and two tax policies), clear differences emerge in the timing of the reductions, despite the fact that all achieve the same cumulative reduction target. Fig. 3 shows the reduction trajectories in the a) FES policy and b) gasoline tax cases. Several differences are worth noting. Gasoline use decreases in the early periods under the gasoline tax (which is implemented as a constant ad valorem tax starting in 2010) because it bears on the decisions of drivers of all

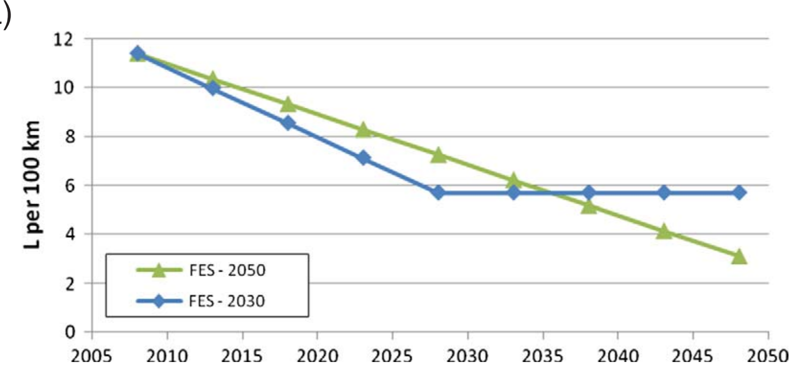
[8] There are different economies of scale and costs associated with scaling up production of the PHEV in each of the two cases considered, depending on the relative stringency of the constraint.

[9] This tax is applied ad valorem before the application of refining and retail margins as well as per-gallon national average tax, and does not apply to any advanced biofuels blended into the fuel supply.

[10] The price of petroleum in the reference (No Policy) case rises over time due to the effects of rising demand and increasingly scarce supply, and as a result the constant tax is multiplied by a higher base gasoline price, increasing the amount of the tax in absolute terms. The retail gasoline price increase includes refining and distribution margins.

[11] Net present value of the costs depends on the choice of discount rate. We use a discount rate similar to the rate recommended by the US Office of Management and Budget (2003).

a)



b)

Year	FES 2050 – Gradual				FES 2030 – Sharp			
5-year average	% below 2010	UA L/100 km	Adj. L/100 km	Adj. mpg	% below 2010	UA L/100 km	Adj. L/100 km	Adj. mpg
2005-2010	0.0%	9.1	11.4	20.6	0.0%	9.1	11.4	20.6
2010-2015	9.1%	8.3	10.4	22.7	12.5%	8.0	10.0	23.5
2015-2020	18.1%	7.5	9.3	25.2	25.0%	6.8	8.6	27.5
2020-2025	27.2%	6.6	8.3	28.3	37.5%	5.7	7.1	33.0
2025-2030	36.3%	5.8	7.3	32.3	50.0%	4.6	5.7	41.2
2030-2035	45.3%	5.0	6.2	37.7	50.0%	4.6	5.7	41.2
2035-2040	54.4%	4.2	5.2	45.2	50.0%	4.6	5.7	41.2
2040-2045	63.4%	3.3	4.2	56.3	50.0%	4.6	5.7	41.2
2045-2050	72.5%	2.5	3.1	74.9	50.0%	4.6	5.7	41.2

Note: UA– unadjusted (regulatory target), Adj. – adjusted (on-road fuel consumption)

Fig. 2. Adjusted (on-road) fuel consumption trajectories for three alternative FES policies shown a) graphically and b) numerically. Note: UA—unadjusted (regulatory target), A—adjusted (on-road fuel consumption).

vehicles and thus affects gasoline use by new and used vehicles in the first year it is implemented. By contrast a FES policy allows gasoline use to continue increasing through 2015 before leveling off and then gradually decreasing. The gradual path, which requires the greatest reductions in fuel economy in the later years, has to compensate for slower reductions during the early periods.

We now compare the cost and GHG emissions reductions associated with achieving the 20% gasoline reduction target using each of these policy instruments. Cost is defined here as equivalent variation, which is an economic measure of the change in consumption due to the policy constraint and measured relative to a reference (No Policy) case.

