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Executive Summary

California has been interested in climate change for decades. As early as 1988, state agencies began developing periodic inventories of statewide greenhouse gas emissions and estimating the potential impacts of a changing climate across the state. California’s foray into climate change policy began in 2002 with the passage of the Pavley Bill (Assembly Bill 1493), which established the nation’s first regulations of mobile greenhouse gas emissions. It was unclear at the time, and somewhat nebulous even now, whether California has the legal authority to establish and enforce such standards.

Carbon dioxide, which comprises the overwhelming majority of greenhouse gas emissions from automobiles (about 95%), is an artifact of fuel combustion. Thus, the amount of CO$_2$ emitted per mile is directly related to the amount of fuel burned per mile of travel, or a vehicle’s fuel economy. While the federal Energy Policy and Conservation Act (1975) prohibits states from developing regulations related to fuel economy standards, which are preempted by the federal Corporate Average Fuel Economy (CAFE) program, a set of state-level regulations that targets mobile greenhouse gas emissions (including more potent gases attributed to cooling systems rather than fuel consumption) are just different enough to create ambiguity. Automobile manufacturers sued California, arguing that the standards were too onerous and that the state’s regulations violated the preemption clause of the Energy Policy and Conservation Act. Since no federal agency regulated mobile greenhouse gas emission directly at the time, the state applied for a Clean Air Act waiver to acquire the authority to do so. The Supreme Court ruling in Massachusetts, et al v Environmental Protection Agency, et al compelled the U.S. EPA to regulate greenhouse gas emissions under the Clean Air Act, which opened the door for California’s waiver request. After several years, EPA granted the waiver to implement the Pavley Standards and the automobile
manufacturers’ lawsuit was eventually defeated. However, the state was actively creating additional climate change policies in the interim.

While California’s Clean Air Act waiver request languished at the EPA, the state enacted a suite of policies that established statewide greenhouse gas emissions targets for the next five decades, established clean energy standards for the electricity sector, and developed the nation’s first greenhouse gas standard for motor fuels, the Low Carbon Fuel Standard. An rigorous evaluation of this collection of climate change policies is important for two reasons.

California mobile source emissions policies have influenced federal policy since the federal government began regulating pollutant emissions from automobiles in 1967. There is already evidence that the state’s climate change policies will be similarly influential. In the wake of the failed automobile manufacturers’ lawsuit and the approval of California’s Clean Air Act waiver request, the state engaged in multi-party negotiations with regulators at the National Highway Traffic Safety Administration (NHTSA), the EPA, and representatives from the automobile industry to develop a new set of national standards that would regulate fuel economy, mobile greenhouse gas emissions, and allow automakers to comply with both the federal program and California’s standards without building vehicles specifically tailored to either set before 2017. Although NHTSA’s updated CAFE standards are still characterized by average miles-per-gallon achievement levels, the EPA’s standards use a set of per-mile greenhouse gas emissions definitions that resemble California’s standards. Additionally, a collection of states in the Northeast and Mid-Atlantic region have worked to develop a regional low carbon fuel standard based on California’s program and other states are currently evaluating similar proposals. In fact, the state’s primary policy objective is not to reduce the atmospheric CO$_2$ concentration associated with climate change, but to provide cost-effective examples of climate change policies that other regions and nations can reproduce.

If California’s climate change policies are going to continue propagating through federal and state agencies, the question of their efficacy becomes paramount. If the state’s estimates of greenhouse gas emissions reductions and cost savings prove to be inaccurate once the policies are fully implemented, California’s foray into mobile greenhouse gas regulation could become a cautionary tale rather than the template for others to copy. The analyses used to support the collection of
transportation climate change policies rely heavily on technical feasibility studies and long range forecasts, rather than explicit models of implementation that consider the important interactions between producers and consumers under the regulations. Like all forecasts, the ones that drive expectations of costs and effectiveness for these policies are sensitive to unexpected conditions and their value is limited by the unpredictability of the future. A model that explicitly considers implementation is able to determine the impact of incorrect assumptions, and identify unintended consequences. If these policies will indeed serve as a model for other regions, even the federal government, a more thorough understanding of their potential impacts and vulnerabilities must be developed.

