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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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The United States has adopted fuel economy standards that require increases the on-road efficiency of new passenger vehicles, with the goal of reducing petroleum use, as well as (more recently) greenhouse gas (GHG) emissions. Understanding the cost and effectiveness of this policy, alone and in combination with economy-wide policies that constrain GHG emissions, is essential to inform coordinated design of future climate and energy policy. In this work 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 five to fourteen times less cost effective than a price instrument (fuel tax) when targeting an identical reduction in cumulative gasoline use. The GHG emissions reduction under a fuel economy standard alone is also shown to be proportionally less than the reduction in gasoline use, in part because GHG emissions from electricity production used in grid-connected electric vehicles are excluded from the regulation. Second, when combined with a cap-and-trade (CAT) policy, the fuel economy standard increases the cost of meeting the GHG emissions constraint by forcing expensive reductions in passenger vehicle gasoline use, replacing other more cost-effective abatement opportunities. Third, the impact of adding a fuel economy standard depends on the availability and cost of abatement opportunities in transport—if advanced biofuels provide a cost-competitive alternative to gasoline, the fuel economy standard does not bind and passenger vehicles provide a significantly larger contribution to GHG emissions abatement. This analysis underscores the potentially large costs of a fuel economy standard relative to alternative policies, as well as importance of jointly considering the effects of policies on petroleum use and GHG emissions reductions, and the associated economic costs.

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1. Introduction

How to treat passenger vehicles under climate and energy policy is under discussion in many countries. Passenger vehicles (most of them owned by private households) 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 (GMID, 2010; EPA, 2010; IEA, 2010). As vehicle ownership and use increases in many developing countries, identifying effective policy approaches will have not only national, but global, import.

This analysis focuses on two policies intended to address the linked goals of reducing petroleum use and GHG emissions in the United States. 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 emissions (see for example Morris et al, 2010). Here we investigate the consequences of combining policies that have the distinct but closely-linked goals of mitigating climate change (through a cap-and-trade policy) and addressing energy security concerns (through a national fuel economy standard that regulates the on-road 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 for GHG emissions has long been considered an economically efficient mechanism for achieving reductions at least cost. The 2009 Waxman-Markey Act, which included a CAT policy, became the first climate-focused bill to pass the U.S. House of Representatives. Although never passed into law, a CAT policy may be proposed again in future rounds of climate policy discussions.

Unlike a CAT policy, fuel economy standards have been implemented in the United States for a several decades. Passed in 1975 to reduce gasoline use 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 GHG emissions as a pollutant under the Clean Air Act, the agency became involved in setting per mile emissions standards, which were harmonized with a more stringent version of CAFE standard, which mandated an increase in the combined average fuel economy to 35.5 miles per gallon in 2016.

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[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 8,500 pounds (3,855.5 kg). Light trucks include minivans, pickup trucks, and sport-utility vehicles (SUVs).

Multiple policies 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 outcomes of interest, as well as the 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 after 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 shifts 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 concludes with implications for policy.

2. Model description

The model used in this analysis is a specialized application of the MIT Emissions Prediction and Policy Analysis (EPPA) model to include 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 (Hertel, 1997; Dimaranan and McDougall, 2002). 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 gas (carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, SF_6) emissions are based on United States Environmental Protection Agency inventory data and projects.

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

Several features were incorporated into the EPPA model to explicitly represent passenger vehicle transport sector detail. These features include trends in the relationship between income growth and demand for vehicle-miles traveled, 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). The structure of the passenger vehicle transport sector in *EPPA5-HTRN* that includes these developments is shown in **Figure 1**.

Table 1. Sectors and regions in the EPPA model.

Sectors	Regions
Non-Energy	*Developed*
Agriculture	USA
Forestry	Canada
Energy-Intensive Products	Japan
Other Industries Products	Europe
Industrial Transportation	Australia & 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 & 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).

