Is Public Transit's 'Green' Reputation Deserved? Evaluating the Effects of Transit Supply on Air Quality*

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Abstract

In recent decades, air quality in the U.S. has improved substantially. Over this time, there has been also been a steady increase in the volume of transit capacity supplied. While public transit has a reputation as a potential means to ameliorate the adverse environmental effects of automobile travel, there have been very few empirical studies of the marginal effect of transit supply on air quality. In this paper, we ask whether any of the substantial improvement in air quality observed in the U.S. from 1991 to 2011 can be attributed to increased public transit supply. To answer this question, we develop an equilibrium model of transit and automobile travel volumes as a function of the level of transit supplied. We then empirically analyze the effects of the level of transit supply on observed ambient pollution levels by applying an instrumental variables approach that accounts for the potential endogeneity of public transit investment to a panel dataset of 96 urban areas across the U.S. over the years 1991-2011. In particular, we analyze the effects of the level of transit supply on the following criteria pollutants: carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM), and sulfur dioxide (SO_2). We find that – at the margin, and given existing urban travel regulations in place – there is no evidence that increased transit supply improves air quality; in fact, transit appears to lead to a small deterioration in overall air quality.

JEL Classifications: D62, H23, H54, Q58, R41, R42, R48, R53

Keywords: public transit investment, urban transportation, air quality, second-best policies, externality regulation

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1 Introduction

The severe deterioration in air quality in the U.S. following the spread of the automobile and the advanced industrialization in the mid-twentieth century led to an array of regulatory changes and technological advancements designed to lower air pollution. Air quality in the U.S. has improved substantially since the 1970s following the implementation of the Clean Air Act. However, current levels of air pollution are still significant[1] and the development of new regulations aimed to diffuse new transportation technologies and curtail future emissions is ongoing.

The Federal Highway Administration (FHWA, 2000) estimated the marginal congestion costs of auto travel to be approximately 5-7 cents per vehicle-mile of travel in 2000, while local pollution damages were estimated at 1.7 cents per vehicle-mile. More recently, the adverse health effects related to vehicle emissions have been linked to 2200 premature deaths and more than $18 billion in related public health costs in the U.S. in 2010 (Levy et al., 2010). Beyond these local effects, transportation is also a major contributor of greenhouse gas emissions and is thus a significant element of the climate change debate, which has garnered increased attention in recent times.

While the excise taxes imposed on fuel purchases are in some part aimed at reducing vehicle travel and emissions,[2] there is limited direct price-based regulation of vehicle emissions. Emission taxes are underutilized in large part due to the transaction costs and asymmetric information inherent in regulating any non-point source emissions.

There are three relevant strands of literature related to urban transportation and air quality: (i) studies of the air quality impacts of transportation policy (see e.g., Davis (2008); Gallego, Montero and Salas (2013a,b); Wolff (2014); Gibson and Carnovale (2015); and Zhang, Lin Lawell and Umanskaya (2017)); (ii) studies linking auto travel and pollution with the associated health effects (see e.g., Friedman et al. (2001); Currie and Walker (2011); Knittel et al. (2014); and Sun et al. (2014)), and (iii) a limited body of literature focusing directly on the effects of public transit on air quality. While there is generally a consensus that *auto* travel leads to adverse health outcomes, there is very little empirical evidence of the incremental effect that transit supply may or may not have on air quality.

Anas and Timilsina (2009) found that increased bus service in downtown Beijing did not lead to a reduction in carbon dioxide emissions, in large part due to the improvement in bus travel times at-

[1] For example, in their analysis of trends in exceedances of the ozone air quality standard in the continental U.S., Lin, Jacob and Fiore (2001) find that, except in the Southwest, air quality improvements during the 1980s leveled off in the 1990s.

[2] Federal and state fuel taxes of 40 cents per gallon imply an average tax on auto travel of 2 cents per vehicle-mile, though this tax is not directly linked to congestion or emissions (Parry, 2009, section 3F).

tracting new riders that previously walked or cycled, and not attracting many car users to switch to transit. Chen and Whalley (2012) found that the opening of Taiwan's new rail system led to a small reduction in carbon monoxide but had no effect on ground level ozone pollution. Lalive et al. (2013) found that increases in rail service frequency in Germany lead to a reduction in some pollutants (nitrogen dioxide and carbon monoxide), though not others (sulfur dioxide and ground level ozone).

Cutter and Neidell (2009) found that 'Spare the Air' advisories in the San Francisco Bay Area that encourage commuters to switch to public transit on days with ozone level warnings were moderately successful. However, Sexton (2012) found that the free transit fares and public information provision associated with the 'Spare the Air' campaign actually leads to increases in both car and transit ridership. While Sexton finds that transit fare reductions do not lead to cross-modal substitution, his study does not address the effects of a change in the supply of public transit. Harford (2006) discusses the theoretical ambiguity of the relationship between transit and observed pollution levels, with the implication that it is difficult to impute the effect of transit on air quality based on previous studies focusing on auto travel's effects on air quality.

Rivers et al (2016) study the effect of public transit supply on air quality at the extensive margin, by comparing ambient pollution levels during transit strikes in Canadian cities with observed pollution levels in periods without transit strikes. This can be viewed as a short run effect of transit supply on air quality, as individuals are unlikely to make significant changes in travel behavior in the presence of a temporary transit strike. They find that public transit leads to a slight decrease in CO, but to an increase in NO_2. Using a similar approach, Bauernschuster et al (2017) find that transit strikes in Germany lead to an 11-13% increase in total car hours and a 14 % increase in particle pollution.

While public transit typically has a reputation as a 'green' alternative to auto travel, it remains to be seen whether this reputation holds up to empirical scrutiny; of interest is whether increased supply of public transit leads to substitution of auto trips for transit trips and improvements in air quality. Can any of the substantial improvement in air quality observed in the U.S. from 1991 to 2011 be attributed to increased public transit supply?

Notably, there do not appear to be any widespread studies of transit's effect on air quality in the U.S. It is an open question whether the previous studies' results in Asia and Europe can be extrapolated to the U.S. Beaudoin and Lin Lawell (2017) show that public transit service can reduce auto congestion, though the magnitude of this reduction varies significantly across regions. Our results are the first that estimate the effect of transit supply on air quality in North America at the intensive margin. We find that transit has no effect on CO, O_3, PM_{10}, and SO_2, and that transit actually increases NO_2 and $PM_{2.5}$. These findings are reasonable, given the per-unit emission rates of these pollutants across the auto and transit modes. The small degree of substitution from auto travel to transit travel following increases in transit supply appears to not offset the additional pollution generated from the increase in transit supply. Of note, we estimate that the increase in NO_2 is approximately 48% as large as the estimate of Rivers et al (2016). This finding is consistent with the differing identification strategies employed; our model is an equilibrium model that incorporates potential induced auto travel demand following increased transit supply, which would offset some of the short run potential air quality effects that may exist.

In this paper, we examine the effects of the level of transit supply on observed ambient pollution levels by applying an instrumental variables approach that accounts for the potential endogeneity of public transit investment to a panel dataset of 96 urban areas across the U.S. over the years 1991-2011. In particular, we analyze the effects of the level of transit supply on the following criteria pollutants: carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM), and sulfur dioxide (SO_2). We find that – at the margin, and given existing urban travel regulations in place – there is no evidence that increased transit supply improves air quality; if anything, public transit in the U.S. may actually lead to slightly *worse* air quality.

2 Urban Transportation and Air Quality

To assess the effects of public transit provision on regional air quality, we incorporate air quality data for 96 urban areas across the U.S. From 1982 to 2011, auto travel increased by 83% and transit travel increased by 16%. From 1991 to 2011, an aggregate 50% increase in the capacity of public transit service was met with a 43% increase in transit travel. In this section, we provide an overview of our air pollutant data and its relationship to our data on traffic congestion and transit capacity.

2.1 Overview of Air Pollutants

The Clean Air Act of 1970 enabled the U.S. Environmental Protection Agency (EPA) to enact National Ambient Air Quality Standards (NAAQS) for six air pollutants (denoted 'criteria pollutants') with the aim of limiting emissions from point and non-point sources.[3] These criteria pollutants are: carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM), and sulfur dioxide (SO_2). Auto travel generates CO, NO_2, O_3, PM, and SO_2. While historically fuel consumption of on-road vehicles was a major contributor of lead emissions, lead has been largely eradicated from gasoline following increasingly stringent regulation, which has cur-

[3] Point sources are identifiable (and generally stationary) sources of pollution, such as an industrial factory. Non-point sources of pollution are not traceable to a specific source or location, such as automobile emissions.

tailed transportation emissions of lead by 95% between 1980 and 1999 and led to a 94% reduction in the ambient concentration of lead in the air over this same period. As a result, lead emissions are no longer a significant concern and are not analyzed in this paper. We next briefly summarize the other five criteria pollutants.

We report two different measures of air quality. One measure is the average daily ambient concentration of the pollutant, which represents the typical level of exposure to the pollutant. The other measure is the EPA's Air Quality Index (AQI); see EPA (2014) for an explanation of the AQI. The AQI measures daily air quality according to a scale of 0 to 500, with higher values indicating greater air pollution and health risks. An AQI value of 100 corresponds to the NAAQS for the pollutant and the AQI is categorized as described in Table 1. It should be noted that when averaged over time, the AQI is essentially a linear transformation of the daily ambient concentration of the pollutant. For the annual means across UZAs, the correlation between the average daily ambient concentration and the average AQI exceeds 0.96 for the six criteria pollutants.

Table 1: Air Quality Index (AQI) categories

AQI Value	**Label**	**Interpretation**
0 - 50	Good	Satisfactory; little or no risk.
51 - 100	Moderate	Acceptable; moderate health concern for at-risk groups.
101 - 150	Unhealthy for Sensitive Groups	Greater concern for at-risk groups.
151 - 200	Unhealthy	Potential health effects for all; serious effects for at-risk groups.
201 - 300	Very Unhealthy	Health alert triggered; serious health effects possible.
301 - 500	Hazardous	Warning of emergency conditions; entire population affected.

The costs of air pollution are primarily manifested in higher healthcare costs associated with increased hospital admissions and emergency room visits, and the non-market valuation of premature death and lowered quality of life. These costs are borne particularly by the at-risk population of children, the elderly, people with heart and lung diseases, and people who work or exercise outdoors.

2.1.1 Carbon Monoxide (CO)

Carbon monoxide (CO) is produced directly during the combustion of fuels. CO exposure is linked with adverse health effects related to the decreased delivery of oxygen to the body's organs via the individual's blood. Those with a history of heart disease are at the highest risk of these effects (EPA, 2015a).

Average CO concentrations in the U.S. have decreased markedly over time: the national average decreased by 84% from 1980 to 2013 (including a 76% decrease from 1990 to 2013) (EPA, 2015a). For the urban areas included in our dataset, Table A.1 in the Appendix shows that the average CO concentration decreased by 73% from 1991 to 2011, which is in line with the national trend over this time. The significant reduction in CO since 1990 is largely due to improvements in motor vehicle emissions controls. As shown in Table A.2 in the Appendix, road traffic is the largest contributor of CO emissions across the U.S., accounting for approximately 34% of the total in 2011.