This dissertation addresses many of the analytical limitations of previous studies by using a two-stage analysis. The first stage develops a dynamic simulation model that explicitly incorporates the behavioral changes forced by implementation of these (and other) policies to curb greenhouse gas emissions from passenger transportation. In the model, California’s policies are implemented both individually and as sets over a common baseline policy environment, defined by concurrent federal transportation policies. Rather than relying on a limited set of static forecasts to evaluate the performance of policies once they are implemented, the second stage of the analysis applies Robust Decision Making (RDM) scenario analysis techniques to evaluate the performance of policies under a wide range of plausible conditions. In particular, these methods identify conditions under which the state’s policies fail to meet near-term greenhouse gas targets, accrue large costs, or both. The analysis is used to answer the following research questions:

- What vulnerabilities (demographic, technological, or economic) over the next decade negatively affect Californias ability to meet its emissions targets or lead to unacceptable costs?
- Can complementary policies address these vulnerabilities and help CA meet emissions targets?
- Are there lower cost, more effective strategies to meet near-term objectives?
- What effect do federal policies have on state GHG goals?
Reducing greenhouse gases from transportation

One way to reduce greenhouse gas emissions from passenger vehicles is to target inefficiencies in the air conditioning systems. However, these gases are only the most potent, not the most prevalent. In order to reduce CO₂ emissions from passenger travel, a policy must improve vehicle fuel economy, reduce aggregate vehicle miles traveled (VMT), or shift the mix of transportation fuels in the direction of lower carbon alternatives. While California’s current strategy targets large CO₂ reductions through improvements in vehicle fuel economy and lower carbon motor fuels, this dissertation also evaluates a set of potential augmentations to address VMT growth.

The state’s greenhouse gas standards, the Pavley Standards (since re-named the California Clean Car Standards), regulate automakers that sell cars in California and mandate minimum average grams of CO₂ /mile for both passenger cars and light trucks. Like the national fuel economy program, manufacturers are expected to respond to California’s standards by adding technology to their vehicles in an effort to increase fuel economy, and reduce CO₂ emissions. Since the state received its Clean Air Act waiver, the Pavley Standards have been superseded by the new joint national program — a set of harmonized fuel economy and greenhouse gas standards for automobiles that is jointly administered by the National Highway Traffic Safety Administration (NHTSA) and EPA. Although California still implemented its program, it was modified to ensure that compliance with the national program would ensure compliance within the state. As a result of this harmonization, the implemented standards are expected to have little impact on CO₂ emissions relative to the levels achieved under the national program. However, it is uncertain whether the national program would have been possible without California’s threat to implement a set of state-level standards related to vehicle fuel economy. Although the national program has been approved through model year 2016, the state maintains the authority to implement a more stringent set of standards at their expiration. However, as long as regulatory action continues at the federal level (a set of joint regulations is currently under development for model years 2017 – 2025) the state has little incentive to enforce a separate set of standards. In addition to the Clean Car Standards, California has developed a set of tire pressure regulations that will impact vehicles already on the road. This program is likely to be extended in the future to include low friction engine oils and
other efficiency measures, but each of these is only expected to have a small impact on greenhouse gas emissions.

The Low Carbon Fuel Standard (LCFS) uses a system of credits and deficits to encourage drivers to shift consumption away from gasoline and diesel fuel and toward lower carbon alternatives like electricity and advanced biofuels, with the goal of reducing the average carbon intensity of transportation fuels by 10% by the end of 2020. The standard develops estimates for the carbon intensity of a wide variety of fuels over their entire lifecycles — including extraction (or cultivation), transportation of raw materials, fuel production, distribution, and combustion — accounting for the CO₂ produced at each stage. The carbon intensity of each fuel is measured by unit of energy to allow comparisons of fuels with different energy densities. The standard becomes increasingly stringent over the next decade and favors lower carbon fuels, using the permit market as a mechanism to change the relative prices of fuels based on their carbon intensity. The state expects the standards to reduce annual greenhouse gas emissions from passenger travel by 10.3 million metric tonnes (15 MMT including heavy duty vehicle fuel usage), and be cost neutral.

Each of these policies affects one component of greenhouse gas emissions from passenger travel, but none of them directly impacts growth in vehicle miles traveled (VMT). The Low Carbon Fuel Standard has the potential to reduce VMT if the integration of lower carbon alternatives raises fuel prices and increases the average cost of travel per mile. By contrast, the Clean Car Standards have the potential to increase VMT by reducing travel costs (a result of increasing fuel economy known as the “rebound effect”). While the state is developing land-use and development targets for regional planners, the targets are not mandatory and will play a role in longer-term emissions abatement, if at all. In the short-term, price mechanisms are an effective way to address VMT growth — and this dissertation evaluates a series of incremental fuel price changes as a strategy to hedge against challenging conditions where the existing state-level strategies perform less well than expected. The pricing strategies are modeled as fuel excise tax increases, but merely represent changes in the average retail price of motor fuels, which could be achieved through alternative policy mechanisms like a carbon tax, or the state’s proposed cap-and-trade program for CO₂. Chapter 2 describes the relevant set of transportation policies in greater detail.
Analytical approach

Unlike the analytical work supporting the state’s greenhouse gas regulations for transportation, this work develops a dynamic simulation model, the California Light-Duty Greenhouse Gas Emissions model (CALD-GEM), that explicitly focuses on the implementation of California’s policies and the effects of compliance behavior on both consumers (in aggregate) and regulated industries. The model estimates annual greenhouse gas emissions from statewide passenger transportation under each specified policy regime. A series of connected modules address the various components of the system related to energy consumption: manufacturer technology response, vehicle sales, alternative fuels market, and travel behavior.