Figure 1. Schematic overview of the passenger vehicle transport sector incorporated into the representative consumer's utility function of the MIT EPPA model. New developments are highlighted on the right-hand side of the utility function structure.
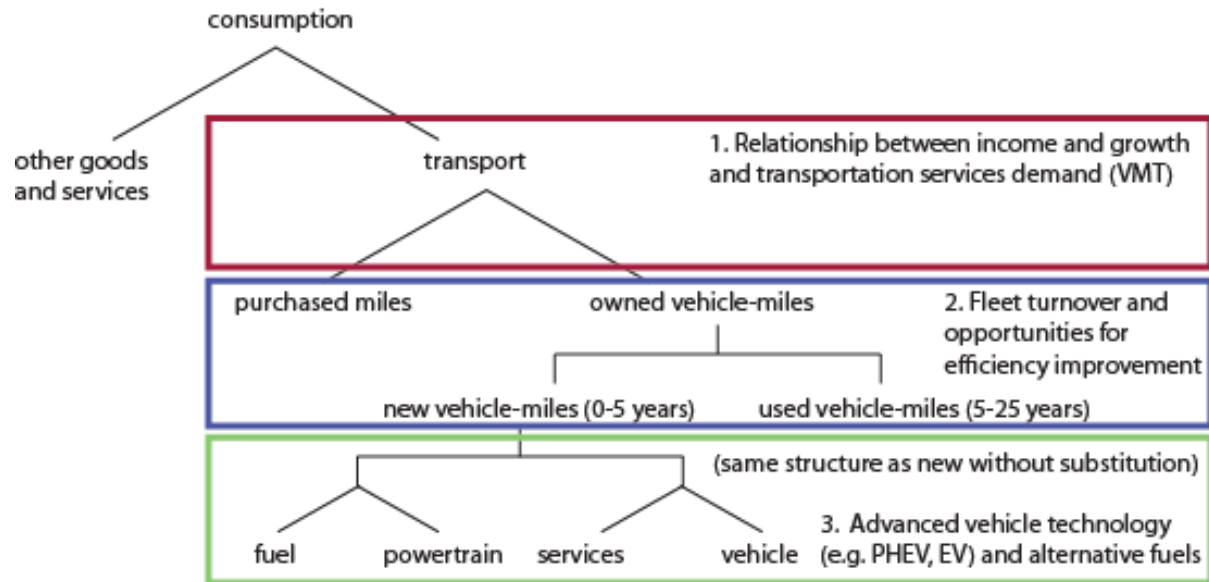
The main innovation in the *EPPA5-HTRN* model is the use of disaggregated empirical economic and engineering data to develop additional model structure and introduce detailed supplemental physical accounting in the passenger vehicle sector. First, to capture the relationship between income growth and VMT demand, econometric estimates were used in the calibration of the income elasticities, 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). Second, to represent fleet turnover and abatement opportunities in existing technology, global data on the physical characteristics of the fleet (number of vehicles, vehicle-miles traveled, 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. Engineering-cost data on vehicle technologies were used to parameterize elasticities that determine substitution between vehicle fuel and efficiency capital. Third, alternative vehicle and fuel technologies were introduced into the model, using engineering-cost data and building on methods developed in previous work (Karplus et al., 2010).

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

The new model structure allows comparison of energy, environmental, and economic outcomes in the 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., 2005). 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. It is implemented as an auxiliary constraint that forces the model to simulate adoption of vehicle technologies that achieve the target fuel economy level at the least cost.

The vehicle fuel economy constraint equation is shown in **Equation 1**. All future reductions are defined relative to the ratio of fuel, Q_{f,t_0}, to miles-traveled, Q_{f,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 kilometers (L/100 km).[3] Targets set by policymakers are typically reported in the literature and popular press using unadjusted fuel consumption (or fuel economy) figures. Unadjusted fuel consumption refers to the fuel requirement per unit distance determined in the course of laboratory tests, while adjusted figures reflect actual energy consumption on the road. To obtain adjusted fuel economy, we divide the unadjusted numbers by 0.8 (EPA, 2010). The trajectory A_t is a fraction that defines allowable per-mile fuel consumption relative to its value in the model benchmark year. The constraint requires that the on-road fuel consumption (FES_t) realized in each period remain below the target for that year by inducing investment in energy saving technology, which is a substitute for fuel. 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.

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

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. Due to the fact that the EPPA model forecasts in five-year time steps, the fuel economy standard was calculated to constrain fuel consumption to a level that reflects the stringency of the standard in each of the past five years, weighted by imputed new vehicle sales (based on expenditures on vehicle

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[3] 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.

capital) in the intervening years. The policy trajectories are shown in **Figure 2**. We choose two representative FES 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.