2.1.2 Nitrogen Dioxide (NO_2)

Nitrogen dioxide (NO_2) is a highly reactive gas that is formed directly from vehicle emissions, and is the main indicator (and most important) of the broader class of nitrogen oxides (NO_x) which contribute to the formation of both ground level ozone and fine particle pollution. NO_2 exposure is linked with a number of adverse respiratory system effects, contributing to respiratory diseases such as emphysema and bronchitis and aggravating existing heart diseases. Those at highest risk are asthmatics, children, and the elderly. Additionally, the concentration of NO_2 is particularly localized near major roadways, with near-roadway concentrations of NO_2 being 30-100% higher than concentrations away from roadways (EPA, 2015b).

Average NO_2 concentrations have decreased substantially over the years, with the national average having decreased by 60% from 1980-2013 (including by 46% from 1990-2013) (EPA, 2015b). For the urban areas included in our dataset, Table A.3 in the Appendix indicates that NO_x concentrations have decreased by 38% from 1991 to 2011, which is largely consistent with the national trend over this period. This trend is forecasted to continue due to the recent enactment of more stringent NO_x standards for mobile sources. Table A.4 in the Appendix shows that road traffic is also the main contributor of NO_x emissions in the U.S., comprising 38% of the total in 2011.

2.1.3 Ozone (O_3)

Ozone (O_3) can be categorized as two different types. 'Good' ozone, which occurs naturally in the Earth's upper atmosphere, provides a layer of protection from the ultraviolet rays of the sun. 'Bad' ozone occurs at ground level (and is also referred to as tropospheric ozone). Ground level ozone is not emitted directly into the air, but rather is created by chemical reactions between NO_x and volatile organic compounds (VOC) in the presence of heat and sunlight. O_3 is of particular concern on hot, sunny days and is a major component of urban smog. There are many associated health issues, including reduced lung function and aggravation of lung diseases, and a variety of respiratory symptoms. O_3 also affects sensitive trees and vegetation by reducing growth and causing aesthetic damage to leaves, and also has detrimental effects on the surrounding ecosystems (EPA, 2015c).

O_3 levels decreased in the 1980s, stagnated in the 1990s, and again decreased during the 2000s and onward. Overall, the average concentration across the U.S. decreased by 33% from 1980 to 2013 (and by 23% from 1990 to 2013) (EPA, 2015c). However, Lin, Jacob and Fiore (2001) find that, except in the Southwest, ozone air quality improvements during 1980s leveled off in the 1990s. Morever, Table A.5 in the Appendix shows that for the urban areas in our sample there was no reduction in average O_3 concentration from 1991 to 2011 (though the average Air Quality Index measure improved by 8% over this time). Though road traffic is only responsible for 4.5% of total VOC emissions in 2011 – as summarized in Table A.6 in the Appendix – it is a significant source of O_3 due to the sizable contribution of NO_x.

2.1.4 Particulate Matter 2.5 ($PM_{2.5}$) and Particulate Matter 10 (PM_{10})

Particulate matter (PM) refers to a variety of different mixtures of several extremely small solid particles and liquid droplets, which may or may not be visible. Primary particles are directly emitted from a source, while secondary particles (the most prevalent, and the type generated by vehicle emissions) form via reactions in the atmosphere when emissions of nitrogen and sulfur oxides interact with other substances. Particulate matter less than 2.5 micrometers in diameter ($PM_{2.5}$) is 'fine' and found in smoke and haze. Particulate matter between 2.5 and 10 micrometers in diameter (PM_{10}) is 'coarse' and found near roads and industrial sites.[4] Both $PM_{2.5}$ and PM_{10} are inhalable through the throat and nose and can enter the lungs and bloodstream. If inhaled, these particles (fine particles, particularly) can affect the heart and lungs and lead to adverse public health effects such as premature death for those with pre-existing heart or lung disease; heart attacks and irregular heartbeat; decreased lung function; and respiratory issues such as coughing, difficulty breathing, and heightened asthma symptoms. PM also has adverse environmental effects such as visibility impairment (haze), aesthetic damage to buildings and architecture, and negative repercussions for water sources, soil, forests, crops and the broader ecosystem (EPA, 2015d).

PM concentrations have decreased in the U.S. recently, with the national average of $PM_{2.5}$ and PM_{10} concentrations decreasing by 34% and 30%, respectively, from 2000-2013 (EPA, 2015d). Tables A.7 and A.9 in the Appendix show that for the urban areas in our sample, $PM_{2.5}$ and PM_{10} concentrations decreased by 28% and 22% from 1999 to 2011, which is representative of the observed national trend. Road traffic is a relatively small generator of PM emissions; as Tables A.8 and A.10 show, road traffic is responsible for only 3.2% and 1.8% of total $PM_{2.5}$ and PM_{10} emissions, respectively. Regions vary in the relative extent of $PM_{2.5}$ and PM_{10} present; the correlation between the concentrations of these two types of pollutants across the UZAs is 0.38.

[4] The EPA does not regulate particles exceeding 10 micrometers in diameter.

2.1.5 Sulfur Dioxide (SO_2)

Sulfur dioxide (SO_2) is a highly reactive gas generated directly from fossil fuel combustion, primarily at power plants and industrial facilities. SO_2 is the main indicator and greatest concern of the broader class of sulfur oxides (SO_x). SO_2 exposure is linked with a number of adverse effects on the respiratory system, as it reacts with other compounds in the air to form small particles that enter the lungs. These effects include worsened respiratory disease (such as emphysema and bronchitis), increased asthma symptoms, and aggravated existing heart disease (EPA, 2015e).

Nationally, average SO_2 concentrations have decreased by 81% from 1980-2013 (and by 76% from 1990-2013) (EPA, 2015e). Table A.11 in the Appendix shows that SO_2 concentrations across the urban areas in our dataset decreased by 74% from 1991 to 2011, which is again consistent with the national average. Road traffic generates a negligible amount of SO_2 emissions; as Table A.12 shows, it was responsible for less than 1% of total emissions in 2011.

2.1.6 Pollutant Interactions

Figure 1 summarizes the changes in the average concentration of the criteria pollutants across the UZAs in our sample, indexed to 1991 values. As shown, average O_3 concentrations have remained very stable over time. PM_{10} (and $PM_{2.5}$, though not shown due to data being unavailable prior to 1999) and NO_2 concentrations have steadily decreased and are now more than 30% lower than in 1991. CO and SO_2 concentrations have shown steady and significant declines and are now more than 70% lower than in 1991.

It should be noted that the generation and observed concentrations of certain pollutants are not independent. For example, variation in NO_2 emissions will be correlated with broader NO_x emissions, which will in turn affect the formation of O_3 and PM. Table 2 shows the pairwise correlation between the criteria pollutants across the UZAs.

There is significant variation in the observed air quality across UZAs. Tables A.13 to A.18 in the Appendix show the mean of the daily maximum concentrations of the criteria pollutants for each UZA in 2011; the lack of a clear relationship across pollutants indicates that the effects of transit supply on air quality should be assessed separately for each pollutant.

2.2 Traffic Congestion, Transit Supply, and Air Quality

There is a link between the degree of traffic congestion and the dynamics of traffic flow with the associated air quality in a region. First, the emission rate of vehicles is a function of travel speed,

Figure 1: Ambient pollution levels of criteria pollutants: 1991-2011

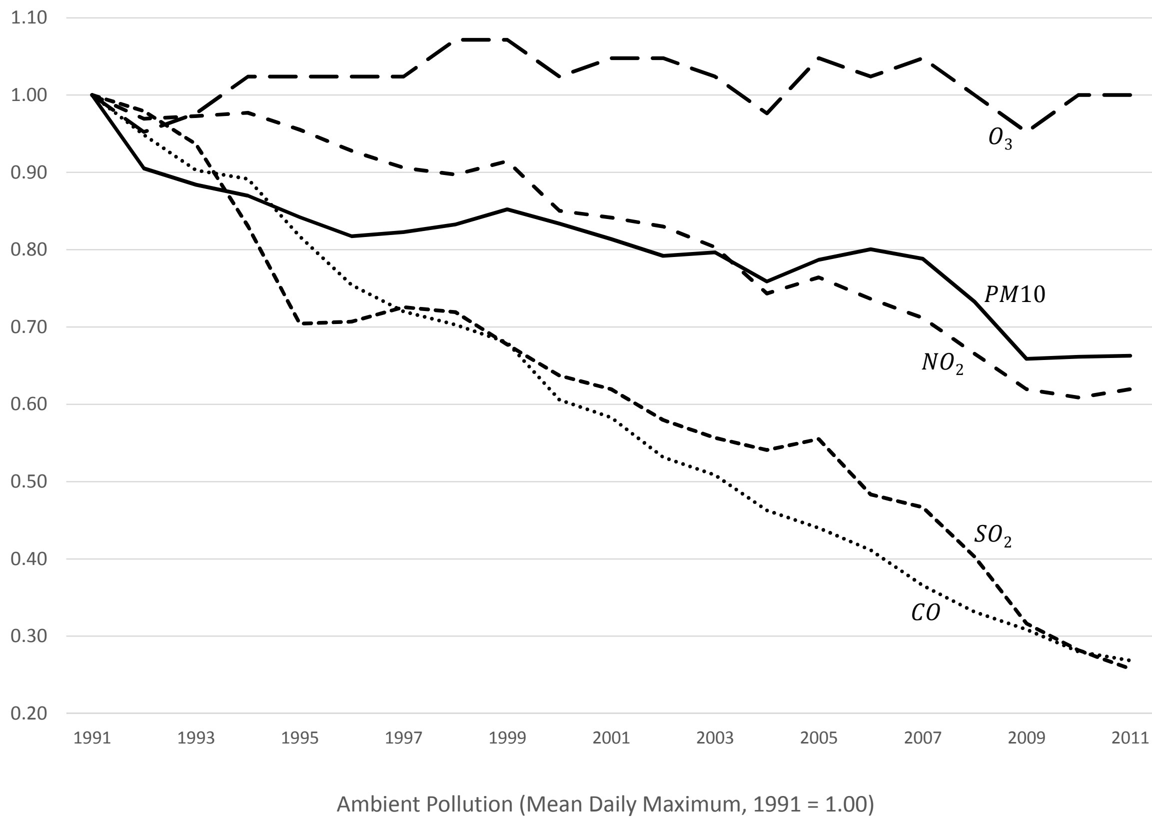


Table 2: Pairwise correlation between daily maximum pollutant concentrations, 1991-2011

	CO	**NO_2**	**O_3**	**$PM_{2.5}$**	**PM_{10}**	**SO_2**
CO	1.000	-	-	-	-	-
NO_2	0.553	1.000	-	-	-	-
O_3	0.009	0.253	1.000	-	-	-
$PM_{2.5}$	0.049	0.446	0.502	1.000	-	-
PM_{10}	0.341	0.498	0.268	0.379	1.000	-
SO_2	0.318	0.334	0.128	0.538	0.174	1.000

Notes: CO and O_3 are in units of parts per million (ppm).
NO_2 and SO_2 are in units of parts per billion (ppb).
$PM_{2.5}$ and PM_{10} are in units of micrograms per cubic meter ($\mu g/m^3$).