The types of vehicles that are available for sale in each year are influenced by the presence, or absence, of state-level fuel economy policies. To develop annual vehicle offerings, the simulation model incorporates outputs from the Volpe Center’s CAFE Compliance Model, which is used to simulate the technology changes made to new vehicles that must meet fuel efficiency standards at either the state or federal level (or both), depending upon the strategy. A sales module determines how these new vehicles enter the population in each year (a function of vehicle offerings, the policy environment, fuel prices, and other economic variables). The vehicles in the population (both old and new) travel and consume fuels of differing types to meet the demand for VMT. The model uses fuel consumption to calculate annual greenhouse gas emissions and tracks the consumer costs associated with fuel and technology expenditures.

While the CALD-GEM model is deterministic, many of the most important drivers of emissions have values that are deeply uncertain over the next decade. Factors like world oil prices, costs within the emerging biofuels market, GDP growth and unemployment in California all impact the quantities and types of transportation fuels used. However, no single forecast of future prices or economic conditions is likely to be reliable over the next decade, and have rarely been so in the past. To account for the uncertainty in critical factors, this dissertation utilizes Robust Decision Making (RDM) ensemble scenario analysis techniques to evaluate a large number of scenarios and identify groups of scenarios in which preferred policies fail to meet expectations. Strategy performance is measured not by optimality under any single set of conditions, but by robustness across the
scenario ensemble — seeking a strategy that performs reasonably well (satisfactorily) across the widest range of uncertainty about key factors. After identifying vulnerabilities, preferred strategies are augmented with a set of policies designed to specifically hedge against the underlying conditions that lead to poor performance. In this case, fuel price mechanisms are used as hedging strategies to construct a set of 20 distinct suites of policies evaluated in the analysis, although only an interesting subset of these is carried throughout the entire analysis. Interested readers can find much more detail about the simulation model and the application of Robust Decision Making techniques in chapters 3 and 4, respectively.

California’s strategies fail to meet expectations under a variety of conditions

In addition to considering alternatives to California’s current strategy, this study provides a more rigorous estimate of the reductions that can be expected from the individual policies that comprise the state’s Scoping plan strategy for transportation — namely the Low Carbon Fuel Standard (LCFS), Pavley Standards, and vehicle efficiency program. Each of these policies is expected to reduce statewide GHG emissions and save California consumers money. Table 1 compares the greenhouse gas reduction estimates developed by the California Air Resources Board with those achieved by each policy (over the baseline defined by the national fuel economy program)\(^1\) in the nominal scenario, characterized by the current “best-guess” estimates of each uncertainty in the analysis. Chapter 5 discusses the performance of a large set of strategies in the nominal scenario.

Despite small differences between the nominal scenario used here, and the single scenario that the ARB considered, the impact of the Pavley standards and the vehicle efficiency program appear comparable, if slightly smaller. However, the impact of the Low Carbon Fuel Standard is estimated to be dramatically lower. The performance of each policy (and their performance as a set) is briefly discussed below.

\(^1\)All emissions reductions refer to the incremental change in greenhouse gas emissions in a given strategy compared to the baseline strategy, defined as the national fuel economy program with no additional action within the state.
Table 1: Nominal 2020 emissions\(a\) reductions for California policies, using CALD-GEM model

<table>
<thead>
<tr>
<th>Policy</th>
<th>Current ARB estimate(a)</th>
<th>Nominal Emissions(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions Standards</td>
<td>3.8</td>
<td>3.6</td>
</tr>
<tr>
<td>Vehicle Efficiency Measures</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Low Carbon Fuel Standard(b)</td>
<td>10.3</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14.7</strong></td>
<td><strong>4.4</strong></td>
</tr>
</tbody>
</table>

\(a\) – Emissions measured in MMTCO\(_2\)\(e\)

\(b\) – Gasoline-only portion of reductions to account for light-duty travel focus of this study.