The costs and associated GHG emissions reductions under each of the policies are shown in Table 2. The first observation is that for the same cumulative gasoline reduction, the FES policies are at least six to fourteen times more expensive than the gasoline tax, with the relative cost advantage depending on the availability of advanced biofuels in the tax cases. Comparing the two fuel economy standards, the gradual path is much more expensive than the sharp path. To understand why, it is important to consider how the policy operates. Its mandate is limited to the efficiency of new vehicles, while its impact on gasoline use depends on how much the vehicles are driven. In order to achieve significant reductions in gasoline use, the higher efficiency vehicles must be driven on the road over multiple years. Thus for a linear path to achieve the same reduction in gasoline consumption, the target in the final compliance year must be very tight in order to compensate for the effects of the more relaxed standard in earlier periods. The marginal cost associated with obtaining additional reductions from advanced internal combustion engine (ICE) vehicles and plug-in hybrid electric vehicles (PHEVs) to produce a five-year new vehicle fleet average fuel consumption of lower than 2.5 L per 100 km (unadjusted fuel consumption) increases non-linearly and is very high at these low fuel consumption levels. If the electric vehicle (EV) is available at a markup of 60% (and assumed to offer an equivalent range and other functionality as an ICE vehicle or PHEV), the cost of achieving this tough target is reduced by more than half, demonstrating the importance and sensitivity of this result to the cost and availability of advanced vehicle technology and fuels. It is also worth noting that in a model with perfect foresight, agents would anticipate high costs in future periods and act earlier to reduce fuel economy so that total gasoline use reductions would be achieved at lower cost. However, as of this writing, no fuel economy targets have been set firmly beyond 2016, and so the myopic logic of the model is consistent with the current limited information upon which agents must make decisions about future fuel economy investment.

The results indicate that for a fixed level of cumulative gasoline reduction (20%), the cost and CO_2 emissions impact varies. A fuel tax is the lowest cost way of reducing fuel use, with a total cumulative discounted cost of $1.7 or $0.7 billion/year, respectively. The impact on total economy-wide CO_2 emissions is slightly less under the tax because the tax has the effect of increasing the relative price of gasoline used in passenger vehicles relative to fuel used in other non-covered transportation modes, and fuel demand (as well as CO_2) emissions from these related sectors increases slightly relative to the reference case. In the FES-gradual case, the cost is sensitive to