Figure 2. Adjusted (on-road) fuel consumption trajectories for three alternative FES policies shown a) graphically and b) numerically.

a)
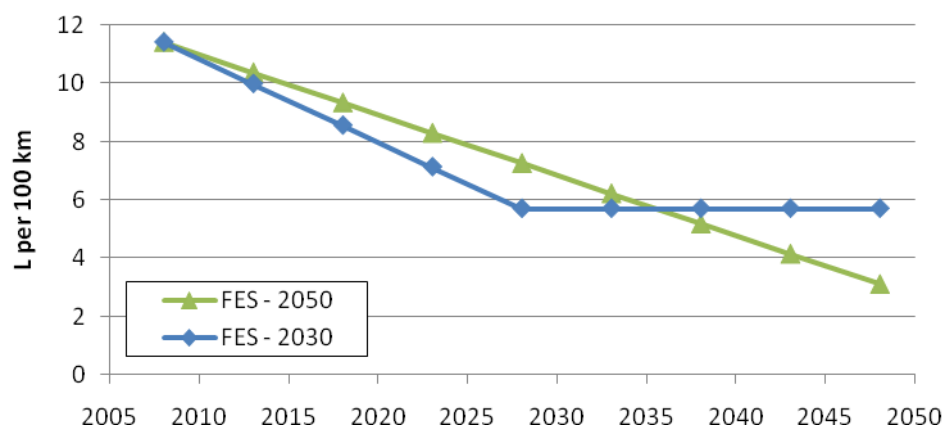
b)

Year	FES 2050 – Gradual				FES 2030 – Sharp			
5-year average	% below 2010	UA L/100 km	A L/100 km	A mpg	% below 2010	UA L/100 km	A L/100 km	A 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), A – adjusted (on-road fuel consumption)

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, we do not model consider the potential for oligopolistic behavior among automotive manufacturers in their response to the standards. Including this additional component would likely make fuel economy standards look even worse on the basis of economic cost, since the additional deadweight loss associated with oligopoly rents would need to be included. 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.

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.[4] Second, we briefly focus on the role of passenger vehicles under a CAT policy using the *EPPA5-HTRN* model. 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 alternative technology scenarios to understand their 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 be economically optimal—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 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. To allow a consistent basis for comparison, policy costs are discounted at a rate of 4% per year and expressed as a net present cost in U.S. 2004 dollars.

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[4] 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.

Figure 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.

a)
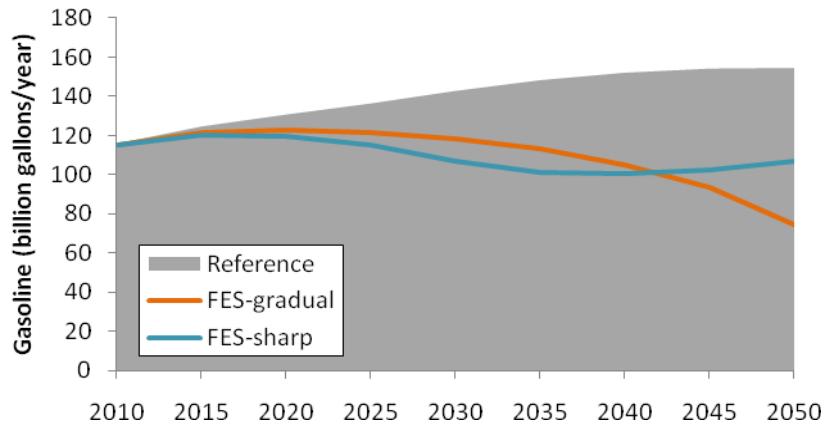
b)
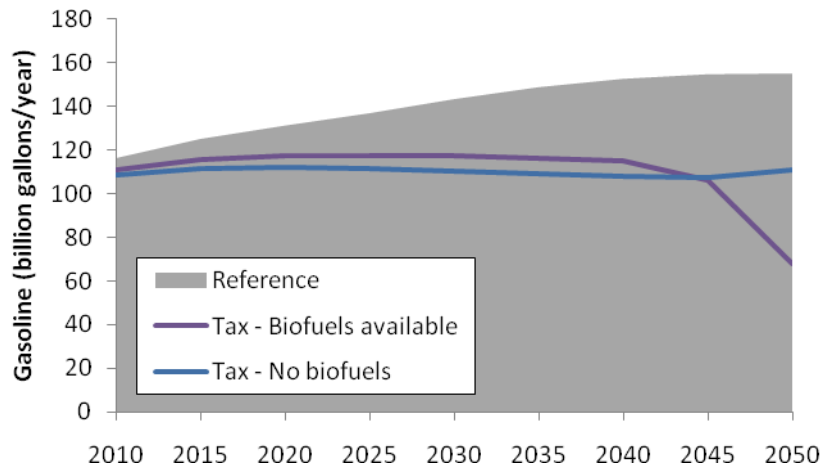
When comparing the four policy trajectories (two FES policies and two tax policies), clear differences emerge in the timing of the reductions, despite the fact that all achieve the same cumulative reduction target. **Figure 3** shows the reduction trajectories in the a) FES policy and b) gasoline tax 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 vehicles and thus affects gasoline use by new and used vehicles in the first year it is implemented. By contrast an FES policy allows gasoline use to continue increasing through 2015 before leveling off and then gradually