Table 3: Pairwise correlation between pollution, congestion and transit, 1991-2011

	Freeway congestion (vehicle-miles traveled per lane-mile)	**Transit capacity (vehicle-miles of service)**
CO	-0.2520	-0.0432
NO_2	-0.0010	-0.0065
O_3	0.0099	-0.0410
$PM_{2.5}$	0.2551	0.0148
PM_{10}	0.0011	-0.0169
SO_2	0.1356	-0.0744

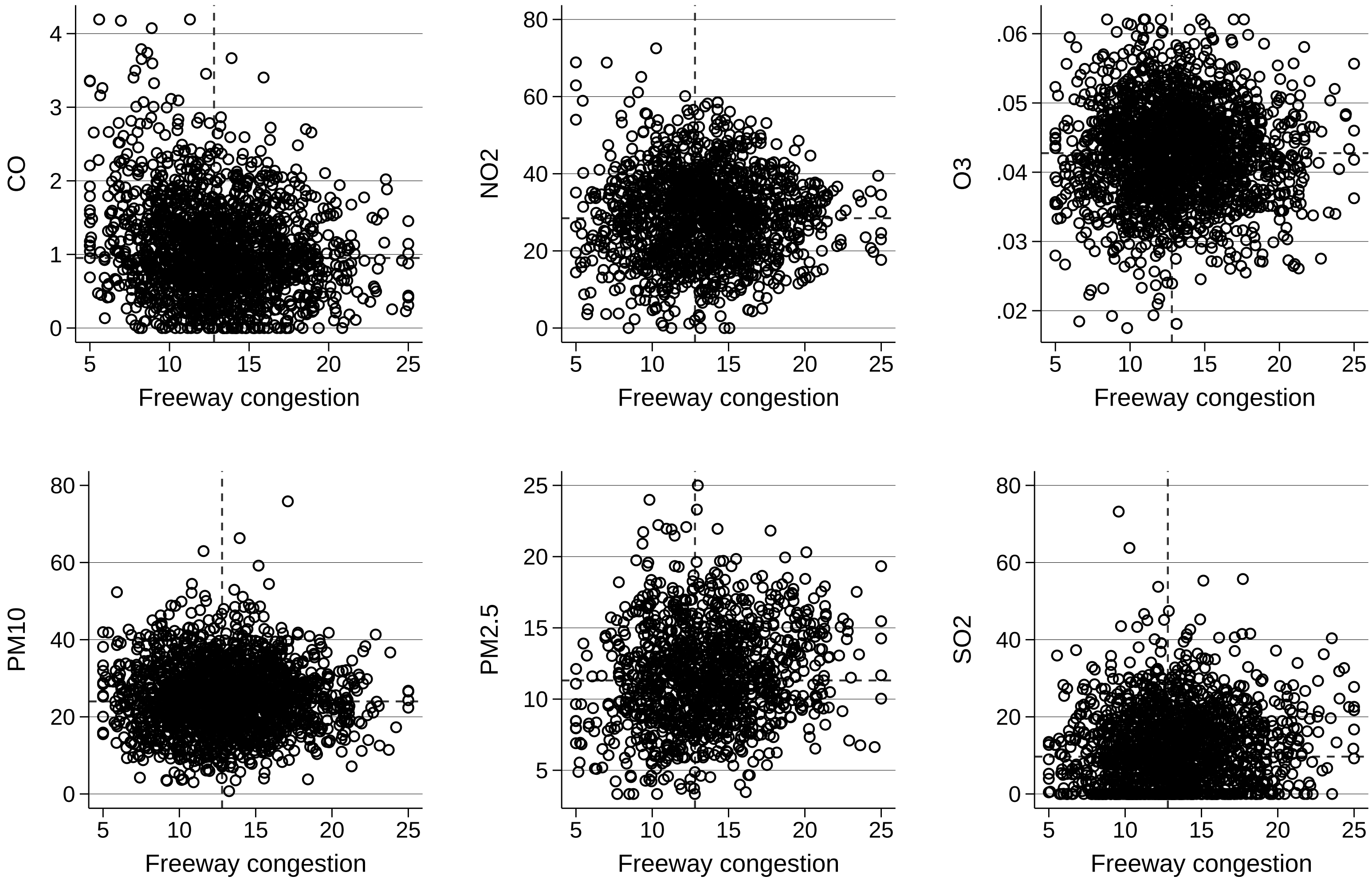
Notes: Pollution concentrations are daily maximum pollution levels.
CO and O_3 are in units of parts per million (ppm).
NO_2 and SO_2 are in units of parts per billion (ppb).
$PM_{2.5}$ and PM_{10} are in units of micrograms per cubic meter ($\mu g/m^3$).

which is dependent upon overall travel volumes, given fixed roadway capacity. Barth and Boriboonsomsin (2009) summarize the empirical relationship between travel speeds and vehicle emissions, and Berechman (2009, pp. 259) discusses how "low speeds from gridlock conditions, which characterize many urban commuting patterns, are major contributors to emissions and therefore to air pollution." Anas and Lindsey (2011, pp. 69) mention that the emissions rate is a "flat-bottomed, U-shaped function of speed with a minimum at an intermediate speed that depends on the pollutant" and that heavy congestion yields travel speeds that are below this minimum speed. Beevers and Carslaw (2005) also highlight the importance of considering the effects of both traffic volume and travel speeds on emissions. Second, in measuring changes in air quality, there may be a selection bias if higher levels of pollution occur in the most congested regions, as these regions tend to have the densest population and highest levels of economic activity.

Figure 2 shows the underlying relationship between traffic congestion and air quality for each pollutant; as summarized in Table 3, there is generally a low correlation between the level of congestion and the concentration of the pollutants. This is likely due to the location of non-transportation sources of emissions being uncorrelated with traffic congestion.

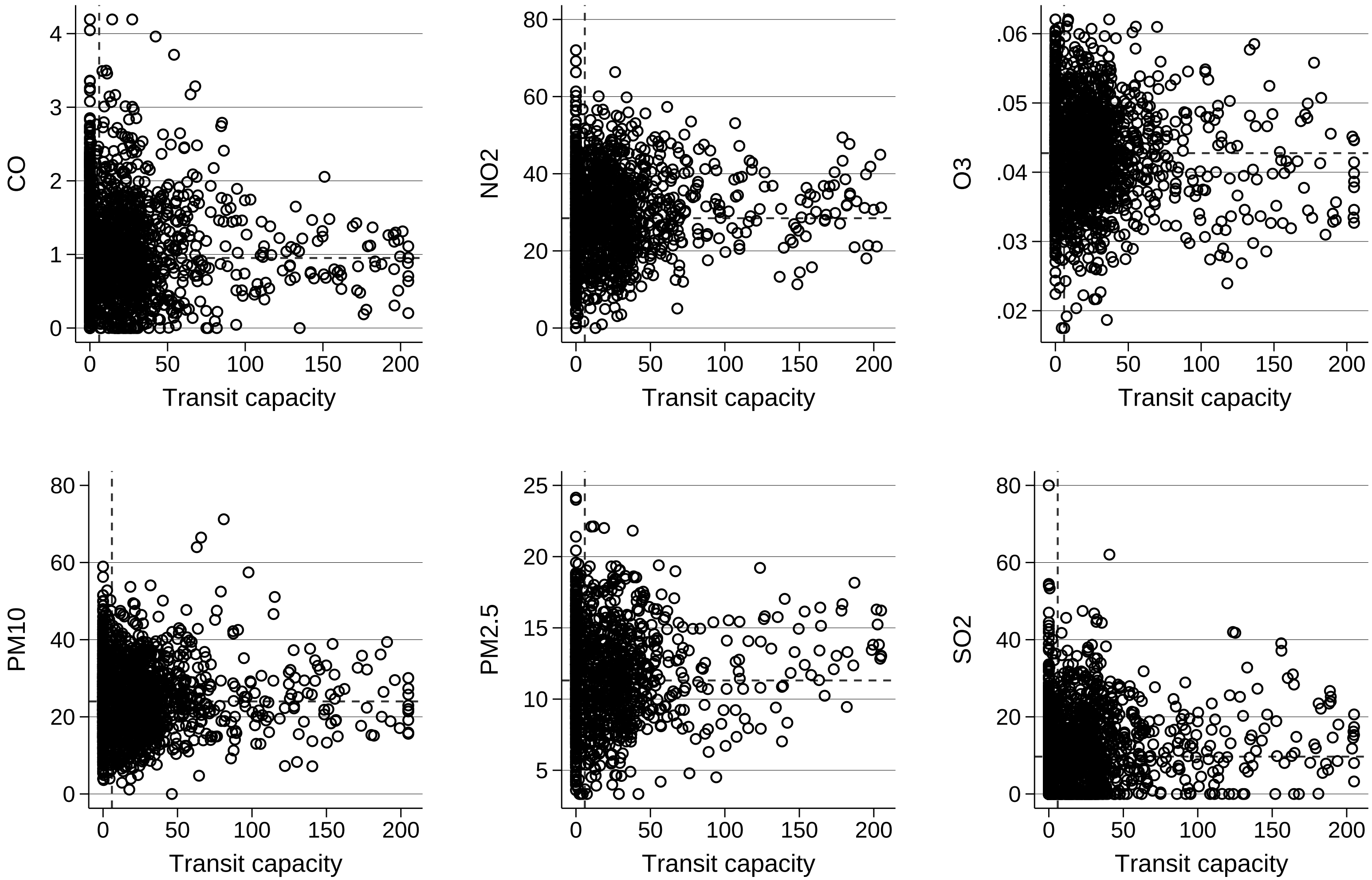
Similarly, Figure 3 shows the unconditional relationship between transit capacity and air quality for each pollutant; Table 3 indicates that there is no clear relationship between the level of transit capacity and the concentration of pollutants.

Figure 2: Relationship between freeway congestion and air pollutant concentrations



Notes: CO, O_3 : ppm, daily max.; NO_2, SO_2 : ppb, daily max.; $PM_{2.5}$, PM_{10} : $\mu g/m^3$, daily max.; Freeway congestion: vehicle-miles traveled per lane-mile

Figure 3: Relationship between transit capacity and air pollutant concentrations



Notes: CO, O_3 : ppm, daily max.; NO_2, SO_2 : ppb, daily max.; $PM_{2.5}$, PM_{10} : $\mu g/m^3$, daily max.; Transit capacity: vehicle-miles of service

2.3 Auto Travel Externalities

Congestion and emissions are both produced by auto travel, with the joint distribution of these externalities dependent on the spatial and temporal allocation of auto travel across the urban area. Roadway congestion is represented by the volume-to-capacity ratio, $\frac{V_A}{\overline{K}_A}$, where V_A is the vehicle-miles traveled by auto and $\overline{K}_A$ is the number of lane-miles of roadway available.

For region r at time t and mode $j \in \{A = \text{auto}, T = \text{transit}\}$, the aggregate social cost of pollutant p is the product of the per unit damage d and the quantity Q of the ambient concentration of pollutant p in the region. Q is based on how emissions e_{pjrt} are produced by travel volumes V_j and converted to the ambient concentration Q:

$$Q_{prt} = \sum_j e_{pjrt}\left(\frac{V_{A,rt}}{\overline{K}_A}\right) \cdot c_{pjrt} \cdot V_{jrt} + \overline{Q_{prt}}, \tag{1}$$

where c_{pjrt} is the transmission ratio from emissions to ambient concentration, and $\overline{Q_{prt}}$ is the baseline ambient level of pollutant p due to non-personal travel emission sources.

The monetized per unit damage of ambient pollutant p varies by region, degree of traffic congestion, and pollutant concentration level, but is independent of the original emission source:

$$d_{prt} = d_{prt}\left(Q_{prt}, \frac{V_{A,rt}}{\overline{K}_A}\right). \tag{2}$$

We note that both emission rates e and monetized damages d are functions of the degree of traffic congestion, due to the fuel consumption process and the extent of pollution exposure, respectively. d is a function of Q in that the damages may be convex with respect to ambient concentration levels, particularly if there is a threshold value where the health damages become a concern.