The Low Carbon Fuel Standard may fall short of expectations

There are two reasons why estimates of emissions reductions from the Low Carbon Fuel Standard vary significantly between the ARB analysis and the results in the nominal scenario. The first, and more significant, reason for the discrepancy results from the ARB’s failure to accurately consider the means by which fuel providers may comply with the standard, thus attributing naturally occurring emissions reductions to the implementation of the policy. The ARB analysis (California Air Resources Board, 2009d) considers four “scenarios” that lead to LCFS compliance for light-duty vehicles (which are used to meet the carbon intensity requirements for gasoline and its substitutes). However, as one reviewer noted, the reductions in these scenarios are attributed to the policy despite a lack of modeling (or justifying) the mechanism by which the policy forces these scenarios (Reilly, 2009). Similar scenarios are considered in this study, but emissions reductions from mechanisms other than the LCFS are not attributed to the policy. They are determined exogenously and are deemed no more or less likely to occur in the presence, or absence, of the LCFS.

The second reason for the large discrepancy in estimated impact is an accounting problem. To the extent that liquid fuel providers are able to comply with the LCFS, they must do so by purchasing credits from non-liquid fuel providers (like utilities that provide electricity) and blending low carbon ethanol. Any electricity consumed for transportation in the CALD-GEM model is automatically credited to the fuels industry (and treated as a transfer between the purchasers of liquid motor fuels and electricity, bearing no net cost). So the only compliance strategy available within the model (and arguably, in reality as well), is to blend lower carbon ethanol. The accounting problem arises from the fact that the state’s GHG inventory and emissions targets are based on
combustion, rather than the life-cycle perspective used in the LCFS. Practically, this means that a substitute fuel must produce fewer greenhouse gas emissions during the combustion stage than the one it displaces in order to affect GHG reductions for the inventory targets. While the LCFS does indeed force fuel providers to blend lower carbon ethanol (either from Brazilian sugarcane or cellulosic ethanol made from one of many different feedstocks and conversion processes), this ethanol is chemically no different from the corn ethanol that is prominent now. Ethanol produces fewer greenhouse gas emissions through combustion than California’s blended gasoline, but the low-carbon intensity ethanol is no better than corn in this respect. Emissions reductions do occur over the life-cycle of the fuel, reducing the total GHG emissions for which California can be said to be responsible, but these “upstream” reductions accrue in other states — during the cultivation of ethanol feedstocks and across the transportation and distribution phases of the fuel, rather than during combustion. These emissions reductions do not contribute to the targets. Only by increasing the overall quantity of ethanol consumed — for example, by subsidizing the consumption of E85 — and displacing gasoline, can the LCFS affect reductions in GHG emissions. Unfortunately, the ARB’s estimated emissions savings from the program simply represents a 10% reduction in the CO₂ emissions from the combustion of motor fuels based on the goal of the standards to reduce emissions by 10% (California Air Resources Board, 2009e). However, one cannot expect fuel providers to reduce the emissions from motor fuel combustion when the standard allows them to achieve credits by reducing the CO₂ emissions in other stages of the fuels’ life-cycle, even though they occur beyond California’s boarders. The accounting discrepancy is not a large problem for electricity, which incurs most of its life-cycle carbon emissions when it is generated, but represents a considerable challenge for compliance strategies that rely heavily on ethanol blending.

This is a shortcoming of California’s current strategy, and represents an important disconnect between the accounting methodology used to calculate the state’s Greenhouse Gas Inventory and the methodology used to estimate savings from the LCFS. Updating the LCFS standards for carbon intensity so that they are based on the baseline GHG emissions from combustion, rather than the full life-cycle, could induce the desired GHG savings from combustion, but would change the nature of the standards. Alternatively, since emissions reductions would occur in other states as a result
of the program, redefining the accounting methodology of the state’s GHG Inventory to account for the life-cycle emissions generated by California’s industrial, energy, and transportation sectors would allow the state to preserve the current LCFS regulations and take a broader perspective of its responsibility for the GHG emissions involved in consuming its goods and services.

The ARB’s estimate that the LCFS creates no net cost appears to be similarly optimistic in the nominal scenario, where it costs nearly $33 billion more than the federal-only policy. While that is certainly larger than the ARB estimate, it is important to consider this cost in the context of the LCFS compliance strategy. With the exception of electricity credits (which are treated as a transfer, and carry no net cost), providers are forced to sell more ethanol (of sufficient carbon intensity to comply with the standards). When low carbon ethanol is more expensive than the gasoline used for blending (California Reformulated Gasoline Blendstocks for Oxygenate Blending (CARBOB)) or cheaper ethanol alternatives, or when providers are forced to subsidize E85 to increase sales, the cost of gasoline will rise. In the nominal scenario when only the LCFS is implemented, 148 billion gallons of gasoline are consumed between 2010 and 2020. In order to accrue a strategy cost of $33 billion, complying with the LCFS standards need only result in an increase of $0.22/gallon in the price of gasoline to accrue such large program costs. If domestic production capacity of advanced ethanol fails to reach billion gallon per year production volumes in the next decade, the per-gallon price increase induced by the program could be much larger. Given the limited number of electricity credits likely to be available in the early years of the program, and the uncertainty surrounding both the quantity and cost of advanced ethanol, such a cost increase is plausible.