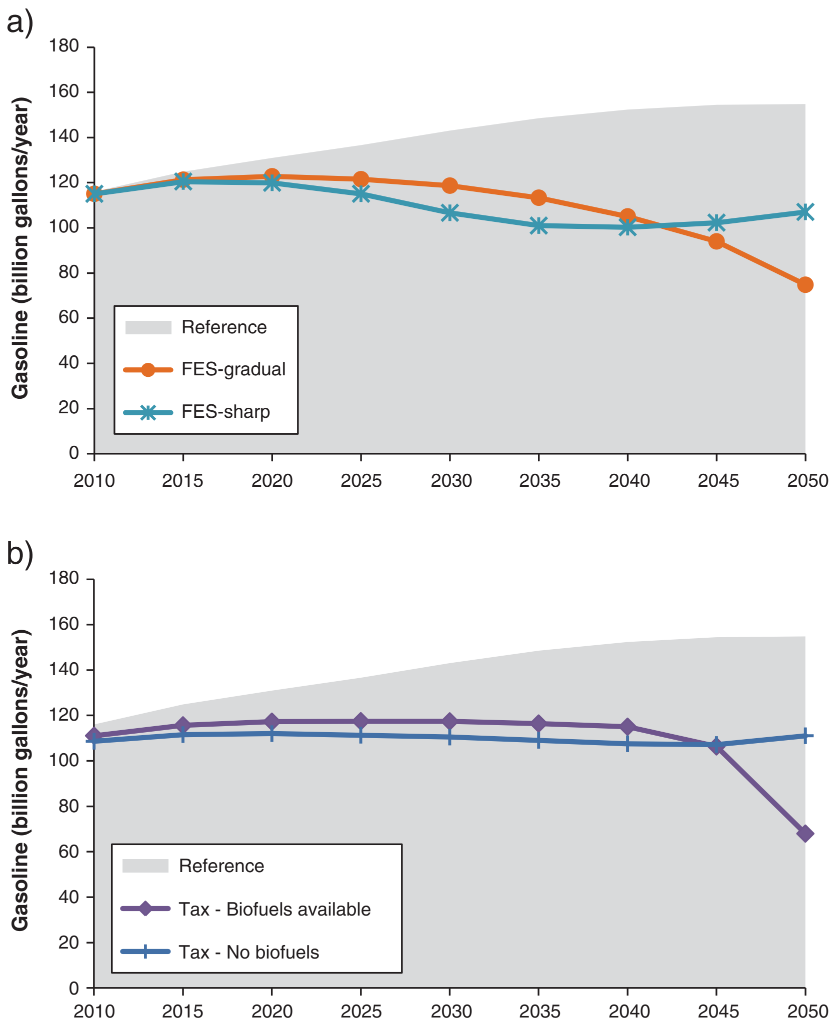


Fig. 3. Gasoline reduction trajectories for a) the fuel economy standard and b) the gasoline tax (with and without biofuels) that achieves a total cumulative reduction in gasoline use of 20% relative the reference (No Policy) case.

the availability of EVs (which, if available, result in a reduction in cost from $63 billion/year to $56 billion/year).

Table 2 also summarizes the technology outcomes forecasted by the model under each different policy, which helps to explain why the FES policies are significantly more costly relative to the tax option. A tax policy incentivizes the pursuit of abatement opportunities according to least cost across the entire vehicle-fuel-user system in each model period through 2050. In the initial periods, the tax policy encourages reductions in gasoline use through mileage conservation, while in the longer term, it incentivizes a mixture of increased ICE vehicle efficiency and PHEV adoption. The most striking difference with the FES policy is that the gasoline use by the total fleet continues to increase in the early periods, since the policy can only act through changes in the composition of the new vehicle sales mix. A FES also induces a rebound effect as consumers drive more in response to lower per mile fuel costs, while the tax induces a conservation response. The FES-gradual policy is particularly costly because vehicle efficiency requirements in the later periods must be especially tight to achieve the targeted reduction, since vehicles sold in these later years will only make a limited contribution on the road to total cumulative gasoline demand during the period considered.

Table 2
A comparison of the cumulative change in total fossil CO_2 emissions, on-road adjusted fleet average fuel consumption, PHEV adoption, and economic welfare loss for the two FES policies, the RFS policy, and the gasoline tax that achieve the same level of cumulative gasoline reduction from passenger vehicles.

	ΔVMT in 2030	ICE fuel consumption 2030 (L/100 km)	ICE fuel consumption 2050 (L/100 km)	% PHEV in new VMT 2030	% PHEV in new VMT 2050	Cost ($ billion/year USD 2004)	Loss (%) relative to reference
Reference	N.A.	10.2	9.6	1%	14%	N.A.	N.A.
Gasoline tax (biofuels)	−0.36%	8.9	7.2	19%	46%	0.70[a]	0.01%[a]
FES-sharp	+0.13%	7.2	8.4	14%	45%	10	0.2%
FES-gradual	+0.14%	8.6	4.8	5.5%	40%	63[b]	1.2%

[a] No biofuels—Cost is $1.7 billion USD 2004 per year, and loss relative to reference is 0.03%.
[b] With EV in FES-gradual scenario—$56.2 billion USD 2004 per year and loss relative to reference is 1.2%.