9

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 relative to a reference (No Policy) case. Costs are calculated using the 4% discount rate, which is also assumed in the model structure.

The costs and associated GHG emissions reductions under each of the policies are shown in **Figure 4**. The first observation is that for the same cumulative gasoline reduction the FES policies are at least six to fourteen times more expensive in than under 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.

Figure 4. A comparison of the cumulative change in total fossil CO_2 emissions and household consumption in a) graphical and b) tabular form from 2005 to 2050 for the two FES policies, the RFS policy, and the gasoline tax that achieve the same level of cumulative gasoline reduction from passenger vehicles.

a)

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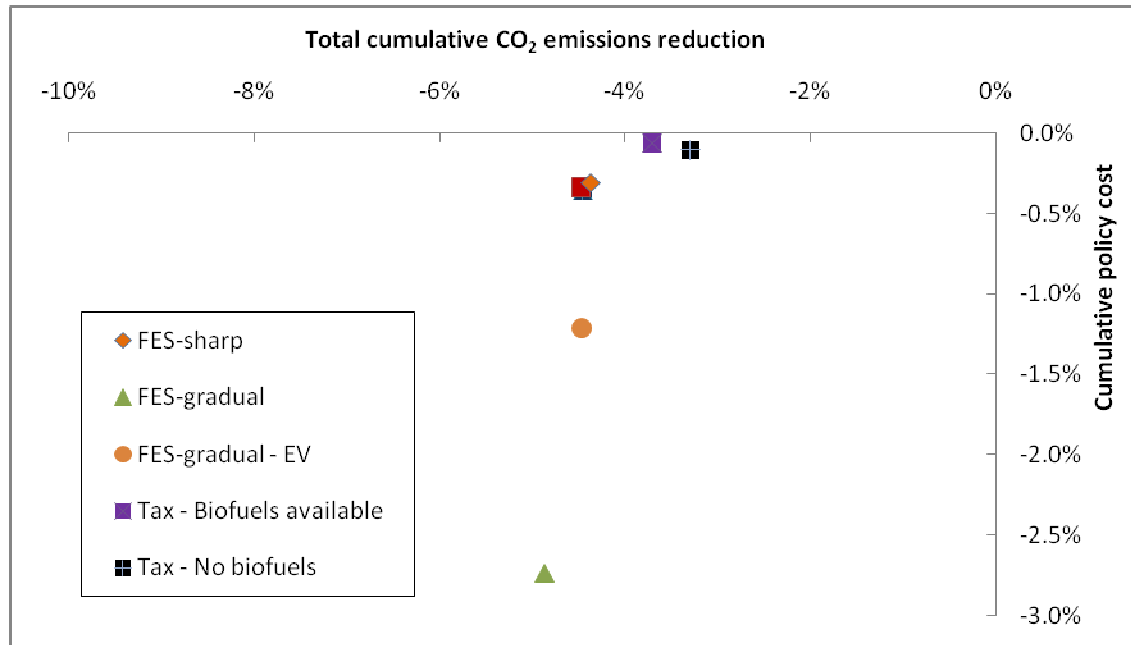
|	ΔVMT in 2030	ICE fuel consumption 2030 (L/100 km)	ICE fuel consumption 2050 (L/100 km)	% PHEV in new VMT 2030	% PHEV in new VMT 2050	Cost ($ billion / year USD 2004)	Loss (%) relative to reference
Reference	N.A.	10.2	9.6	1%	14%	N.A.	N.A.
Gasoline tax (biofuels)	-0.36%	8.9	7.2	19%	46%	0.70*	0.01%*
FES-sharp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

* No biofuels – Cost is $1.7 billion USD 2004 per year, and loss relative to reference is 0.03%)

11

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, respectively. The impact on CO_2 emissions is slightly less under the tax because the tax has the effect of increasing the relative price of fuel 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 the availability of EVs (which, if available, result in a reduction in cost from $63 billion to $56 billion).