The Low Carbon Fuel Standard’s performance across the full scenario ensemble bears a strong resemblance, at least qualitatively, to its performance in the nominal scenario; small emissions reductions over the baseline policy and potentially high costs. Like all strategies in the analysis, the LCFS achieves emissions levels sufficient to meet the 2020 greenhouse gas target in about 40% of all scenarios\(^2\). The LCFS leads to emissions reductions in fewer scenarios than the Scoping Plan strategy and generally of a slightly smaller magnitude, achieving its expected emissions (10.3 MMT)

\(^2\)Note that these are percentages, not probabilities. The percentages are based upon the size and design of the scenario ensemble, and would be different using a different ensemble. They are not probabilities, and should not be interpreted as such.
in only 16% of scenarios. The LCFS reduces emissions by at least 10.3 MMT over the baseline when both the ethanol blender’s credit and import tariffs remain in place, the ethanol blend wall is increased before 2015, and market shares of electric vehicles remain below nominal levels in 2020. This should not suggest that fuel providers fail to comply with the standards; compliance is forced in the CALD-GEM model, and so occurs in all years of the policy for all scenarios. While this forced compliance fails to yield significant reductions in GHG emissions in nearly all scenarios, it does create significant costs under some conditions.

Although the LCFS reduces total cost relative to no-action in about 20% of scenarios, these cost savings are typically less than $1 billion over the course of the decade. Conversely, cost increases greater than $10 billion occur in about 30% of scenarios. The most important driver of high cost scenarios for the LCFS is the year in which the ethanol blend-wall, the amount of ethanol that can be legally blended into gasoline for use in all vehicles, is increased. Blend-wall increases later than 2014 are associated with all of the high cost scenarios, since fuel providers will be forced to sell and, in most cases, subsidize more expensive E85 in order to sell enough gallons of ethanol to comply with the LCFS standards. The existence of the federal ethanol blenders’ credit and the removal of the ethanol import tariff, which makes low carbon Brazilian sugarcane ethanol artificially expensive, act to mitigate the cost increases associated with delayed increases in the blend-wall, but don’t counteract them entirely. Additionally, some of the highest cost cases occur when the cost of corn ethanol decreases over the next decade and lignocellulosic ethanol (LCE) is either more expensive, or less available than assumed in the nominal scenario. The cost of lignocellulosic ethanol can drive high cost scenarios, but not low cost scenarios. Fuel providers must blend ethanol at an average of about 8% into California gasoline as an oxygenate, and will naturally choose the least expensive ethanol available to do so. When LCE is the lowest cost option, fuel providers will choose to blend this instead of midwestern corn ethanol, even in the absence of the LCFS. Based on this analysis, it appears that both the expected emissions savings 10.3 MMT\(\text{CO}_2\)e, and the assumed zero cost impact are unwarranted except under a narrow set of conditions.
The Pavley Standards have more value as a way to gain leverage on national policy

Comparing the *no-action* strategy that exclusively relies on the federal standards to reduce GHG emissions and the strategy that overlays California’s Pavley standards on the baseline, illustrates their limited emissions benefit. Across the entire scenario ensemble, enforcement of these state-level targets leads to emissions savings in only 11 (of over 3,000) scenarios, and results in small increases, typically about 1 MMTCO$_2$e, in the rest. This is largely a result of mix shifting to meet the separate targets for cars and trucks.

California’s greenhouse gas standards for passenger vehicles lead to additional reductions over the baseline strategy across the scenario ensemble, but only when the second set is adopted in 2017. The standards generally produce emissions reductions over the baseline, but still fail to achieve the 2020 emissions target in more than 55% of all scenarios. The impact is not large over the next decade (in terms of either costs or emissions reductions), but such policies are technology-forcing policies, and continually transform the vehicle population for decades after implementation as older inefficient vehicles are retired and replaced by increasingly efficient new models.

The expectations for the tire pressure program are modest, as are its performance. Nonetheless, such efficiency programs incur little cost and do result in small emissions savings over the baseline. However, the expectations for the impact of the second set of Pavley standards are less modest, but perhaps similarly realistic. The addition of a second set of Pavley standards leads to GHG emissions reductions over the existing Scoping Plan (as modeled here) in over 90% of all scenarios, and matches (or bests) the expected emissions savings of 3.8 MMTCO$_2$e in about 35% of scenarios. However, this strategy rarely results in cost savings. Incremental costs over the Scoping Plan range from about $3 billion to about $12 billion over the decade. Unlike some of the more nuanced vulnerabilities that appear elsewhere in the analysis, this is a relatively simple story. Technology costs and manufacturers’ decisions about how to allocate fuel efficiency improvements (i.e. how much of the improvement is allocated to improving fuel economy rather than power) are the principle drivers of high cost scenarios. However, the real potential of this policy to reduce emissions is hampered by evaluating it so soon after implementation; vehicles subject to these standards (or future versions
of them) will be on the road for the next two decades, and will consume less fuel over that time than if the standards had not existed.

