**Supplemental Information:**

**Detailed methodology for creating NOx air quality transfer coefficients**

To estimate the transfer coefficients, written as (or ) in the model above, we leveraged a series of 19 photochemical emissions sensitivity model simulations (Table S-1), available from ([U.S. EPA, 2015b](#_ENREF_2_3)). These simulations perturbed projected 2025 NOX or VOC emissions inputs in different ways for each simulation providing information on the responsiveness of ozone concentrations at monitors to regional emissions reductions. Where the NOX or VOC emissions sensitivity regions spanned multiple states (as indicated by the regions in Table S-1), we used information from source apportionment modeling to estimate state-level transfer coefficients.

**Table S-1**

Photochemical model simulations used to estimate air quality transfer coefficients. All emissions reductions are relative to the projected 2025 emissions.

| **Simulation**  **no.** | **Region over which**  **emissions reductions were applied (emissions sensitivity regions)** | **Emissions reductions**  **relative to 2025 projections** | **Type of emissions reductions** |
| --- | --- | --- | --- |
| 1 | California | Explicit control scenario1 | NOX |
| 2 | San Joaquin Valley and Northern California | 50 percent beyond simulation no. 1 | NOX |
| 3 | San Joaquin Valley and Northern California | 90 percent beyond simulation no. 1 | NOX |
| 4 | Southern California | 50 percent beyond simulation no. 1 | NOX |
| 5 | Southern California | 90 percent beyond simulation no. 1 | NOX |
| 6 | Nevada | 50 percent | NOX |
| 7 | Arizona and New Mexico | 50 percent | NOX |
| 8 | Utah and Wyoming | 50 percent | NOX |
| 9 | Colorado | 50 percent | NOX |
| 10 | East Texas2 | 50 percent | NOX |
| 11 | West Texas3 | 50 percent | NOX |
| 12 | Oklahoma, Arkansas, Louisiana | 50 percent | NOX |
| 13 | Kansas and Missouri | 50 percent | NOX |
| 14 | Wisconsin, Illinois, Indiana, and Michigan | 50 percent | NOX |
| 15 | Ohio, West Virginia, Kentucky, Tennessee | 50 percent | NOX |
| 16 | Northeastern U.S.4 | 50 percent | NOX |
| 17 | Virgina5 | 50 percent | NOX |
| 18 | All other states in the Contiguous U.S. | 50 percent | NOX |
| 19 | National | 50 percent | VOC |

1 This scenario applied all additional control measures in California using the U.S. EPA’s CoST tool, as described in U.S. EPA (2014).

2 East Texas is defined as including all Texas counties within 200 km of Texas monitors projected to have ozone concentrations above 70 ppb in 2025 (EPA 2014).

3 West Texas is defined as all Texas counties not included in the East Texas region.

4 Northeastern U.S. is defined as including all counties within 200 km of Ozone Transport Region (OTR) monitors projected to have ozone concentrations above 70 ppb in 2025 (EPA 2014).

5 Virginia is defined as all Virginia locations not included in the Northeastern U.S. region.

For each emissions sensitivity simulation, we calculated the projected ozone design values. We then estimated the transfer coefficient for each emissions perturbation simulation as follows:

 (S-1)

where represents the ozone design value at monitor *m* within the emissions sensitivity simulation for region *r*, and  represents the total change in emissions (in short tons) between the unperturbed 2025 model simulation and the emissions sensitivity simulation. Note this approach enables us to estimate a transfer coefficient relating emissions reductions in region *r* to changes in ozone concentrations at monitor *m* regardless of whether the monitor physically resides in the region.

Many of the emissions sensitivity regions shown in Table S-1 span multiple states. To provide state-level transfer coefficients, we leveraged additional existing air quality modeling. [U.S. EPA (2015a)](#_ENREF_2_2) describes source apportionment modeling[[1]](#footnote-2) that used the same 2011 CAMx modeling platform used in [U.S. EPA (2015b)](#_ENREF_2_3), but with design values projected to 2018. That modeling tracked emissions from each state to estimate state-level contributions to ozone concentrations at each monitor. In the emissions sensitivity regions covering multiple states, we used the source apportionment modeling to determine the relative contribution from each state within a region compared to the total regional contribution at all monitors. We then applied Equation (S-2) to estimate state-level transfer coefficients:

 . (S-2)

Here, is the state-level ozone contribution based on the source-apportionment modeling, is the total regional ozone contribution based on the source-apportionment modeling, and is the total change in emissions from the state between the unperturbed 2025 model simulation and the emissions sensitivity simulation.[[2]](#footnote-3) The results from applying Equations (S-1) and (S-2) were meshed to yield the final set of transfer coefficients by region and by monitor.

In Section 2.4 of the manuscript, we discuss how in the optimization context we propose to linearize the response of ozone concentrations to emissions reductions in regions where large emissions reductions might be needed to attain analyzed ozone goals. Here we develop multiple coefficients or “impact steps” that depend upon the amount of abatement already obtained within the California and the Northeast regions. In Northern and Southern California, three sets of emissions perturbations were modeled, as shown in Table S-1. For the Northeast region, a similar approach was followed -- previous modeling simulated multiple levels of emissions perturbations over a larger Northeast region than is used here ([U.S. EPA, 2014](#_ENREF_2_1)). In this modeling, the relative change in response factors between the 50 percent and 90 percent NOX reductions was applied here within the Northeast region for emissions reductions beyond 50 percent.

**References**

U.S. EPA, 2014. Regulatory Impact Analysis of the Proposed Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone. Office of Air Quality Planning and Standards. <[http://www.epa.gov/airquality/ozonepollution/pdfs/20141125ria.pdf>](http://www.epa.gov/airquality/ozonepollution/pdfs/20141125ria.pdf%3e).

U.S. EPA, 2015a. Memorandum from Stephen D. Page to Regional Air Division Directors, Regions 1-10: Information on the Interstate Transport “Good Neighbor” Provision for the 2008 Ozone National Ambient Air Quality Standards (NAAQS) under Clean Air Act Section 110(a)(2)(D)(i)(I), Air Quality Modeling Technical Support Document, January 22, 2015, Research Triangle Park, NC.

U.S. EPA, 2015b. Regulatory Impact Analysis of the Final Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone. Office of Air Quality Planning and Standards, Research Triangle Park, NC. <[http://www.epa.gov/airquality/ozonepollution/pdfs/20141125ria.pdf>](http://www.epa.gov/airquality/ozonepollution/pdfs/20141125ria.pdf%3e).

1. 17 Source apportionment modeling shows how much ozone can be attributed to emissions from a specific location, which is different from the emissions sensitivity modeling. Emissions sensitivity modeling provides information about how ozone concentrations will change in response to emissions changes. [↑](#footnote-ref-2)
2. 18 This state-level attribution was not performed for the Northeast region since this region did not exactly follow state boundaries, and thus could not be easily matched to the state-level source apportionment modeling. [↑](#footnote-ref-3)