Each of the regulatory policies achieves reductions in GHG emissions relative to the baseline case, although these reductions are relatively modest. Cumulative 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 the combination of a large increase in the relative price of petroleum for passenger vehicles relative to other sectors. By increasing the retail price of gasoline, the gasoline tax has the effect of reducing total petroleum demand, which results in lower relative prices of petroleum in sectors excluded from the tax. This larger relative price difference has the offsetting effect of increasing demand for fuel and associated CO_2 emissions in these sectors.

An important related question is the impact of excluding GHG emissions from to the production of electricity for 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 **Figure 5**. 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 **Figure 6**. 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. 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).

**Figure 5.** Fraction of new vehicle-miles traveled in PHEVs. FES – Fuel economy standard (sharp path).
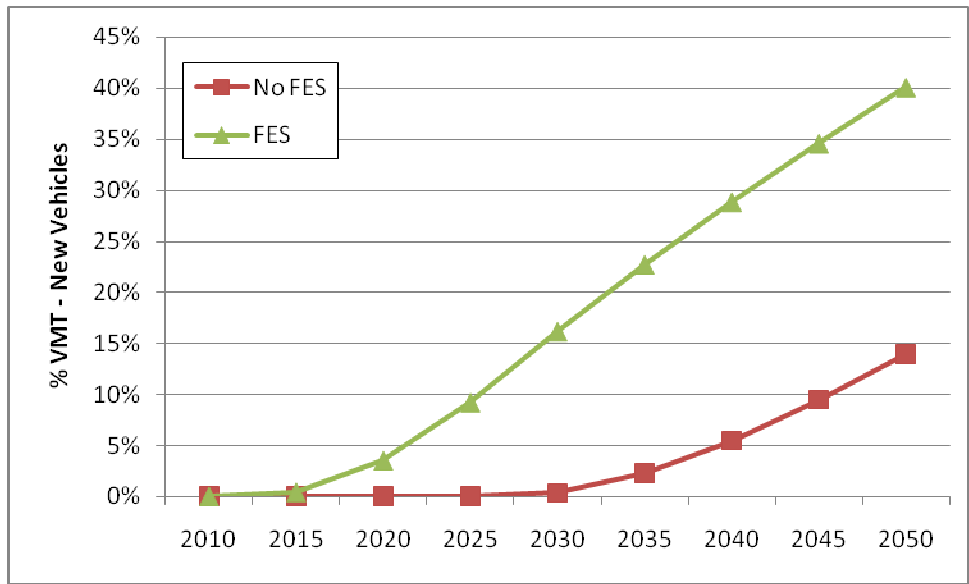
The mix of electricity also changes as a result of shifts in the use of primary energy sources. A decline in motor gasoline consumption leads, through lower petroleum prices, to an increase in oil use in electric power generation, as well as slight increases in coal, natural gas, and wind power.

Figure 6. The electric power generation mix through 2050.