The first set of Pavley Standards, since re-labeled the California Clean Cars program, is intended to be of similar stringency to the EPA program at the national level. This analysis assumes that manufacturers build a fleet of vehicles to sell in all 50 states that they assume will allow them to comply with the (joint) national program. The assumption, by both industry and regulators, is that selling the vehicles from those product plans in California will result in compliance with the state’s standards without any additional action. In fact, state (and national) standards have been harmonized to produce this result. However, deliberate mix-shifting by industry is necessary to achieve compliance with state-level efficiency standards (in at least one year) in most scenarios.

The automobile industry is represented simplistically within the CALD-GEM model, using class-level vehicles and lacking manufacturer heterogeneity. However, this is an issue that should be investigated by parties with access to higher quality data — mix-shifting can impose additional costs on California drivers (as manufacturers are required to influence the market shares of passenger cars and light trucks sold in the state) and erode the effectiveness of the standards.

The most important effect of the Pavley standards may have been to create pressure to develop a new set of national standards. After the national standards are in place, enforcing state-level standards has little additional value; it increases the complexity of compliance for manufacturers and retailers, and places an additional regulatory burden on state agencies (notably, the ARB). The real power of the standards appears to be in the threat of enforcement, rather than enforcement itself. As long as California has the legal authority to implement a set of state-level emissions standards for vehicles (at least with respect to GHG emissions), it is guaranteed a seat at the table when discussions of national policy take place.

The Scoping Plan may require augmentation to deal with challenging conditions

The Scoping Plan (defined here as the set of policies in Table 1), like all strategies considered here, meets the 2020 greenhouse gas emissions target for passenger travel in about 40% of all scenarios. This is not to suggest that it generally performs as expected, and merely falters under challenging circumstances. Even under the “best-guess” forecasts of future conditions, the Scoping Plan, and
the policies that comprise it, fails to meet the state’s emissions target. The expected cost savings from these policies never materialize in most scenarios, and emissions savings are consistently smaller than expected. The Scoping Plan does lead to emissions reductions over the no-action baseline in about 75% of scenarios, although only about 10% of those scenarios exhibit savings greater than 4 MMTCO₂e, far less than expected. In fact, the Scoping Plan only achieves the expected emissions reductions over the baseline in 14 (out of 3,061) scenarios, despite the fact that it meets the 2020 target in many more. Emissions reductions typically occur under two different sets of conditions: when the federal ethanol blenders’ credit is still active and the cost of midwestern corn ethanol doesn’t increase more than $0.05/gallon each year, or when the ethanol blend-wall is increased to 15% before 2017, the tire pressure program performs well, and electric vehicle market share tops 3% in 2020. Each of these scenarios has some plausibility, and it is not unreasonable to expect that the Scoping Plan will result in some emissions reductions — but not at the level expected.

Evaluating alternative strategies illustrates tradeoff between emissions and cost

In addition to the individual policies that comprise the Scoping Plan Strategy, this evaluated an additional set of strategies that were built upon the state’s main options: do nothing and rely on national fuel economy program (no-action), stay with the Scoping Plan (or just use a single piece of it), or augment the Scoping Plan with either additional fuel economy standards or fuel price mechanisms. Each strategy may have components that begin later in the decade (such as the fuel tax increases that begin in 2016 or the second set of Pavley Standards that begin in 2017), but the strategy is modeled to be static once it is implemented in 2010. The fuel price mechanisms are modeled as a fuel tax increase, but could be achieved by a carbon tax or cap-and-trade program as well.

While there are multiple strategies that prove to be robustly low-cost or low-emissions strate-
gies across the full scenario ensemble, no strategy is simultaneously robust in both dimensions. Additionally, the scenario in which a strategy is implemented is critically important. Under some favorable conditions, the state need not take any action at all to achieve its emissions goals; while in others, even aggressive and costly actions fail to meet the target. Adapting to prevailing conditions in a scenario can lead to improved robustness. However, even relatively robust strategies can have vulnerabilities. Finally, this analysis was conducted without direct input from the stakeholder groups that would properly define the scope and purpose of the analysis. Decisions about thresholds for acceptable outcomes and adaptive policy actions are intended to demonstrate how such choices can be incorporated into a RDM analysis for transportation policy, and should not be interpreted to reflect any particular perspective or agenda.