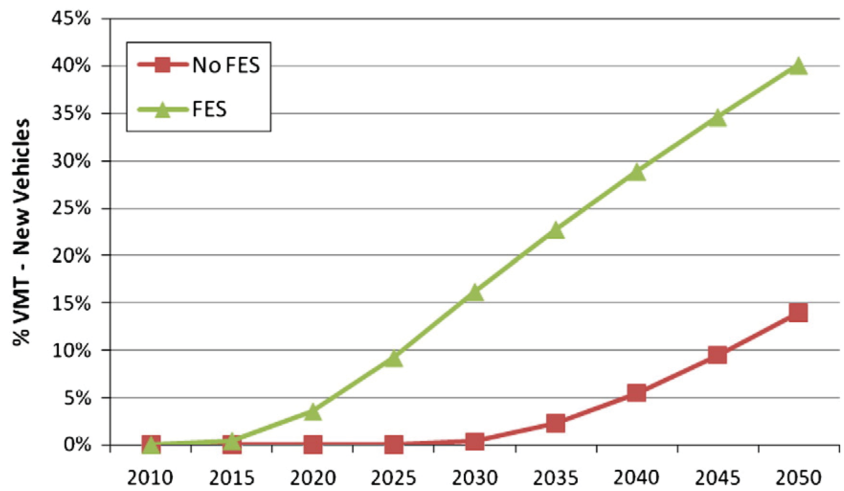


Fig. 4. Fraction of new vehicle-miles traveled in PHEVs under the FES-sharp policy.

Each of the regulatory policies achieves reductions in CO_2 emissions relative to the baseline case, although these reductions are relatively modest. Cumulative economy-wide fossil CO_2 emissions reductions are less than 5% in all cases, with the smallest reductions achieved under the two tax policies. Part of the reason why the tax policies result in lower cumulative reductions is due to a large increase in the relative price of gasoline for passenger vehicles relative to other sectors. By increasing the retail price of gasoline, the gasoline tax has the effect of reducing total demand, which results in lower relative prices of petroleum in sectors not subject to the tax. This larger relative price difference has the offsetting effect of increasing demand for petroleum-based fuels as well as associated CO_2 emissions in these sectors.

An important related question is the impact of excluding from the regulation the GHG emissions resulting from the production of electricity used in passenger vehicles. If grid emissions do not decline, a switch from gasoline to electricity will not translate into commensurate reductions in GHG emissions. PHEV adoption as forecasted by the model is shown in Fig. 4. Under the FES policy, a PHEV is adopted more rapidly and contributes more to offsetting gasoline use than under a No Policy scenario. The consequences of PHEV adoption for the electricity sector are shown in Fig. 5a. There is a net increase in total electricity production after accounting for an increase in electricity use to power PHEVs and a decrease due to reduction in electricity for other uses, which occurs as increasing electricity prices incentivize reduction in demand and improvements in efficiency. By 2050 PHEV electricity use accounts for around 26% of total electric power use (1.75 TkWh), and total electric power use has increased by 3% (from 6.7 to 6.9 TkWh).

The mix of electricity also changes as a result of shifts in the use of primary energy sources (Fig. 5b). A decline in motor gasoline consumption leads, through lower petroleum prices, to an increase in oil use in electric power generation, as well as slight increases in coal, natural gas, and wind power.

The combined effects of a slightly *more* GHG intensive power grid under a FES policy and a net increase in output due to the addition of electric vehicles lead to a net increase in total GHG emissions from electric power generation. This increase is offset by a reduction in GHG emissions related to gasoline use in passenger vehicles. Under our modeling assumptions, the net effect of an FES policy on reducing total cumulative petroleum use (considering PHEV adoption) is around 11% over the period 2010 to 2050, while the effect on GHG emissions is only around 5%. This difference is not surprising, given that substituting PHEVs for conventional ICE vehicles directly reduces demand for gasoline, but substitutes an energy carrier that at present has a relatively high GHG emissions intensity. In fact, including upstream electricity-related GHG emissions makes PHEVs a potentially less compelling option relative to off-grid hybrids or other more efficient variants of the ICE-only vehicle in terms of the cost effectiveness of achieving GHG emissions reductions. We note that these results are sensitive to our assumptions about the costs of the PHEV and fuel efficiency technology, as well as the future composition of the electricity mix. While sensitivity analysis in Karplus (2011) to the assumed income elasticity of transport demand and to the cost of incremental vehicle efficiency improvements for the ICE-only vehicle showed an impact on the absolute magnitude of demand reductions, it did not substantively change the implications of the comparison discussed here.

3.2. Combining a new vehicle fuel economy standard with a cap-and-trade policy

We now consider the combination of a vehicle fuel economy standard with an economy-wide cap-and-trade policy. Building on the analysis of the vehicle fuel economy standard in the previous section, we consider how a CAT policy implemented alone affects passenger vehicle transport. This CAT policy scenario is then compared to a scenario in which the CAT policy is combined with the FES policy.