a)
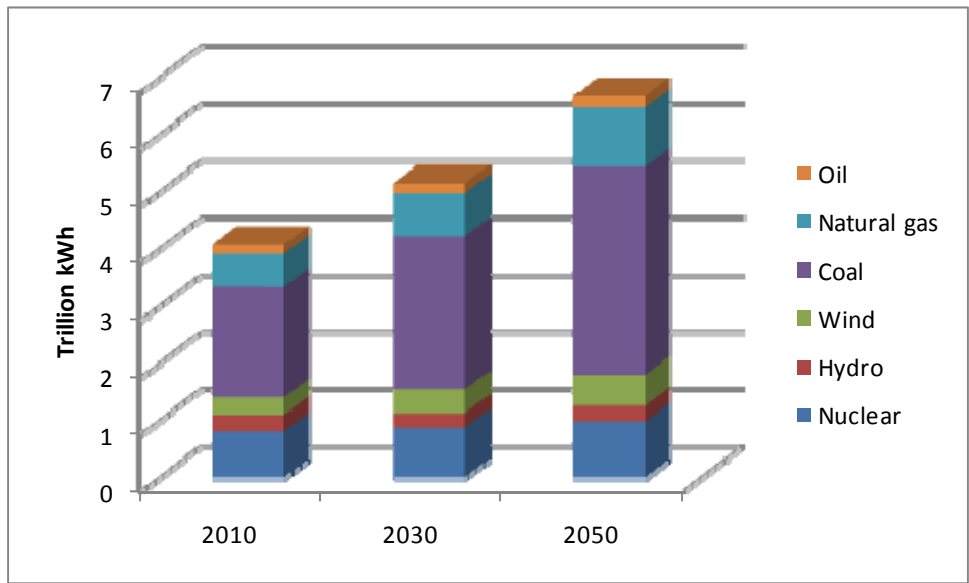
b)
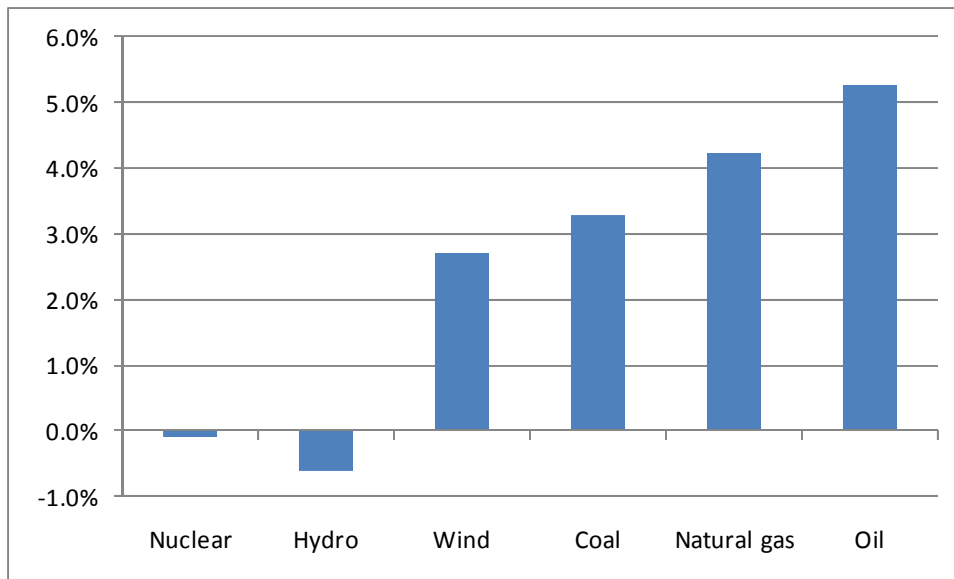
The combined effects of a slightly *more* GHG intensive power grid under an FES policy and a net increase in output due to the addition of electric vehicles result in a net increase in total GHG emissions from electric power generation. This increase is partially offset by a reduction in GHG emissions related to oil use. Te net effect on total petroleum use of an FES (considering PHEV adoption) is around 11% over the period 2010 to 2050, while the effect on GHG emissions is only around 5%. The reduction in per mile gasoline use by vehicles and the higher adoption of the PHEV under the FES policy act through effects on prices and demand for electricity and primary fuels across disparate sectors to produce the discrepancy between effects on gasoline use and GHG emissions.

3.2 Impact of the CAT policy on passenger vehicle transport

A cap-and-trade (CAT) policy is a constraint on economy-wide GHG emissions under which emissions from regulated sources are capped. Regulated sources then engage in trade that results in the allocation of reductions to emitters with the lowest marginal cost. 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., 2005; Paltsev et al, 2008). 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 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.[5] The policy trajectory is shown in **Figure 7**.