Figure 1 shows a scatterplot of the 25\textsuperscript{th}, 50\textsuperscript{th}, 75\textsuperscript{th}, and 90\textsuperscript{th} percentiles for emissions (on the y-axis) and incremental strategy cost (on the x-axis) for a subset of strategies, with the 2020 GHG target represented by a red line. To improve readability, the strategies are color-coded and labeled with their Strategy ID, while the relevant percentiles are represented by different shapes. It is important to note that each percentile for emissions likely represents a different set of scenarios than the same percentile for cost. These are merely slices of two sets of outcomes, distributed across their ranges. The ranges themselves, are not tied together. However, using a scatterplot of the percentiles does illustrates the relative performance of each strategy across both metrics.

Each set of percentiles traces out a frontier that starts with high emissions and low costs, then generally moves down and right toward lower emissions and higher cost. Each successive percentile traces out a slightly higher frontier of a similar shape. In addition to generally moving in the same direction, each successive percentile also has a longer and less clustered frontier than the one preceding it. At the lower percentiles (e.g. the 25\textsuperscript{th} percentile) all strategies meet the target and the fed-only strategy does so at the lowest cost. However, by the 50\textsuperscript{th} percentile, some strategies are already over the target, with the cost break-point of between $30 billion and $40 billion over the decade. By the 75\textsuperscript{th} percentile, only strategy 19 meets the target (although 12 is very close), and none do at the 90\textsuperscript{th} percentile despite incurring very large costs. While Strategies 12 (Fed\_GD200, the national fuel economy program (only) with a $2.00/gallon gasoline and diesel tax increase in
Figure 1 illustrates that the state’s chosen set of actions, the Scoping Plan, performs about as well as the federal only baseline strategy on greenhouse gas emissions, but has a nontrivial number of very high incremental cost outcomes. No strategy meets the 2020 emissions target in all scenarios, even the SP_GD250 Strategy, despite costing in excess of $100 billion in about 20% of scenarios. Along each frontier curve, the strategies with the lowest emissions are typically also the most expensive. In the strategies where taking no-action leads to achievement of the 2020 emissions
Adaptive strategies can reduce high cost outcomes and improve emissions performance in challenging conditions

In general, scenarios in which growth in vehicle miles traveled (VMT) continues over the next decade fail to achieve the emissions target. In the CALD-GEM model, total California VMT is modeled as a function of fuel prices (all fuels, specific to the vehicles that use them), changing fuel efficiency, and per-capita income (which is tied to California GDP growth). Combinations of these factors create scenarios in which policies fail to create reductions in fuel consumption sufficient to meet the greenhouse gas objective. Fuel prices and economic prosperity must move in the same direction in order to prevent continued growth in statewide VMT; vigorous economic growth must be coupled with increased fuel costs, and low fuel prices with low growth. The former should be the focus of policymakers — when the California economy is sluggish, there is no reason to artificially increase the price of transportation fuels, but, to reduce GHG emissions, fuel prices should be manipulated to influence VMT when the economy is healthy.

To demonstrate the performance of a potential response to growing VMT, we develop three adaptive strategies based upon strategies from the initial set of 20. These are summarized in Table 2 summarizes the definitions of the adaptive strategies. The first uses the national fuel economy program only, and adds a $2.00/gallon gasoline and diesel tax increase in 2016 if statewide VMT has not decreased from 2008 levels by 2015. If VMT has decreased, then no tax increase occurs. The second adaptive strategy uses the Scoping Plan in the same way, adding a $2.50/gallon gasoline and diesel tax increase in 2016 based on the VMT trigger. The third adaptive strategy uses the Scoping Plan with a second set of Pavley Standards (from 2017 - 2020), adding a $1.00/gallon gasoline and diesel tax increase based on the VMT trigger.

Examining the performance of the adaptive strategies across the scenario ensemble shows that adaptivity is able to improve the inherent conflict between high costs and high emissions. The adaptive strategies reduce the number of high emissions outcomes that occur when the modest strategies on which they are based are poorly matched to challenging scenarios, and reduce the
Table 2: Defining adaptive strategies from 2010 to 2020

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unnecessarily high costs that occur under conditions are favorable to low greenhouse gas emissions. In order to more accurately distinguish the performance of the strategies from the conditions of the scenario, performance metrics (emissions and incremental cost) are converted to regret. Simply, a given strategy’s regret in a scenario is the difference between its performance and the best performance (across all strategies) in that scenario. In other words: in hindsight, which strategy would have been best and how did the chosen action do by comparison?