3.2.1. The impact of a CAT policy on passenger vehicle transport

We first assess the impact of introducing a CAT policy to build intuition about the types of changes it induces across the economy. The CAT policy instrument is a longstanding feature of the EPPA model and was adapted for this analysis (for more information, see Paltsev et al., 2009). A CAT policy is defined by the sources covered, the stringency of the constraint, and a base year relative to which GHG emissions reductions are measured.

The CAT policy represented in this analysis is based on policies recently proposed in the U.S. Congress. The policy considered is defined by a GHG emissions target with gradually increasing stringency, reaching a reduction of 44% of GHG emissions in 2030 relative to 2005. The GHG emissions reduction targets are consistent with the Waxman–Markey proposal that passed the House of Representatives in 2009, which includes a modest amount of international offsets.[12] The policy trajectory is shown in Fig. 6.

[12] Offsets are reductions that are taken from emissions sources not covered by the policies, but once certified by an appointed authority these reductions can be used to meet some fraction of the GHG emissions reduction obligations of covered sources. Offsets can thus help to contain the cost of the CAT policy.

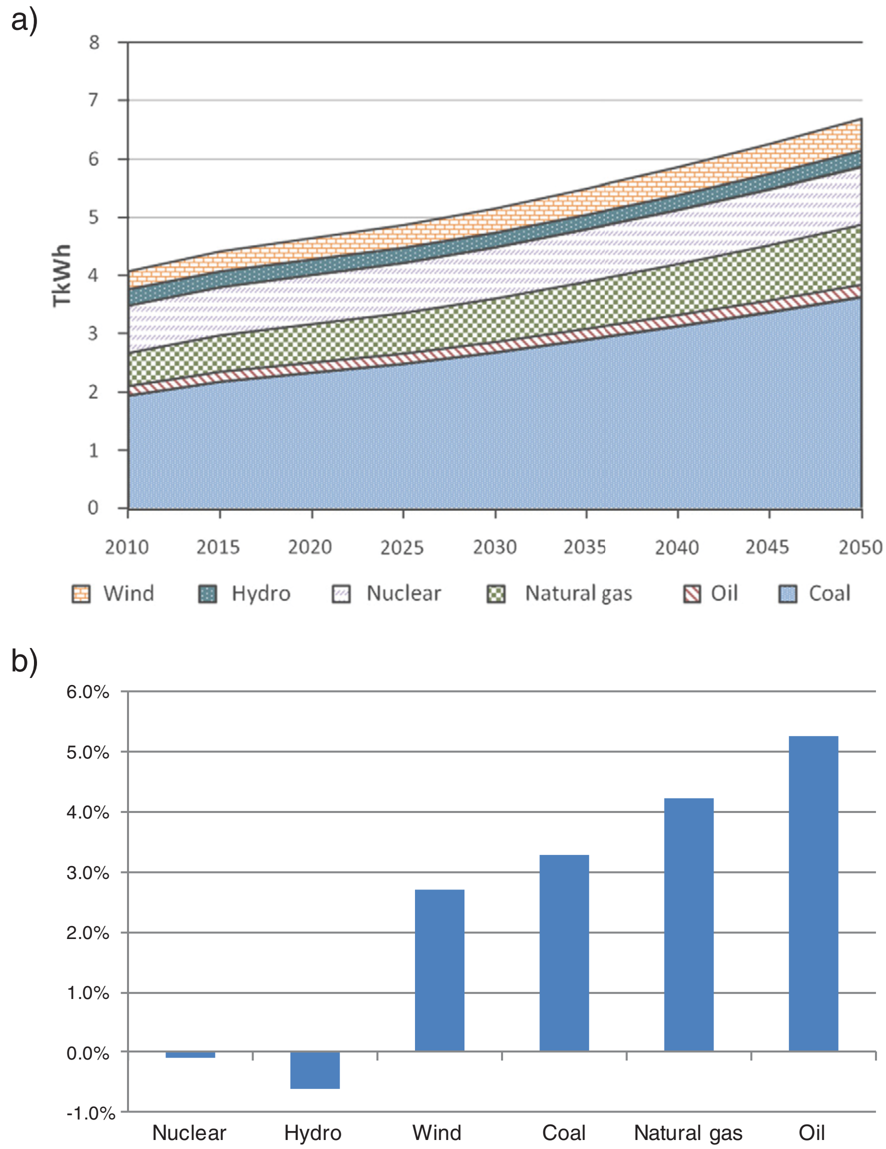


Fig. 5. Energy system trends when PHEVs are available: a) the evolution of electric power generation mix through 2050 and b) percentage change in primary fuel use in the electricity sector in 2050 due to an FES policy, relative to the No Policy reference case.