Figure 7. Target GHG emissions reductions under the CAT system considered in this analysis.
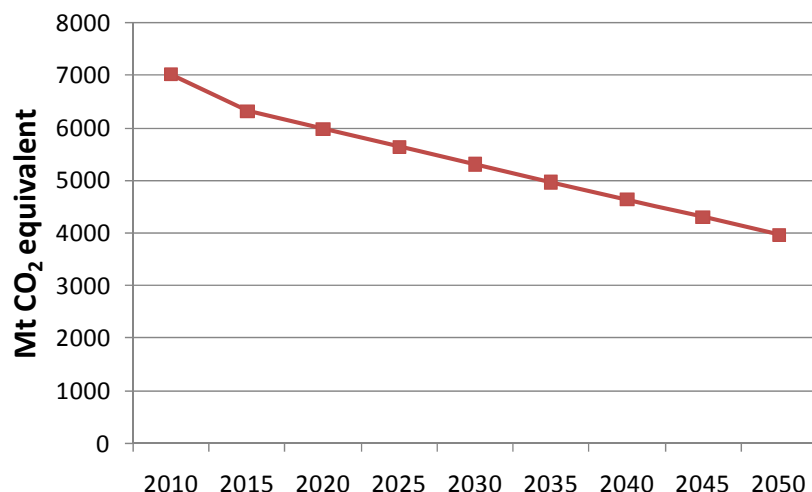
The unmodified version of the EPPA model gives a projection for primary energy use in the United States shown in **Figure 8** below. Under this representative CAT policy, coal (used primarily in the electricity sector) is phased out in favor of nuclear, natural gas, and renewable sources. Most of the 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 per ton CO_2-equivalent by 2050.

Figure 8. Total primary energy use in the United States by source under the CAT policy.

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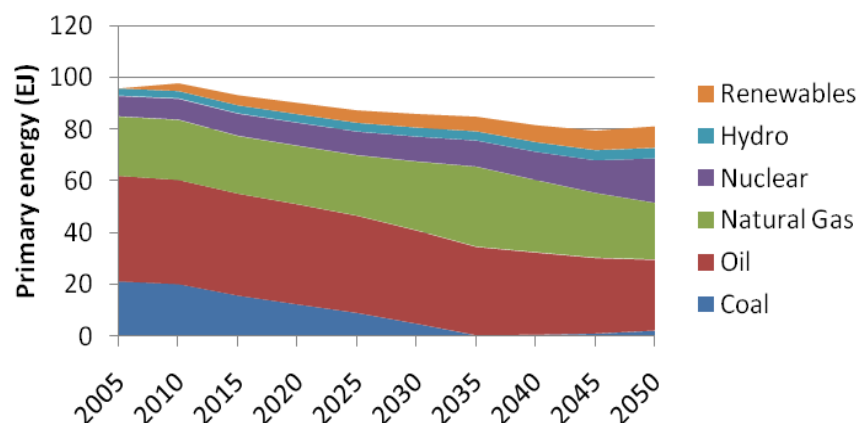
[5] International offsets are reductions that are taken from emissions sources not covered by the policies, but once certified by an appointed authority reductions can be used to meet some fraction of the GHG emissions reduction obligations of covered sources. Offsets thus help to reduce the cost of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

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 2** below.

Table 2. The impact of a CAT policy on passenger vehicle gasoline use, total GHG emissions, and the contribution of the PHEV to new VMT in 2050.

Scenario	Gasoline - passenger vehicles (billion gal)	Total GHG emissions (Mt)	% PHEVs in new VMT, 2050	Gasoline - passenger vehicles (% change)	Total GHG emissions (% change)
Reference	6,900	370,000	14%	N.A.	N.A.
CAT Policy	3,800	230,000	42%	-45%	-38%

It is important to note that the availability of advanced biofuels with negligible GHG emissions affects the role that passenger vehicles will play under the GHG emissions constraint. If advanced GHG neutral biofuels are available to be used in passenger vehicles, they are introduced widely during the period from 2030 to 2050. Two alternative cases include scenarios in which biofuels are restricted to non-passenger vehicle uses of petroleum-based fuel (for instance, only in freight and purchased transport as well as other non-transport household applications).

3.3 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 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, carbon-neutral 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 (**Figure 9**). The total reduction in CO_2 emissions does not change, because that reduction is set by the cap.

