

Unintended Consequences of Carbon Policies: Transportation Fuels, Land-Use, Emissions, and Innovation

Stephen P. Holland,^{1;4} Jonathan E. Hughes,² Christopher R. Knittel,^{3;4} Nathan C. Parker⁵

¹Department of Economics, University of North Carolina at Greens-boro. ²Department of Economics, University of Colorado at Boulder. ³ William Barton Rogers Professor of Energy Economics, Sloan School of Management, Massachusetts Institute of Technology. ⁴ National Bureau of Economic Research. ⁵ Institute of Transportation Studies, University of California, Davis.

Executive summary

Policy makers have pursued a variety of policies to lower carbon emissions from transportation fuels. A number of studies have shown that renewable fuel standards (RFS) or mandates, low carbon fuel standards (LCFS), and direct subsidies are inefficient instruments for achieving emissions reductions relative to cap and trade (CAT) or carbon pricing. Unfortunately, these inefficient policies can also have unintended consequences. For example, a policy which leads to more agricultural production from intensive cultivation will lead to more erosion and habitat loss than a policy which leads to an equivalent carbon reduction but less intensive agricultural production. We ask whether unintended consequences associated with ethanol blending, land-use changes,

uncontrolled emissions, and innovation incentives increase or decrease the relative inefficiencies of the different policies.

Our results highlight the potential negative effects of current transportation sector carbon policies, effects that would be less severe under a CAT policy. To assess these unintended consequences, we simulate long-run equilibrium outcomes for two existing policies: ethanol subsidies and the 2022 US RFS; and for two policies currently under consideration: a national LCFS and a CAT system. To increase comparability across the policies, we calibrate the LCFS and CAT to achieve the same reduction in carbon emissions as the RFS. Our simulations exploit engineering models of ethanol production and detailed data on agricultural production and waste biomass resources to construct county-level supply curves for corn ethanol and six cellulosic ethanol fuels. Based on these supply curves, we estimate emissions, ethanol production, energy crop and biomass consumption, land-use, and related externalities under each policy.

We find that, as intended, carbon emissions fall under each of the policies: by 10.2 percent for the RFS (and LCFS and CAT) and by 6.9 percent for the subsidies. However, these emissions reductions are achieved by dramatically different processes. In particular, annual ethanol production increases substantially under the RFS, LCFS, and subsidies by 14.9 to 18.5 billion gasoline gallon equivalents (gge), relative to our business as usual scenario. Under CAT, the increase is much more modest at approximately 3.8 billion gge.

The inefficient policies, by requiring substantially more ethanol production, have several unintended consequences. First, the existing vehicle fleet may not be able to use the vast amounts of ethanol required under these policies. The existing vehicle fleet can safely utilize approximately a 10 percent ethanol blend by volume (the "blend wall").

We estimate that the inefficient policies would require substantially more ethanol than can currently be blended, whereas CAT would not.

Second, because some ethanol is produced from energy crops, the policies would require shifts in agricultural activity. We estimate that under the RFS, LCFS, and subsidies, between 27.6 and 39.0 million additional acres of land are used for energy crop production, or between 6 and 9 percent of existing US cropland. Under CAT, only 1.2 million additional acres are required. The large shifts in agricultural activity under the alternatives to CAT create social costs from habitat loss and increased erosion. We estimate land-use related costs between \$147 million and \$693 million per year for the RFS, LCFS, and subsidies. Under CAT, these costs are essentially zero.

A third unintended consequence arises due to the impossibility of precisely measuring lifecycle carbon emissions from biofuels. If regulated emissions intensities are set too low, large increases in ethanol production can lead to "uncontrolled" emissions above or below the level intended by policy makers. Because the alternatives to CAT require more ethanol production, these policies are much more sensitive to errors in assigning emissions intensities. If the emissions rate for corn ethanol is 10 percentage points higher than expected, we estimate between \$174 million and \$308 in damages from uncontrolled emissions under the RFS, LCFS or subsidies. Under CAT, damages from uncontrolled emissions are only \$30 million.

Finally, because cellulosic or "second-generation" ethanol fuels cannot yet be produced at commercial scale, the innovation incentives of any carbon policy are crucial. We analyze the incentives for developing cellulosic ethanol, reducing its costs, and lowering fuel emission intensities across the different policies. We first estimate the social gains from innovation across the policies. Under CAT, we find that social gains

from innovation are positive and substantial. However, the social gains under the inefficient policies are surprising. Social gains depend on both the amount each policy relies on ethanol and on whether increased ethanol use increases or decreases the inefficiency of the policy. Surprisingly, in some cases, this latter effect can dominate. In fact, we estimate that social gains from innovation can be *negative* for the inefficient policies.

We also investigate the distribution of gains from innovation across consumers and the different types of firms under the policies. Private incentives for innovation can be too large or too small depending on whether surplus gains to ethanol producers are larger or smaller than social gains. We find that under CAT, incentives for innovation are generally too small when ignoring carbon market revenue because some gains accrue to consumers. However, we estimate that carbon market revenue would be sufficient to compensate producers fully for efficient innovation expenditures. Under the inefficient policies, the gains to ethanol producers can lead to very inefficient incentives. For example, under subsidies, we estimate that gains to producers are substantially greater than social gains. Under the RFS and LCFS, private incentives for innovation can be too large, too small, or *negative*. Under the LCFS and CAT, corn producers are harmed by innovation that leads to the development of cellulosic ethanol, lowers cellulosic costs or reduces cellulosic emissions. In general, the different types of innovation lower energy prices, increase consumer surplus, and reduce carbon abatement costs.

Overall, we show that transportation sector carbon policies vary along a number of important dimensions. The alternatives to CAT create different fuel mixes, land use patterns, and incentives for innovation. These differences can increase social costs

substantially. The unintended consequences highlight the important trade-offs faced by policy makers in evaluating approaches for reducing carbon emissions in transportation.