The projection for primary energy use in the United States under a CAT policy is shown in Fig. 7 below. Coal (used primarily in the electricity sector) is phased out in favor of nuclear, natural gas, and renewable sources, and energy demand is reduced in response to an increase in underlying energy prices. Most of the changes in energy use occur in the electricity sector, while petroleum (refined oil) use, including use by passenger vehicles, does not decline as significantly. The model also produces a GHG emissions price in dollars per ton CO_2 equivalent, which rises under the model assumptions used in this analysis to around \$200/ton CO_2-equivalent by 2050.

The impact of the CAT policy on passenger vehicle fuel use, GHG emissions, and PHEV adoption in the absence of additional regulation is shown in Table 3 below. This case serves as an important comparison to the combined policy cases, since the fuel economy standard acts primarily on a part of the energy system that offers reductions that are too high in cost relative to other CO_2 emissions reduction opportunities to be pursued under the CAT policy modeled here.

3.2.2. Combining a fuel economy standard with a CAT policy

An important question for policymakers involves determining the impact of adding a regulatory policy that targets reductions in gasoline use to a CAT policy that targets economy-wide reductions in GHG emissions. First, we consider the effects on policy cost, gasoline use reduction, and economy-wide fossil CO_2 emissions reduction. For

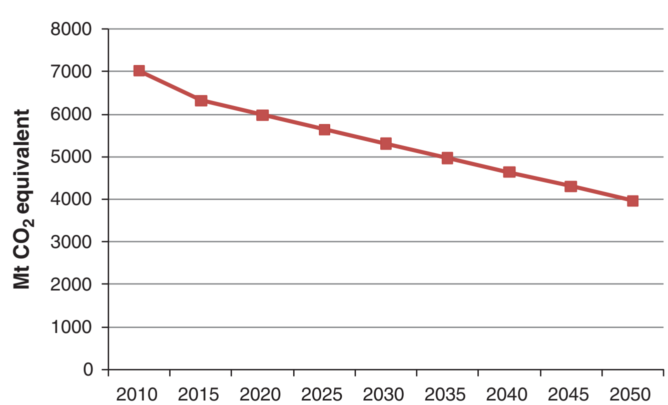


Fig. 6. Target GHG emissions reductions under the CAT system considered in this analysis.

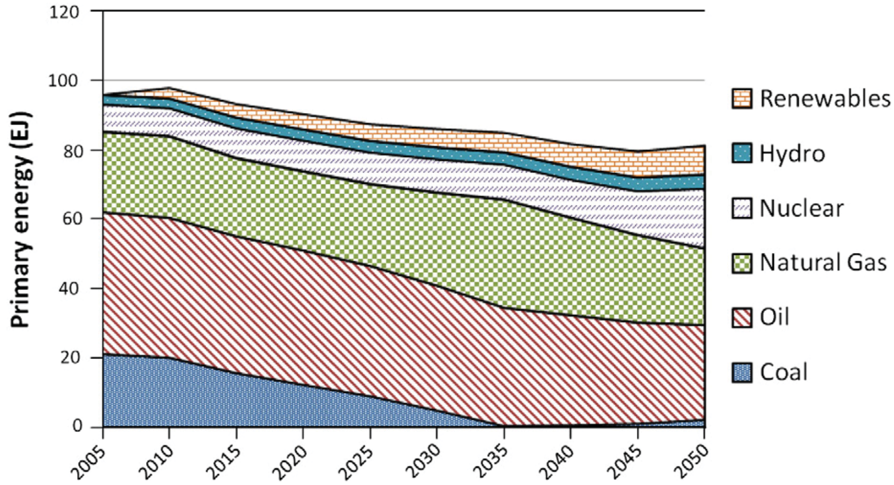


Fig. 7. Total primary energy use in the United States by source under the CAT policy.