The aggregate social cost of emissions, E can be defined as:

$$E\left(V_A, V_T, \frac{V_A}{\overline{K}_A}\right) = Q\left(V_A, V_T, \frac{V_A}{\overline{K}_A}\right) \cdot d\left(Q, \frac{V_A}{\overline{K}_A}\right). \tag{3}$$

The congestion externality arises from the effect that the marginal auto user has on increasing the average generalized cost of both auto and transit travel, with this effect being imposed on each individual in the transportation network. Similarly, the emission externality has two components: (1) the effect that the marginal auto traveler has on the level of ambient pollutant concentration that all individuals in the network are exposed to, and (2) the effect on the marginal damages due to the higher congestion and ambient pollution levels associated with their travel.

Santos and Newbery (2001) studied the combined pricing of congestion and nine pollutants in

Britain, concluding that the environmental benefits of the regulation are expected be less than 10% of the benefits of reduced congestion (c.f. Anas and Lindsey, 2011, pg. 77). In our context, we are interested in assessing whether a similar ratio of benefits would arise with transit investment as the policy instrument in the place of taxation.

Johansson-Stenman (2006) discusses how the optimal taxation of auto travel should reflect the fact that the costs of emissions increase along with the greater pollution exposure in densely populated areas: when congestion increases, speed decreases and vehicle density and exposure increase, and the optimal emissions charge should reflect this higher exposure. In practice, however, the welfare gains from implementing the emission tax that conveys the necessary spatial and temporal incentives must be evaluated relative to the transaction costs of measuring and implementing the tax.

Figure 4 shows the first-best equilibrium auto travel volume $V_A^{*,\text{ congestion + emissions}}$ relative to the unregulated outcome V_A^u, as well as the Pigouvian tax on auto travel τ^*_{c+e} that would internalize the externalities generated by auto travel. Failing to tax auto travel leads to inefficiently high auto travel volumes, with $V^u > V^{*,\text{ congestion + emissions}}$.

It could be argued that public transit investment is a second-best policy instrument in this context. If auto travel is underpriced relative to its full marginal social cost, then there is the potential for public transit to increase social welfare by reducing the deadweight loss of the equilibrium auto travel externality due to congestion and emissions. Subsidizing public transit investment for this purpose would require that the demand for auto decreases and/or the magnitude of the auto travel externality decreases following an increase in transit supply.

Figure 5 illustrates the theoretical reduction in the deadweight loss associated with the congestion and emission externalities following an investment in public transit. An increase in public transit capacity from K_T^0 to K_T^1 decreases the generalized cost of transit travel (primarily by decreasing access and/or wait times) and leads to a subsequent reduction in the demand for auto travel from D_A^0 to D_A^1 as some commuters switch from auto to transit. The resulting user equilibrium moves from $V_A^{u,0}$ to $V_A^{u,1}$, and the change in the deadweight loss of each externality is determined by:

$$
\begin{aligned}
\Delta DWL_{congestion} &= DWL^1_{congestion} - DWL^0_{congestion} \\
&= (C+D) - (D+F) = C - F < 0 \quad \text{ if } F > C \\
\Delta DWL_{emissions} &= DWL^1_{emissions} - DWL^0_{emissions} \\
&= (A+B+E) - (E+G) = A + B - G < 0 \quad \text{ if } G > (A+B)\,.
\end{aligned}
\tag{4}
$$

The new equilibrium travel volumes following an increase in transit capacity must account for in-

Figure 4: The first-best equilibrium and the optimal tax on auto travel

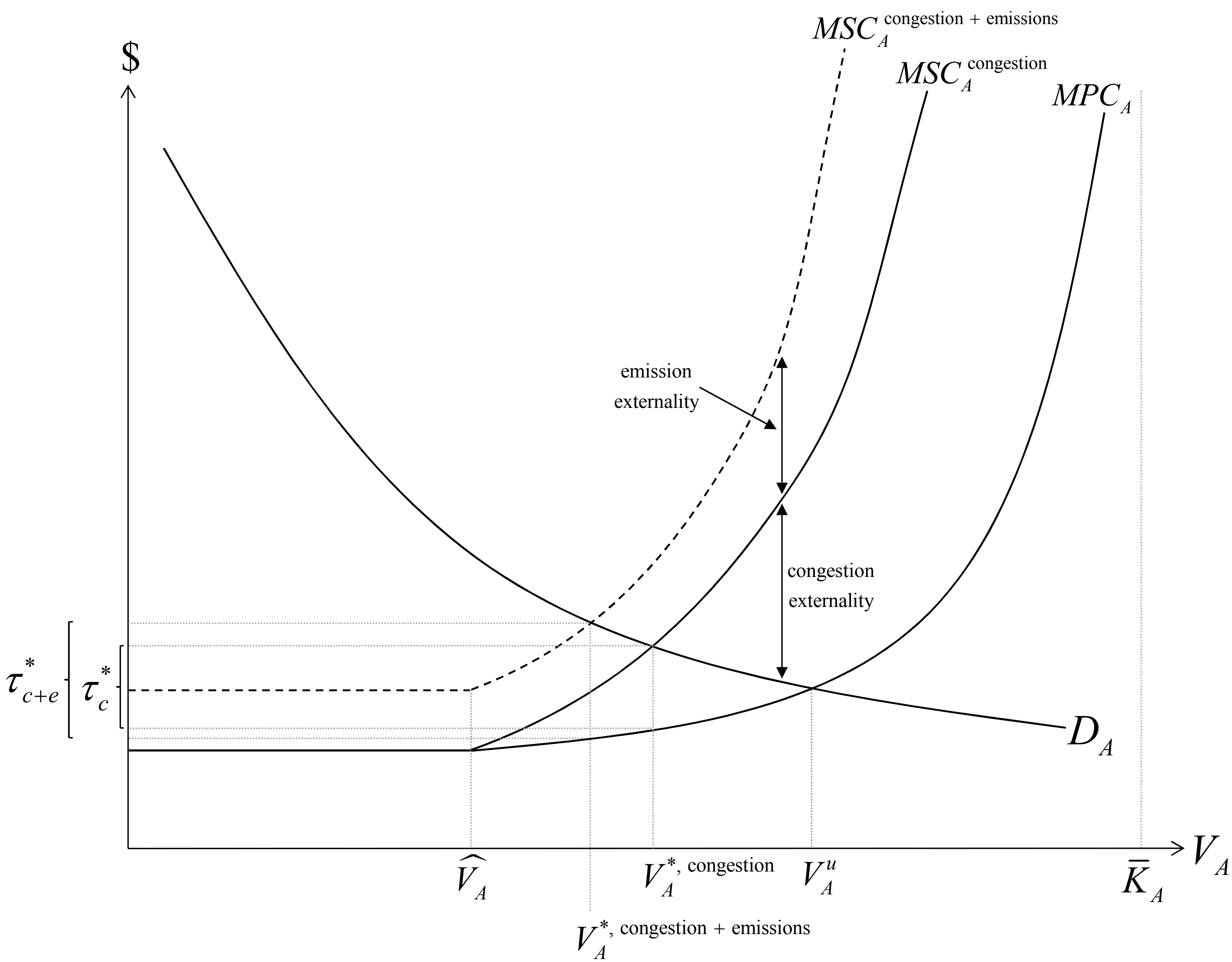
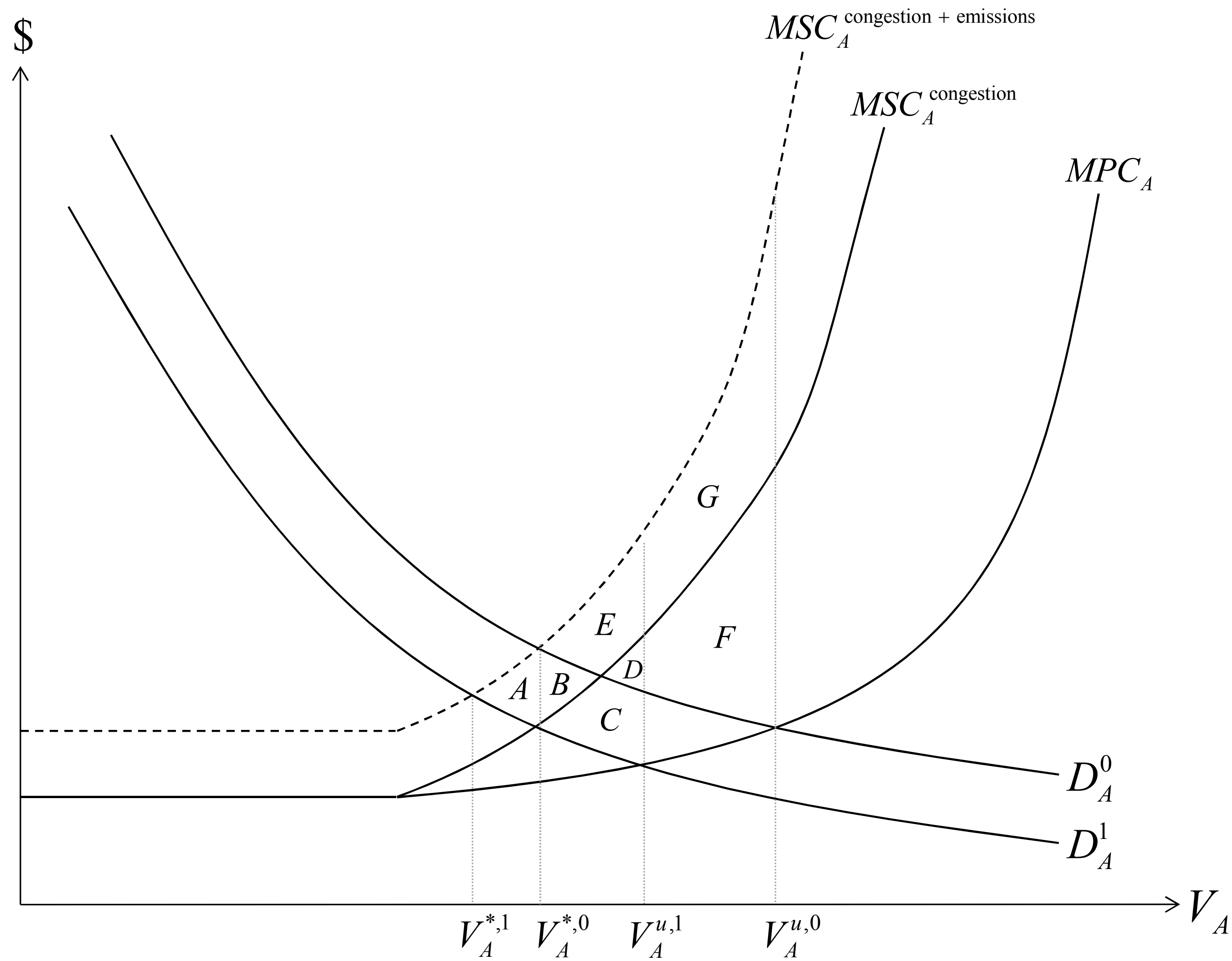


Figure 5: The effect of transit investment on the second-best equilibrium



duced demand and the "fundamental law of highway congestion": in the absence of a congestion tax, any reduction in the cost of travel (such as that brought about by increased transit supply) will lead to latent demand being generated and the short run reduction in congestion being eroded over time. There are then two questions: (1) will transit supply decrease the volume of transit travel?, and (2) how do the resulting pollution levels vary due to effects of changes in V_j and the modal differences in e_{pjrt} and c_{pjrt}?