Figure 2 illustrates the greenhouse gas emissions regret (along the y-axis) for the remaining strategies with one quantitative change: a strategy that achieves the target is defined to have zero regret. This change makes the emissions regret measure symmetric to the constant emissions cost regret measure, which defines the cost regret of a strategy that meets the GHG target as its difference from the lowest cost strategy to do so. Figure 2 illustrates the tradeoff between low emissions regret and low cost regret by displaying various percentiles of each type of regret outcome in a scatterplot. Using different shapes to represent the 25th, 50th, 75th, and 90th percentiles, and different colors to identify strategies (which are also labeled with their strategy ID), the figure shows the generally strong performance of the adaptive strategies across their range of outcomes. While adaptation appears to improve the performance of the SP_GD250 Strategy (Strategy 19), sacrificing little in emissions performance but reducing the set of cost outcomes (Strategy 21), it does little to help mitigate the undesirable results of SP_Pav2,GD100 (Strategy 16). Incorporating adaptivity, as Strategy 22 does (introducing the $1.00/gallon gasoline and diesel tax increase in response to higher-than-expected VMT), leads to slightly lower emissions outcomes, but leads to higher cost regret. Despite incorporating more aggressive elements, the adaptive strategies 21 and 20 still have a number of high emissions regret outcomes beyond the 75th percentile of their distributions.

The figure shows that the adaptive strategies generally perform well, with Strategy 20 (Fed/Fed,GD200)
dominating the others at each point in the distribution. Strategies 21, 11, 12, and 22 cluster relatively tightly at the 90th percentile with Strategies 11 and 12 performing somewhat better at lower points within their distributions (lower medians and slightly lower outcomes at the 75th percentile, for example), although these differences diminish farther out in the distributions. The analysis also shows that adaptive strategies rarely have high regret in both emissions and cost simultaneously, and the adaptive strategy built upon the no-action strategy never does. The first adaptive strategy (Strategy 20) has low regret in both dimensions (emissions and cost) in over 80% of all scenarios, but is still vulnerable to strong economic growth, moderately fast adoption of new alternative fuel technologies, and moderate fuel price growth. This does not imply that Strategy 20 fails to meet the emissions target in all the remaining scenarios, merely that some other strategy performs better.
Policy Implications for California

A number of important implications regarding the state’s existing plan have already been discussed above, but the RDM analysis produced insights about alternative policies. Adaptive strategies improve the ability to meet GHG targets at acceptable costs by responding to observable conditions. However, an important goal of California’s efforts to reduce greenhouse gas emissions was to demonstrate the effectiveness of its policies to other nations and regions who might implement them as well. It is not clear that an adaptive strategy focused on fuel price mechanisms (whatever form they ultimately take) serves that goal, when the state has concentrated so much on technology and regulation.

If the price of gasoline remains around $4.00/gallon over the next decade (in constant dollars), then the national fuel economy program may be sufficient to meet the 2020 GHG target without any action from California. But if fuel prices decrease from current levels, the state’s policies do little to address the resulting increases in VMT and meeting the 2020 target requires action on fuel prices.

Policymakers have been reluctant to increase fuel excise taxes, and have not done so at the federal level since 1993, when the federal gasoline tax was raised to $0.184/gallon. Although recent surveys suggest that Californians exhibit an overall willingness to adopt “green” taxes and fees related to transportation (Dill and Weinstein, 2007), the design of the tax/fee is important and fuel tax increases may still be too politically unacceptable (Argrawai et al., 2009). However, unless the state is bit lucky, fuel tax increases may be necessary even with a statewide cap-and-trade program.

One of the strategies considered in this study, Strategy 17 (SP_GD50), mimics the impact of the cap-and-trade program on fuel prices by adding a $0.50/gallon tax increase in 2016 to the actions in the Scoping Plan, but still only achieves the desired emissions level in 48% of all scenarios. Strategy 14 incorporates the same $0.50/gallon tax increase, in addition to the second set of Pavley standards and fares little better in terms of emissions savings (meeting the target in 51% of all scenarios). This strategy represents the most likely course of action and the most optimistic (from an emissions perspective) assumptions about the cap-and-trade program’s impact on fuel cost and transportation emissions. This suggests that the price floor established in the regulations, should
be expected to have a smaller impact on driving behavior and emissions than the performance of either Strategy 14 or 17, and will need to be augmented with additional policies to reduce VMT if gasoline prices fail to rise to more than $5/gallon over the next decade and California GDP grows at about 1% per year.

The state should develop regulations with a broader perspective on the uncertainty surrounding implementation and compliance. Current methods exhibit an overreliance on forecasts and optimistic assumptions, without a corresponding analysis of their influence on expected costs or effectiveness. This study demonstrates that a limited view of uncertainty can lead to unrealistic expectations about policy performance and attribution challenges, where it is difficult to know if a policy is truly effective because of a limited understanding of the environment in which it is implemented.