Table 3
The impact of a CAT policy on passenger vehicle gasoline use (2005–2050), cummulative GHG emissions (2010–2050), and the contribution of the PHEV to new VMT.

Scenario	Gasoline–passenger vehicles (billion gal)	Total GHG emissions (Mt)	% PHEVs in new VMT, 2050	Gasoline–passenger vehicles (% change)	Total GHG emissions (% change)
Reference	6900	370,000	14%	N.A.	N.A.
CAT policy	3800	230,000	42%	−45%	−38%

simplicity and because the FES-gradual policy is much more costly, we consider only the sharp reduction path as described in Section 2.2 in combination with the CAT policy. In the absence of advanced, cost-competitive biofuels, model results show that combining the FES-sharp with the CAT policy results in additional reductions in gasoline use, but also increases the cost of the policy, as indicated by the relative size of the circles corresponding to each policy (Fig. 8). The total reduction in CO_2 emissions does not change, because that reduction is set by the cap.

It is interesting to compare the implied costs of displacing gasoline and GHG emissions that result from the policy analysis. Assuming that the goal of the FES-sharp policy was solely to reduce gasoline use, the discounted cost per gallon of displacing gasoline is $0.37. If reducing GHG emissions is the only goal, the implied cost would be $31/ton. Under a CAT policy, reducing gasoline use is not the primary target of the policy; nevertheless, if reducing gasoline is the only goal, its implied cost would be $2.00/gal. A CAT policy achieves GHG emissions reductions at an average cost of $18/ton. When the FES-sharp is added to the CAT policy, the additional cost of the gasoline reductions beyond those that would occur under the CAT policy alone is $0.68 (per additional gallon displaced).

If advanced biofuels are available, significantly greater reductions in passenger vehicle gasoline use are cost effective under the CAT policy (orange circle), and the FES-sharp policy does not bind, and therefore does not change the magnitude of the reductions achieved. As long as advanced biofuels with negligible GHG emissions are available, they are the preferred abatement option in the later model periods. In this case, the cost, cumulative fossil CO_2 emissions reduction, and cumulative gasoline use reduction of a CAT policy remain unchanged with the addition of the FES-sharp policy.

When combined with a cap-and-trade (CAT) policy, the impact of the fuel economy standard depends on whether it binds, which in turn depends on the relative cost and availability of other options for abating GHG emissions from passenger vehicles. If advanced biofuels are not available, the fuel economy standard binds, raising the cost of complying with the CAT policy but achieving reductions in gasoline beyond what would have occurred under the CAT policy alone. The implied cost of these additional reductions is an important benchmark for policymakers as they consider both national security and climate change priorities.

4. Conclusions

This paper has provided an analysis of a fuel economy standard (FES) policy, alone and in combination with an economy-wide GHG emissions constraint, the cap-and-trade (CAT) policy. Results demonstrated that the FES policy is at least six to fourteen times as costly to the economy as a gasoline tax that achieves the same cumulative reduction. A new vehicle fuel economy standard only acts on new vehicles and therefore requires a long time horizon to significantly impact fleet fuel use. Fuel economy standards also encourage consumers to drive more by reducing the marginal per-mile fuel cost. The high economic cost of the fuel economy policy is due in part to the fact that as the standard tightens, ever more costly efficiency technology must be deployed in order to meet the target. More efficient ICE vehicles or alternative fuel vehicles such as the PHEV must be added to the vehicle stock and displace miles driven in vehicles with higher emissions in order for environmental and other benefits to be realized.[13] Without a mechanism for spreading the costs over time, the total cost of the policy will inevitably be very high. Banking and borrowing provisions could help to offset these costs.[14] Nevertheless even an “optimally” staged FES policy would not reduce gasoline use as cost effectively as a tax, given that strategies for reducing petroleum use and GHG emissions are limited to vehicle efficiency improvements, which may rapidly become more costly relative to fuel- or usage-focused abatement strategies.