These are both empirical questions. Beaudoin and Lin Lawell (2017) show that public transit appears to reduce congestion; on average, a 10% increase in U.S. transit supply leads to a 0.8% reduction in auto travel, though there is significant regional heterogeneity. This change in auto travel is connected to the effect of public transit supply on regional air quality in the U.S., though the nature of this relationship has received little empirical attention.

3 Empirical Model

To evaluate the potential welfare gains of public transit supply in improving air quality, we next turn to the empirical application. To estimate the effects of transit supply on air quality, we specify a reduced form model to quantify the effects of a marginal increase in public transit supply on equilibrium air quality in the region. For each pollutant $p \in \{\text{CO}, \text{NO}_2, \text{O}_3, \text{PM}_{10}, \text{PM}_{2.5}, \text{SO}_2\}$ in region r at time t:

$$\begin{aligned}\text{Air pollution}_{prt} = {} & \beta_1 \cdot \text{Transit Capacity}_{rt} + \beta_2 \cdot \text{Freeway Capacity}_{rt} \\ & + \beta_3 \cdot \text{Arterial Road Capacity}_{rt} + \beta_4 \cdot \text{Fuel Cost}_{rt} + \beta_5 \cdot \text{Transit Fare}_{rt} \\ & + \beta_6 \cdot \text{Trucking activity}_{rt} + \beta_7 \cdot \text{Employment}_{rt} \\ & + \beta_8 \cdot \text{Income}_{rt} + \beta_9 \cdot \text{Population}_{rt} \\ & + \beta_{10-11} \cdot \text{Pollution Point Sources}_{rt} + \beta_{12-15} \cdot \text{Weather Controls}_{rt} \\ & + \beta_{16-17} \cdot \text{NAAQS Standard Dummies} + \text{UZA Fixed Effects} + \varepsilon_{prt}\end{aligned} \tag{5}$$

In equation (5) the dependent variable is the regional air pollution. In addition to freeway capacity, the capacity of arterial roadways are added to measure the effects of non-freeway travel on emissions. The weather controls include the annual snow and rain in the region, as well as heating and cooling degree days. To control for emission sources additional to auto and transit travel that contribute to the underlying ambient pollution in the region via $\overline{Q_{rt}}$, trucking activity is measured by the number employed in the region's trucking sector, and pollution point sources are represented by the number employed in the agricultural and manufacturing sectors. As Figure 6 shows, employment levels in agriculture have been stable over time, trucking employment has fluctuated mildly with the business cycle, and manufacturing employment has undergone a significant reduction in the last decade as the urban regions of the U.S. have steadily transitioned towards service and white-collar occupations.

From 1991 onward, NAAQS standards have undergone periodic revision. $PM_{2.5}$ and PM_{10} standards changed in 1997 and 2006, O_3 in 1997 and 2008, NO_2 in 2010, and SO_2 in 2010; CO standards were unchanged from 1991 to 2011 (see EPA (2015f) for current and historical NAAQS standards for the criteria pollutants). To isolate any effects on air quality directly due to these regulatory changes, dummy variables are used to classify each NAAQS regime according to three sequential periods: $NAAQS_1$ = 1991-1997, $NAAQS_2$ = 1998-2006 and $NAAQS_3$ = 2007-2011.

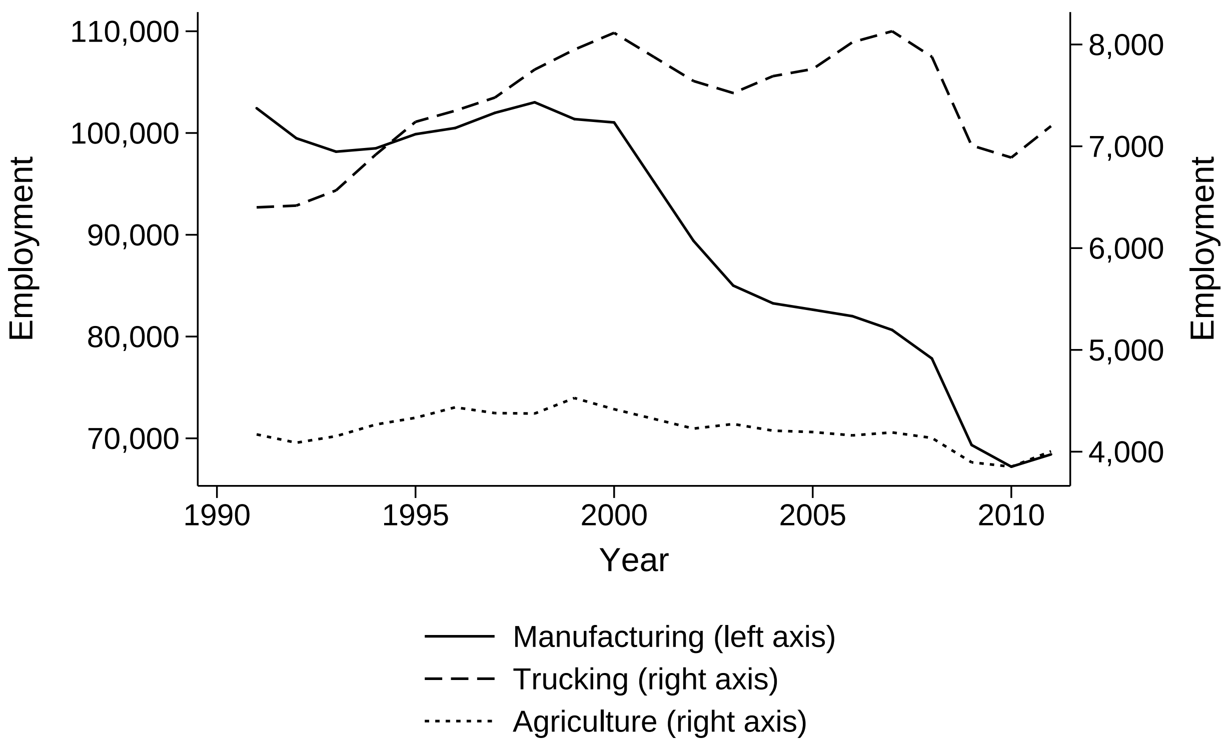
While the relationships outlined in Section 2.2 suggest that public transit investments do not occur disproportionately in urban areas with the highest pollution concentrations, we use instrumental variables to assess the potential endogeneity of transit investment and pollution levels over time.

We use two sources of instrumental variables for public transit investment. To identify the effect of transit investment on air quality, our instruments must be correlated with the level of investment, while the exclusion restriction requires that our instruments have no effect on air quality beyond the direct effect on public transit investment.

The first instrument we use is political voting records; specifically, the Democratic voting share within the urban area averaged over any preceding Presidential, Gubernatorial or Senate elections occurring in the previous year, yielding a full panel of annual voting measures from 1990-2011.[5] Duranton and Turner (2011) use the proportion of Democratic votes in 1972 as an instrument for transit supply in 1983, 1993 and 2003, providing a detailed argument for its validity as an instrument and reporting that it performs well across a variety of diagnostic tests (see their discussion on pp. 2634-2636). Holian and Kahn (2013) provide evidence that Democratic voters are much more likely than Republican voters to support referenda in relation to public transit investment. There are two channels through which Democratic voting shares are expected to be related to public transit investment: through the effect on the total public funds budget, and through relatively stronger preferences for public transit and thus the allocation of total public funds directed to public transit. Conditional on time-invariant region-specific factors that are absorbed by the regional fixed effects, voting records are not related to air quality except through their effect on public transit. Similarly, after controlling for employment rate, income and population, factors causing changes in the Democratic voting share within the urban area in Presidential, Gubernatorial or Senate elections are unlikely to be related to factors that are causing changes in local air quality, as pollution is not an issue that influences elections above the local level. After conditioning on these variables,

[5] The various voting shares cover 6 Presidential, 11 Senate and 22 Gubernatorial elections. The Democratic voting share within the State but outside of the UZA yields qualitatively similar, but less precise, point estimates.

Figure 6: Average annual UZA employment in emission-producing sectors



voting records can be interpreted as a proxy for underlying transit preferences in the region that is orthogonal to pollution.

The second instrument we use is the level of Federal funds provided for transit in the region in the prior year. The funding is disaggregated into operating funding and capital funding to reflect fixed versus variable transit infrastructure costs.[6] As Libermann (2009, pp. 87) states: "...most [Federal] highway, transit and safety funds are distributed through formulas that only indirectly relate to needs and may have no relationship to performance. In addition, the programs often do not use the best tools or best approaches, such as using more rigorous economic analysis to select projects." We assume that local and State funds may be correlated with unobserved factors affecting regional air quality, but that conditional on time-invariant region-specific unobservables that are absorbed by the regional fixed effects, Federal funds are orthogonal to such potential factors. This supposition is consistent with Berechman (2009, pp. 219-222):

"...the proclivity of local decision makers to accept a project regardless of its actual ben-

[6] From 1991-2011, the regions studied received 66.7% of capital funding and 17.3% of operating funding from Federal sources on average, with the remainder via State and Local sources.

> efits and risks increases with the proportion of funding obtained from higher levels...This observation also explains why US federal subsidies to local public transit inherently provide incentives for selecting capital-intensive projects irrespective of their efficiency or effectiveness...Our hypothesis states that local authorities, as recipients of federal and state money, tend to regard external funding as "costless" and as political benefits. They are therefore predisposed to promoting infrastructure projects containing a large external funding component...this tendency promotes the implementation of inefficient projects, selected without any regard for their social rate of return."

Conditional on urban area fixed effects and the other controls (population, in particular), our instruments are plausible. In our sample, there is very little residual correlation between air quality and the instruments after conditioning on the other covariates in the model.

4 Data

The dataset used in this analysis was initially used in Beaudoin and Lin Lawell (2017). We construct a panel dataset spanning 21 years from 1991 to 2011, covering 96 urban areas within 351 counties and 44 states across the U.S. An 'urban area' (UZA) is defined by the Census Bureau and refers to a region that is centered around a core metropolitan statistical area (MSA). The average population of the UZAs in 2011 was 1.8 million, ranging from 0.2 million in Brownsville, TX to 18.9 million in New York-Newark, NY-NJ-CT. The average area was 501 square miles, with Laredo, TX being the smallest at 43 square miles and New York-Newark being the largest at 3,353 square miles.

Data relating to the auto travel components of each UZA's transportation networks are primarily from the Texas Transportation Institute's Urban Mobility Report (Schrank et al., 2012), which are the "best available means of comparing congestion levels in different regions and tracking changes in regional congestion levels over time" (Downs, 2004, pp. 17). While we measure congestion as the daily vehicle-miles traveled per freeway lane-mile, Schrank et al. (2012) contains additional measures of traffic congestion: the Travel Time Index, which measures actual travel time relative to free-flow travel time; total annual hours of delay; percentage of peak vehicle-miles traveled under congested conditions; and the Roadway Congestion Index, which measures the aggregate traffic density of an urban area relative to the capacity of the transportation network.[7] Our empirical results are robust to the particular measure of congestion used.

The per-mile fuel cost of auto travel is derived from the Federal Highway Administration's Highway Statistics records. The average state-wide fuel efficiency in each year (gallons per vehicle-mile traveled) is derived from the total gallons of fuel used and the annual vehicle-miles traveled in each

[7] The Urban Mobility Report measures traffic delay using data from the U.S. Department of Transportation on traffic volumes and the characteristics of the city (see Winston and Langer (2006), pp. 467 for discussion).

state. This value is then multiplied by the average cost of fuel (dollars per gallon) in the state (from TTI's Urban Mobility Report) to compute the cost of fuel on a per vehicle-mile basis. The primary state of each UZA is used in assigning this value, as the underlying data are not available at the UZA level, and the fuel price control variable can thus be considered exogenous with respect to the congestion levels of the UZA. These current values are then converted to 2011 U.S. Dollars via the Consumer Price Index.