Figure 9. A comparison of the cumulative change in gasoline use, total fossil CO_2 emissions, and household consumption from 2005 to 2050 under a FES and CAT policy with and without advanced biofuels available. The size of the circle corresponds to the magnitude of policy cost.
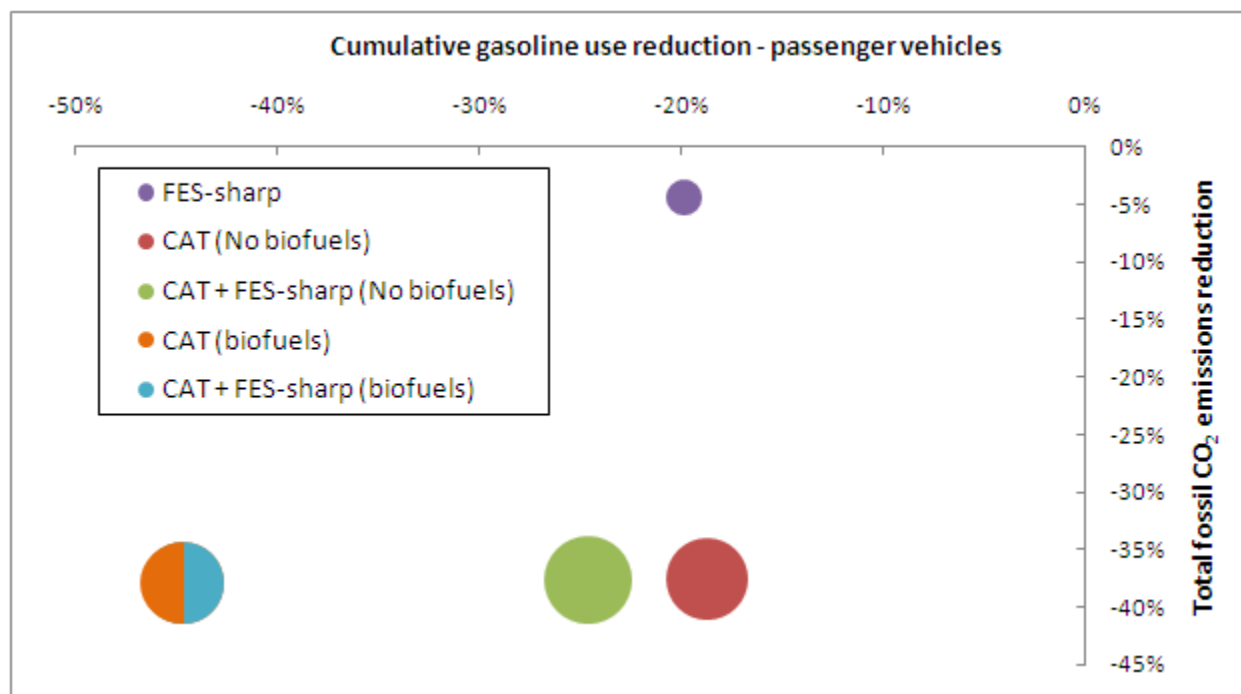
It is interesting to compare the implied costs of displacing gasoline and GHG emissions (which are joint products) that result from the policy analysis. Assuming that the goal of the FES-sharp policy was solely to reduce gasoline use, the discounted cost per gallon of displacing gasoline is $0.37. If reducing GHG emissions were the only goal, the implied cost would be $31 per ton. Under a CAT policy, reducing gasoline use is not the primary target of the policy; nevertheless, if reducing gasoline was the only goal, it would be achieved at $2.00 per gallon. Under a CAT policy, GHG emissions reductions are achieved at an average cost of $18 per ton. When the FES-sharp is added to the CAT policy, additional cost of the gasoline reductions beyond those that would occur under the CAT policy alone is $0.68 (per additional gallon displaced).

If biofuels are available, significantly greater reductions in gasoline use are cost effective under the CAT policy (orange circle), and the FES-sharp 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 optimistic biofuels case, the cost, cumulative fossil CO_2 emissions reduction, and cumulative gasoline use reduction remain unchanged with the addition of the FES-sharp policy.

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. An FES policy could be much more costly if reductions are achieved through a linear path that requires an equivalent cumulative reduction, but achieves that reduction through a more gradual path with a stringent end goal. The higher cost is due to the fact that in order to contribute to gasoline use reductions, efficient vehicles must not just be adopted by consumers, but driven on the road over a period of many years. 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.[6] Nevertheless there are other reasons why even an "optimally" staged FES policy is unlikely to be as efficient as a tax. Increasing fuel efficiency reduces the per-mile cost of driving, incentivizing an increase in travel that offsets the total reduction, while the tax provides direct incentives for reducing gasoline use, both by investing in vehicle fuel efficiency and reducing total mileage.

It is important to note that reductions in gasoline use achieved by a fuel economy standard do not translate into commensurate reductions in GHG emissions for several reasons. If energy use and GHG emissions associated with electric vehicles are not covered under a fuel economy standard, both an increase in electricity generation as well as a slight shift to more carbon-intensive generation mix lead to an increase in GHG emissions.

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. 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.

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[6] As currently written the CAFE standard includes banking and borrowing provisions.

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