[13] Our modeling framework is recursive–dynamic, which means that economic agents lack foresight about regulations and technology costs in the next period. If instead policy is formulated far in advance and manufacturers have clarity about the future costs of fuel consumption reduction strategies, abatement strategies may be deployed much earlier to increase their contribution to the cumulative reduction.

[14] As currently written, the 2012 to 2016 CAFE standard includes such provisions.

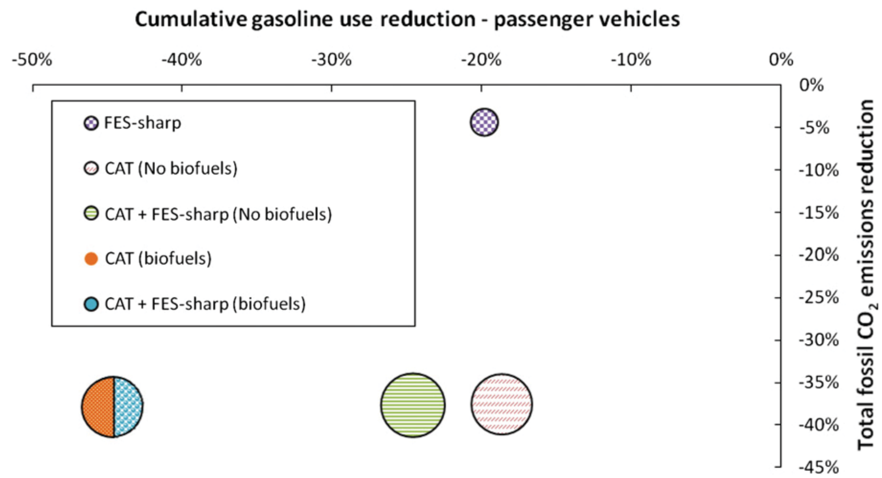


Fig. 8. A comparison of the cumulative change in gasoline use, total fossil CO_2 emissions, and household consumption from 2005 to 2050 under FES and CAT policies with and without advanced biofuels available. The size of the circle corresponds to the magnitude of policy cost.

Our analysis also underscores that climate policy goals may be more difficult to achieve with a fuel economy (per-mile emissions) standard than reductions in petroleum use. Petroleum based motor vehicle fuel can be displaced by moving to alternative fuels, but depending on the emissions intensity of fuel alternatives, the net impact on GHG emissions is uncertain. If emissions associated with grid-supplied electricity used in vehicles are not constrained by the standard, the reduction in GHG emissions will be lower. In part these concerns can be addressed by careful design of the fuel economy standard. As currently designed, the per-mile emissions standard does not count electricity-related emissions until sales of PHEVs and EVs exceed several hundred thousand. However, until then only tailpipe emissions will be counted and multipliers that more heavily weight the contribution of PHEVs and EVs under the standard will be applied (EPA, 2010b, 2011). Considering the economy-wide implications of a passenger vehicle fuel economy standard is very important, too. Displacing gasoline use from light-duty vehicles is predicted to affect its usage in other sectors of the economy, as a reduction in demand places downward pressure on the price of gasoline, encouraging its usage in unconstrained sectors.

Finally, our analysis identifies several issues to consider when combining a fuel economy standard with an economy-wide cap-and-trade system. We show that when a fuel economy standard binds, it will also increase the cost of a cap-and-trade system that constrains total economy-wide GHG emissions. While adding a fuel economy standard will mean that the combined policies deliver greater reductions in gasoline use, which may be desirable for energy security or other reasons, it is important to consider the implied cost of these reductions. Under the assumptions made here, we find an implied cost of additional gasoline displacement is \$0.68 2004 U.S. dollars per gallon, but it is important to note that these costs depend on availability and cost of alternative fuel vehicle and fuel technologies. A key sensitivity is the availability and cost of a low-carbon biofuel that could deliver significant emissions reductions but that would not be directly incentivized by a fuel economy standard. The cost and availability of vehicle efficiency technology, alternative fuel vehicles, and advanced low carbon fuels relative to other economy-wide GHG emissions abatement opportunities will determine whether a fuel economy standard binds when combined with a cap-and-trade policy, and the magnitude of its incremental economic cost.

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