Transit data are obtained from the Federal Transit Administration's National Transit Database.[8] For each UZA's transit system, the network size is measured by directional route-miles and capacity is measured by vehicle-revenue miles. Transit travel is measured by annual passenger-miles traveled, while operating and capital funding is disaggregated by source (fares, Federal, State, Local, and other). Our two measures of transit fares for the UZA are calculated by dividing total transit fare revenue by (1) passenger-miles traveled on transit or by (2) the total number of unlinked transit trips. Since transit fares are very sticky, they are also assumed to be exogenous with respect to the congestion level of the UZA.[9] Operational transit data are distinguished by modal type - fixed guideway modes with separate rights-of-way for the transit vehicle versus mixed traffic modes that share the roadways with automobiles. The fixed guideway modes included are: commuter rail, light rail, heavy rail, hybrid rail, monorail and automated guideway, and bus rapid transit. The mixed traffic modes are: bus and trolleybus. We include fixed schedule service and exclude demand-response modes (such as those typically provided for passengers with mobility issues). In 2011, the modes included in our analysis represent approximately 74% of vehicle-revenue miles and 97% of unlinked passenger trips across the UZAs in our analysis.

Socioeconomic data relating to population, employment rate and income are compiled for the central MSA comprising each UZA and obtained from the Bureau of Economic Analysis's Regional Data records.[10]

Historical voting data at the county level are available from uselectionatlas.org. The proportion of votes cast for the Democratic Party (including total votes cast for Democratic and Republican parties only, and discarding votes for other parties) is computed via two measures: (1) the share of Democratic votes within the UZA (weighing the various counties' votes in the UZA by the percent of that UZA's total population located in the respective county in 2011), and (2) the share of Democratic votes within the primary state of the UZA but outside of the counties contained within that UZA. These measures cover the thirteen U.S. Presidential elections between 1960-2008 and various State-wide elections for the Senate and Governor over the years 1990-2011.

[8] www.ntdprogram.gov/ntdprogram/data.htm.

[9] Though some transit agencies differentiate peak and off-peak fares, there has been little variation in the *average* transit fare over time.

[10] www.bea.gov/iTable/index.cfm under *Local Areas Personal Income and Employment, Economic profiles (CA30).*

For each core-based statistical area (CBSA), daily air quality data is recorded by the EPA at monitoring stations that measure the ambient level of CO, NO_2, O_3, PM_{10}, $PM_{2.5}$ and SO_2.[11] Each CBSA is then mapped to the UZA of our dataset.[12] The available data for the criteria pollutants cover the years 1991-2011 (with the exception of $PM_{2.5}$, which is only available for 1999-2011). Table 4 summarizes the distribution of EPA monitors for the six criteria pollutants as of 2011 for the 96 UZAs in the dataset. Air quality measures are available for 82 to 96 of the UZAs, depending on the pollutant.

Table 4: EPA monitor counts per UZA, 1991-2011

	CO	**NO$_2$**	**O$_3$**	**PM$_{2.5}$**	**PM$_{10}$**	**S0$_2$**
Mean	2.76	3.29	6.97	5.99	4.10	2.83
Median	2	2	5	4	3	2
Minimum	1	1	1	1	1	1
Maximum	19	18	30	35	32	12
# of UZAs with $\geq$ 1 monitor for $\geq$ 2 years	91	82	96	96	94	88
Units of Measurement	ppm	ppb	ppm	$\mu g/m^3$	$\mu g/m^3$	ppb

Notes: Each monitor also records the AQI for each pollutant.
ppm: parts per million, daily maximum.
ppb: parts per billion, daily maximum.
$\mu g/m^3$: micrograms per cubic meter, daily maximum.

Since most UZAs have more than one monitor within its boundary, the measure of air quality for pollutant p in region r at time t, AQ_{prt}, is constructed as the annual mean over the monitors in the region. Specifically, $AQ_{prt} = \sum_{m \in I_{prt}} \sum_{d} \frac{x_{m,d}}{m \cdot d}$, where x is the air quality measure (daily maximum concentration or Air Quality Index (AQI)), m is the monitor within the relevant group of monitors I_{prt} and d is the day of the observed value.[13]

To control for the effects of weather on ambient air quality, the UZA's annual inches of rain and snow are included, as are heating and cooling degree days, due to the potential effect of regional temperature on measured pollution levels. These values were obtained from the National Oceanic and Atmospheric Administration's National Climatic Data Center's Climate Data Online database. Both heating and cooling degree days are measured in units of degrees. Annual heating degree days reflect the cumulative sum across the year of the daily difference between observed temperature levels (the average of the minimum and maximum temperature that day) and 65 degrees Farenheit, for those days where this average temperature exceeds 65 degrees. Heating degree days are

[11] This database is available at www.epa.gov/airdata/ad_data_daily.html.

[12] On average, 98.6% of the UZA population is contained within the CBSA.

[13] As a robustness check, the annual median values were also constructed.

computed analogously for those days where the average temperature is below 65 degrees.

To control for the economic activity of other major point sources of emissions, we use agricultural and manufacturing employment levels for the central MSA of each UZA, based on NAICS sectors 11 (Agriculture, Forestry, Fishing and Hunting) and 31-33 (Manufacturing), from the US Bureau of Labor Statistics' Quarterly Census of Employment and Wages.[14] To control for the impact of freight travel on emissions, we include the number of employees in the MSA's trucking sector (NAICS sector 484).

5 Empirical Results

The model in (5) is estimated using both ordinary least squares and instrumental variables, using the instruments for transit capacity discussed above. Separate regressions are undertaken for each of the six criteria pollutants. The NAAQS dummy variables use the 1991-1997 period as the reference point.[15]

Tables 5 and 6 contain the results for the OLS and IV models, respectively, to show the effects on the average annual daily maximum concentration level for each pollutant. For each pollutant, three additional specifications based on alternative measures of the ambient air quality (median values of the daily maximum concentration level for the year, and the mean and median daily AQI values). Though not shown here, the results are both qualitatively and quantitatively consistent across specifications.

In comparing the OLS and IV results, the qualitative conclusions are similar, though the coefficient estimates differ in some cases. Focusing on the IV estimates in Table 6, we note several results of interest. Of our main focus, transit capacity is not found to reduce the ambient concentration of any of the criteria pollutants, though there is weak evidence that it may lead to a small reduction in CO. In fact, public transit supply is actually linked with *higher* levels of nitrogen dioxide and particulate matter.

Increases in the price of fuel do lead to lower CO, NO_2 and O_3, while there is no evidence that subsidizing public transit fares would lead to improved environmental outcomes. Increased income levels are associated with lower levels of pollution, while growth in employment rates worsen air quality. Baseline ambient pollutant concentrations of the region are largely dependent upon the weather profile (particularly the amount of rain and the average temperature). As expected based

[14] Available at www.bls.gov/cew/datatoc.htm.

[15] The exception is the NAAQS dummy variable for $PM_{2.5}$, where $NAAQS_2$ is relative to the reference point of $NAAQS_3$, since there are no observations for $PM_{2.5}$ during 1991-1997.

Table 5: OLS regression results

	Criteria Pollutant					
	CO (ppm)	**NO_2 (ppb)**	**O_3 (ppm)**	**$PM_{2.5}$ ($\mu g/m^3$)**	**PM_{10} ($\mu g/m^3$)**	**SO_2 (ppb)**
Transit capacity	0.0036	0.1102**	-0.0000	0.0435	0.0487	0.0917
(total vehicle revenue-miles, millions)	(0.0024)	(0.0406)	(0.0000)	(0.0224)	(0.0292)	(0.0556)
Auto capacity: freeways	-0.0062	0.1482	-0.0003*	-0.2603*	-0.6278**	0.2892
(total lane-miles)	(0.0200)	(0.2215)	(0.0002)	(0.1242)	(0.2348)	(0.3768)
Auto capacity: arterials	-0.0146*	-0.1483	-0.0000	-0.0279	-0.0350	-0.1082
(total lane-miles)	(0.0068)	(0.0872)	(0.0001)	(0.0466)	(0.0768)	(0.1510)
Fuel price	-2.0817***	-31.1182**	-0.0190***	-0.6432	8.9153	-7.6157
($ per vehicle-mile)	(0.5558)	(9.9163)	(0.0044)	(2.3953)	(7.2519)	(11.3292)
Transit fare	-0.0264	-0.0035	0.0003	-0.0684	-0.1544	-0.1547
($ per unlinked trip)	(0.0204)	(0.3032)	(0.0002)	(0.0562)	(0.2931)	(0.4567)
Income	-0.0402***	-0.3597*	0.0001	-0.2239***	-0.1809	-0.0177
(real per capita income)	(0.0085)	(0.1589)	(0.0001)	(0.0519)	(0.0963)	(0.1989)
Population	0.1584	-2.2243	0.0012	0.4804	2.0760	-3.7954
(millions)	(0.1066)	(1.4498)	(0.0011)	(0.9089)	(1.5650)	(3.0176)
Overall employment rate	1.7004	38.4200**	0.0192*	33.4314***	22.7867*	-7.1309
(total employed per capita)	(0.9082)	(13.5438)	(0.0086)	(5.9693)	(8.9232)	(18.8551)
Manufacturing employment	0.0004	0.0022	-0.0000	0.0084	0.0068	0.0173
(total employed in sector, thousands)	(0.0008)	(0.0127)	(0.0000)	(0.0045)	(0.0102)	(0.0125)
Agricultural employment	0.0031	0.1563	0.0001	0.1466	0.0313	0.0638
(total employed in sector, thousands)	(0.0074)	(0.0849)	(0.0001)	(0.0798)	(0.1214)	(0.2370)
Trucking employment	-0.0010	0.1045	0.0002*	0.0541	-0.0289	-0.4427
(total employed in sector, thousands)	(0.0090)	(0.1735)	(0.0001)	(0.0550)	(0.1353)	(0.3920)
Rain	-0.0045***	-0.0816***	-0.0000	-0.0280***	-0.0443***	-0.0339*
(annual inches, hundreds)	(0.0010)	(0.0158)	(0.0000)	(0.0052)	(0.0130)	(0.0162)
Snow	0.0014	0.1473	0.0001	0.0368	-0.0012	-0.0484
(annual inches, hundreds)	(0.0056)	(0.0965)	(0.0001)	(0.0366)	(0.0761)	(0.1119)
Heating degree days	-0.1471***	-1.5228**	-0.0011***	0.1559	-1.5505***	-1.3375**
(thousands)	(0.0373)	(0.4890)	(0.0003)	(0.1631)	(0.3387)	(0.5009)
Cooling degree days	-0.0442	-0.9568	0.0031***	-0.0100	0.7003	-1.2600
(thousands)	(0.0424)	(0.9784)	(0.0006)	(0.2317)	(0.4112)	(1.1014)
NAAQS: 1998-2006	-0.3423***	-3.2627**	0.0002	1.0198***	-2.0655***	-3.4996**
($1998-2006=1$, otherwise $=0$)	(0.0537)	(0.9915)	(0.0004)	(0.1369)	(0.5869)	(1.0347)
NAAQS: 2007-2011	-0.5009***	-6.2346***	-0.0005	-	-4.5171***	-7.3711***
($2007-2011=1$, otherwise $=0$)	(0.0662)	(1.0788)	(0.0004)		(0.6998)	(1.3234)
UZA fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	1748	1429	1900	1186	1811	1544
R^2	0.7068	0.5271	0.1724	0.5551	0.3475	0.3973

Notes: Robust standard errors in parentheses; clustered by UZA. The dependent variables are the mean values of the daily maximum concentration level for the year for each pollutant.

Significance levels: $*: p < 0.05$ $**: p < 0.01$ $***: p < 0.001$

Table 6: IV regression results

	Criteria Pollutant					
	CO (ppm)	**NO_2 (ppb)**	**O_3 (ppm)**	**$PM_{2.5}$ ($\mu g/m^3$)**	**PM_{10} ($\mu g/m^3$)**	**SO_2 (ppb)**
Transit capacity	-0.0068	0.2177*	0.0000	0.0837	0.1310*	0.0868
(total vehicle revenue-miles, millions)	(0.0042)	(0.1029)	(0.0001)	(0.0580)	(0.0520)	(0.0812)
Auto capacity: freeways	-0.0212	-0.1179	-0.004*	-0.4596*	-0.2266	0.1863
(total lane-miles)	(0.0198)	(0.2798)	(0.0002)	(0.1950)	(0.1389)	(0.4043)
Auto capacity: arterials	-0.0139*	-0.0618	0.0000	-0.0320	-0.0506	-0.1330
(total lane-miles)	(0.0064)	(0.0988)	(0.0001)	(0.0641)	(0.0585)	(0.1391)
Fuel price	-3.2032***	-30.4933***	-0.0098*	2.3970	2.1891	-11.5386
($ per vehicle-mile)	(0.5638)	(8.6696)	(0.0048)	(7.6691)	(2.8652)	(11.9402)
Transit fare	-0.0301	0.0640	0.0002	-0.0261	-0.0446	-0.0735
($ per unlinked trip)	(0.0204)	(0.2097)	(0.0002)	(0.2518)	(0.0494)	(0.3581)
Income	-0.0337***	-0.4417**	0.0000	-0.1474	-0.2351***	-0.0813
(real per capita income)	(0.0083)	(0.1514)	(0.0001)	(0.0356)	(0.0554)	(0.1896)
Population	0.4372*	-4.6422	-0.0005	-0.5533	-1.3632	-4.1919
(millions)	(0.1799)	(3.4023)	(0.0019)	(2.0289)	(1.7430)	(3.0950)
Overall employment rate	2.7649**	48.3653***	0.0148	22.2628*	30.3506***	12.1851
(total employed per capita)	(0.9088)	(12.9118)	(0.0095)	(10.4412)	(6.1303)	(15.7562)
Manufacturing employment	-0.0007	0.0199	0.0000	0.0088	0.0128**	0.0125
(total employed in sector, thousands)	(0.0008)	(0.0153)	(0.0000)	(0.0120)	(0.0046)	(0.0142)
Agricultural employment	0.0042	0.1234	0.0001	0.0716	0.1354	0.1232
(total employed in sector, thousands)	(0.0062)	(0.0715)	(0.0001)	(0.0874)	(0.1102)	(0.2605)
Trucking employment	-0.0011	0.2158	0.0002	0.1017	0.0491	-0.3355
(total employed in sector, thousands)	(0.0079)	(0.0715)	(0.0001)	(0.1193)	(0.0577)	(0.2600)
Rain	-0.0032***	-0.0748***	-0.0000	-0.0438***	-0.0277***	-0.0190
(annual inches, hundreds)	(0.0008)	(0.0149)	(0.0000)	(0.0110)	(0.0052)	(0.0133)
Snow	0.0061	0.2440**	0.0000	0.0221	0.0280	0.0394
(annual inches, hundreds)	(0.0055)	(0.0840)	(0.0001)	(0.0625)	(0.0362)	(0.1122)
Heating degree days	-0.1096***	-1.0306*	-0.0012***	-0.7591*	0.1925	-0.7594
(thousands)	(0.0311	(0.4585)	(0.0003)	(0.2973)	(0.1560)	(0.4928)
Cooling degree days	-0.0109	-1.1999	0.0028***	0.2198	0.0450	-0.5180
(thousands)	(0.0364)	(0.0985)	(0.0006)	(0.4540)	(0.2302)	(0.5793)
NAAQS: 1998-2006	-0.3323***	-2.6621**	0.0003	-1.1058*	0.9673***	-2.0566*
($1998-2006 = 1$, otherwise $= 0$)	(0.0458)	(0.9534)	(0.0004)	(0.5540)	(0.1329)	(0.8625)
NAAQS: 2007-2011	-0.4830***	-5.1782***	-0.0003	-3.2735***	-	-5.1112***
($2007-2011 = 1$, otherwise $= 0$)	(0.0577)	(1.1105)	(0.0005)	(0.6514)		(1.0539)
UZA fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	1572	1290	1720	1629	1183	1386
R^2	0.705	0.545	0.153	0.311	0.534	0.394
First-stage test statistics						
First-stage AP F-stat, Transit Capacity	10.06	13.11	12.54	12.22	5.71	10.43
Kleibergen-Paap underidentification test: p-val.	0.042	0.042	0.016	0.020	0.271	0.031
Hansen J overidentification test: p-val.	0.639	0.027	0.658	0.035	0.548	0.167
Weak-instrument-robust inference						
Anderson-Rubin Wald F test: p-val.	0.510	0.106	0.891	0.043	0.019	0.189
Anderson-Rubin Wald χ^2 test: p-val.	0.500	0.090	0.890	0.034	0.013	0.171
Stock-Wright test: p-val.	0.268	0.007	0.245	0.045	0.015	0.224

Notes: Robust standard errors in parentheses; clustered by UZA. The dependent variables are the mean values of the daily maximum concentration level for the year for each pollutant. Transit instrumented by: (i) Democratic voting share within UZA, averaged over any Presidential, Gubernatorial or Senate elections occurring in the year prior, and (ii) Federal transit funding in UZA the previous year.

Significance levels: $*: p < 0.05$ $**: p < 0.01$ $***: p < 0.001$

on the underlying trends, the NAAQS standards have made a substantial difference in reducing pollution levels over the past two decades, with successively more stringent regulations leading to signficantly lower pollution levels (with ozone being the lone exception).

6 Conclusion

While there is potentially an additional co-benefit of public transit in reducing the emission externality associated with auto travel, this has not been the case for the large urban areas of the U.S. from 1991-2011. While there have been signficant improvements in air quality over this period, these reductions are not attributable to the large increase in transit service that occurred over this time. While public transit was shown by Beaudoin and Lin Lawell (2017) to have reduced auto travel modestly – relative to the level that would have been observed in the absence of this increased supply of transit – this effect has not manifested itself in air quality benefits.

Table 7 quantifies the relationship between transit supply and air quality to help interpret the results in Table 6. Of note, a 10% increase in transit supply is associated with a 2.29% increase in NO_2 concentration, and a 2.87% increase in PM_{10} concentration. Though not statistically signficant in our sample, the other point estimates are included as a point of reference.

Table 7: Transit Supply Elasticity of Ambient Pollution Concentration

Criteria Pollutant	**Elasticity**
CO	-0.169
NO_2	0.229*
O_3	0.015
$PM_{2.5}$	0.077
PM_{10}	0.287**
SO_2	0.255

Significance levels: $* : p < 0.05$ $** : p < 0.01$ $*** : p < 0.001$

There are several potential explanations for these results. First, the marginal emission externality of urban auto travel, given by $d \sum_{j \in \{A,T\}} \left[e_j + \frac{\partial e_j}{\partial V_A} V_j \right] c_j + Q \frac{\partial d}{\partial V_A}$, has generally been estimated to be of much less economic signficance than the marginal congestion externality: Small and Verhoef (2007, pp. 98) indicate that the marginal social cost of congestion is approximately 35 times the magnitude of the marginal social costs of emissions for urban auto travel. Second, transit generally emits pollutants at a higher rate than auto travel on a per vehicle-mile basis, with $e_{T,rt} \cdot c_{T,rt} > e_{A,rt} \cdot c_{A,rt}$. This is the case for North American buses which typically use diesel, and thus emit higher rates of NO_2 and PM.

Thus, if the aggregate modal travel volumes following an increase in transit capacity V_A^1 and V_T^1 do not differ significantly enough from the *ex ante* travel volumes V_A^0 and V_T^0 in terms of the modal distribution, then an increase in transit supply will not reduce aggregate emissions. Given the relatively low cross-elasticity of auto demand with respect to transit service and the induced demand inherent in the second-best urban travel setting, this is a strong possibility.

It should also be noted that due to the lack of direct emission data, the effects here are being measured in terms of ambient pollution. As the pollutants may be able to travel long distances (this is the case for particulate matter and ozone, in particular), there is a decoupling between the emissions in a region and the resulting measure of ambient pollution within that region's physical boundaries. Given available data, the analysis has been undertaken on a regional scale and via annual averages; it may be of interest to undertake a similar analysis at a finer spatial and/or temporal scale to see whether the effect of transit on air quality varies across these dimensions.

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8 Appendix - Supplementary Tables

Table A.1: Summary statistics: carbon monoxide (CO)

		Mean Daily Max. Level (ppm)					**Air Quality Index**				
Year	# UZAs	Mean	Median	St. Dev	Min	Max	Mean	Median	St. Dev	Min	Max
1991	88	1.75	1.63	0.70	0.64	4.19	19.80	18.54	7.87	7.22	46.95
1992	88	1.66	1.53	0.65	0.85	4.16	18.87	17.36	7.33	9.71	46.50
1993	90	1.58	1.44	0.56	0.87	3.80	17.89	16.39	6.30	9.90	42.78
1994	90	1.56	1.42	0.55	0.82	3.25	17.72	16.15	6.14	9.32	36.71
1995	90	1.43	1.29	0.49	0.63	2.93	16.18	14.69	5.58	7.11	33.15
1996	91	1.32	1.18	0.48	0.58	3.37	15.00	13.43	5.44	6.51	37.80
1997	90	1.26	1.11	0.47	0.56	2.65	14.30	12.67	5.31	6.16	30.01
1998	90	1.23	1.15	0.46	0.40	3.21	13.99	13.07	5.26	4.37	36.22
1999	90	1.19	1.13	0.43	0.43	2.74	13.51	12.91	4.92	4.77	30.94
2000	89	1.06	0.99	0.42	0.40	2.46	12.12	11.28	4.76	4.36	27.94
2001	89	1.02	0.94	0.40	0.41	2.37	11.55	10.64	4.55	4.61	26.86
2002	88	0.93	0.84	0.35	0.39	2.04	10.62	9.65	3.99	4.36	23.15
2003	87	0.89	0.80	0.32	0.38	2.01	10.14	9.09	3.60	4.13	22.89
2004	87	0.81	0.70	0.31	0.31	1.96	9.16	7.94	3.55	3.23	22.26
2005	87	0.77	0.67	0.30	0.31	1.83	8.71	7.64	3.44	3.14	20.80
2006	85	0.72	0.66	0.27	0.30	1.59	8.11	7.53	3.08	3.00	18.15
2007	82	0.64	0.61	0.23	0.19	1.38	7.19	6.94	2.67	1.95	15.78
2008	77	0.58	0.53	0.22	0.22	1.44	6.45	5.99	2.53	2.21	16.31
2009	78	0.54	0.50	0.19	0.08	1.34	5.99	5.59	2.28	0.83	15.34
2010	82	0.49	0.46	0.18	0.10	1.41	5.51	5.10	2.09	1.02	16.07
2011	78	0.47	0.45	0.16	0.17	1.16	5.22	5.03	1.84	1.77	13.23

Source: US Environmental Protection Agency (EPA) - Air Quality System

Table A.2: Carbon monoxide (CO) emissions in 2011: short tons (National)

Source Sector	**Total Emissions**		**% of Total**	
Mobile	42,304,259		52.5%	
On-Road		***27,355,395***		***33.9%***
Non-Road		14,318,316		17.8%
Aircraft		423,022		0.5%
Locomotives		131,713		0.2%
Commercial Marine Vessels		75,813		0.1%
Fires	23,757,042		29.5%	
Wildfires		12,701,426		15.8%
Prescribed Fires		10,091,996		12.5%
Agricultural Field Burning		963,620		1.2%
Biogenics	6,841,519		8.5%	
Vegetation and Soil		6,841,519		8.5%
Fuel Combustion	4,449,598		5.5%	
Residential		2,687,650		3.3%
Electric Generation		779,353		1.0%
Industrial Boilers (Internal Combustion Engines)		499,289		0.6%
Industrial Boilers		321,166		0.4%
Commercial/Institutional		162,140		0.2%
Industrial Processes	2,078,217		2.6%	
Oil and Gas Production		652,699		0.8%
Ferrous Metals		417,318		0.5%
Non-ferrous Metals		329,617		0.4%
Not Elsewhere Classified		208,414		0.3%
Chemical Manufacturing		185,440		0.2%
Pulp and Paper		106,266		0.1%
Cement Manufacturing		76,821		0.1%
Petroleum Refineries		49,712		0.1%
Mining		32,545		0.0%
Storage and Transfer		19,384		0.0%
Miscellaneous	1,156,002		1.4%	
Waste Disposal		1,112,811		1.4%
Commercial Cooking		31,378		0.0%
Miscellaneous Non-Industrial, Not Elsewhere Classified		11,013		0.0%
Bulk Gasoline Terminals		755		0.0%
Gas Stations		44		0.0%
Solvent, Agriculture & Dust	4,067		<1%	
Total	**80,590,919**		**-**	

Source: US Environmental Protection Agency (EPA) - National Emission Inventory (NEI)

Table A.3: Summary statistics: nitrogen dioxide (NO_2)

		Mean Daily Max. Level (ppb)					**Air Quality Index**				
Year	# UZAs	Mean	Median	St. Dev	Min	Max	Mean	Median	St. Dev	Min	Max
1991	67	35.01	35.20	10.85	4.02	69.08	33.07	33.27	10.23	3.80	62.59
1992	70	33.94	34.50	9.66	11.39	62.57	32.07	32.65	9.16	10.69	58.38
1993	70	34.06	34.08	9.83	13.41	58.59	32.15	32.21	9.28	12.68	55.05
1994	71	34.21	33.87	9.93	10.57	62.82	32.34	32.01	9.46	9.99	58.84
1995	70	33.44	33.04	9.10	11.47	61.60	31.55	31.21	8.53	10.79	57.21
1996	72	32.49	32.15	8.74	5.15	55.48	30.71	30.12	8.34	4.92	52.41
1997	72	31.72	31.10	8.93	10.25	64.66	29.99	29.40	8.59	9.66	62.59
1998	71	31.41	31.90	8.41	9.55	51.97	29.65	30.10	7.92	9.07	49.59
1999	72	32.02	32.54	8.21	9.79	55.39	30.24	30.74	7.73	9.25	52.63
2000	74	29.77	30.54	7.94	10.32	50.84	28.07	28.88	7.45	9.73	48.41
2001	74	29.46	30.02	8.15	9.80	48.71	27.85	28.39	7.75	9.29	46.36
2002	71	29.06	29.49	8.34	9.68	47.53	27.45	27.62	7.91	9.21	45.06
2003	71	28.12	28.51	7.96	9.25	50.34	26.58	26.91	7.56	8.83	47.98
2004	71	26.02	26.77	7.65	7.18	42.22	24.57	25.27	7.25	6.84	39.98
2005	71	26.75	26.95	7.21	9.66	43.91	25.27	25.42	6.84	9.20	41.60
2006	70	25.78	24.94	7.12	8.58	44.28	24.34	23.56	6.74	8.19	41.89
2007	70	24.92	24.37	7.43	6.96	43.95	23.53	22.97	7.03	6.68	41.71
2008	70	23.30	23.37	7.44	2.94	39.56	21.99	22.06	7.05	2.49	37.50
2009	70	21.69	21.86	6.79	1.85	35.56	20.42	20.61	6.44	1.41	33.60
2010	70	21.31	21.07	6.76	2.15	38.83	20.02	19.83	6.39	1.67	36.72
2011	69	21.69	21.18	6.78	5.80	41.16	20.29	19.55	6.41	5.15	38.98

Source: US Environmental Protection Agency (EPA) - Air Quality System

Table A.4: Nitrogen oxides (NO_x) emissions in 2011: short tons (National)

Source Sector	**Total Emissions**		**% of Total**	
Mobile	8,951,727		57.9%	
On-Road		***5,870,346***		***38.0%***
Non-Road		1,656,902		10.7%
Locomotives		865,376		5.6%
Commercial Marine Vessels		448,481		2.9%
Aircraft		110,621		0.7%
Fuel Combustion	3,699,228		23.9%	
Electric Generation		2,024,919		13.1%
Industrial Boilers (Internal Combustion Engines)		842,864		5.5%
Residential		334,705		2.2%
Industrial Boilers		249,966		1.6%
Commercial/Institutional		246,774		1.6%
Industrial Processes	1,307,837		8.5%	
Oil and Gas Production		667,583		4.3%
Not Elsewhere Classified		179,883		1.2%
Cement Manufacturing		119,489		0.8%
Petroleum Refineries		75,829		0.5%
Chemical Manufacturing		75,191		0.5%
Pulp and Paper		71,145		0.5%
Ferrous Metals		55,502		0.4%
Mining		32,947		0.2%
Non-ferrous Metals		15,159		0.1%
Storage and Transfer		15,111		0.1%
Biogenics	1,020,946		6.6%	
Vegetation and Soil		1,020,946		6.6%
Fires	396,179		2.6%	
Wildfires		184,802		1.2%
Prescribed Fires		168,204		1.1%
Agricultural Field Burning		43,172		0.3%
Solvent, Agriculture, Dust & Miscellaneous	86,537		<1%	
Total	**15,465,216**		**-**	

Source: US Environmental Protection Agency (EPA) - National Emission Inventory (NEI)

Table A.5: Summary statistics: ozone (O_3)

		Mean Daily Max. Level (ppm)					**Air Quality Index**				
Year	# UZAs	Mean	Median	St. Dev	Min	Max	Mean	Median	St. Dev	Min	Max
1991	90	0.042	0.041	0.007	0.021	0.060	40.86	38.21	9.25	17.35	71.39
1992	90	0.040	0.040	0.006	0.025	0.058	37.43	36.13	7.63	20.98	69.07
1993	91	0.041	0.041	0.007	0.024	0.059	39.41	37.53	9.95	20.17	67.89
1994	91	0.043	0.042	0.006	0.029	0.058	40.53	40.22	8.57	24.75	70.38
1995	92	0.043	0.043	0.006	0.026	0.056	41.97	42.06	8.45	21.80	65.02
1996	94	0.043	0.043	0.007	0.020	0.059	40.43	40.11	9.04	16.92	66.61
1997	94	0.043	0.043	0.007	0.025	0.059	40.72	39.25	8.83	21.28	64.50
1998	94	0.045	0.044	0.007	0.027	0.062	44.12	41.36	10.48	23.00	72.59
1999	94	0.045	0.046	0.007	0.026	0.060	44.15	42.89	9.99	22.13	70.17
2000	94	0.043	0.043	0.006	0.021	0.054	40.00	39.78	7.92	17.89	62.33
2001	95	0.044	0.045	0.006	0.024	0.058	41.61	41.40	8.36	20.04	68.19
2002	95	0.044	0.044	0.006	0.025	0.058	42.94	42.04	9.21	21.17	69.29
2003	95	0.043	0.044	0.005	0.021	0.056	40.21	39.97	6.75	18.16	62.59
2004	95	0.041	0.041	0.005	0.023	0.053	37.20	36.80	5.86	19.07	58.08
2005	95	0.044	0.045	0.006	0.023	0.055	40.76	41.02	6.82	19.75	54.63
2006	95	0.043	0.044	0.006	0.018	0.055	40.03	40.12	6.42	15.57	56.80
2007	95	0.044	0.044	0.007	0.018	0.056	40.30	39.68	7.98	14.79	56.55
2008	95	0.042	0.042	0.005	0.023	0.053	37.81	37.14	5.99	19.63	55.70
2009	95	0.040	0.040	0.004	0.026	0.051	34.83	34.54	4.62	21.78	51.57
2010	96	0.042	0.042	0.006	0.025	0.052	37.52	36.63	5.91	21.17	50.46
2011	96	0.042	0.042	0.005	0.025	0.052	37.49	37.17	5.81	21.54	52.83

Source: US Environmental Protection Agency (EPA) - Air Quality System

Table A.6: Volatile organic compounds (VOC) emissions in 2011: short tons (National)

Source Sector	**Total Emissions**		**% of Total**	
Biogenics	40,727,602		69.2%	
Vegetation and Soil		40,727,602		69.2%
Fires	5,286,919		9.0%	
Wildfires		2,891,271		4.9%
Prescribed Fires		2,320,330		3.9%
Agricultural Field Burning		75,318		0.1%
Mobile	4,799,261		8.2%	
On-Road		***2,642,225***		***4.5%***
Non-Road		2,068,121		3.5%
Locomotives		45,752		0.1%
Aircraft		29,612		0.1%
Commercial Marine Vessels		13,551		0.0%
Industrial Processes	3,464,983		5.9%	
Oil and Gas Production		2,728,115		4.6%
Storage and Transfer		235,702		0.4%
Not Elsewhere Classified		195,119		0.3%
Pulp and Paper		116,790		0.2%
Chemical Manufacturing		95,907		0.2%
Petroleum Refineries		54,983		0.1%
Ferrous & Non-ferrous Metals		32,367		0.1%
Cement Manufacturing & Mining		5,999		0.0%
Solvent	2,811,220		4.8%	
Consumer and Commercial Use		1,676,425		2.8%
Industrial Surface Coating and Use		571,191		1.0%
Non-Industrial Surface Coating		333,997		0.6%
Degreasing		148,325		0.3%
Graphic Arts		72,471		0.1%
Dry Cleaning		8,811		0.0%
Miscellaneous	1,182,853		2.0%	
Gas Stations		685,906		1.2%
Miscellaneous Non-Industrial, Not Elsewhere Classified		201,352		0.3%
Bulk Gasoline Terminals		156,902		0.3%
Waste Disposal		125,404		0.2%
Commercial Cooking		13,288		0.0%
Fuel Combustion	604,941		1.0%	
Residential		461,213		0.8%
Industrial Boilers (Internal Combustion Engines)		78,201		0.1%
Electric Generation		40,482		0.1%
Commercial/Institutional		14,318		0.0%
Industrial Boilers		10,728		0.0%
Agriculture & Dust	191		<1%	
Total	**58,878,011**		**-**	

Source: US Environmental Protection Agency (EPA) - National Emission Inventory (NEI)

Table A.7: Summary statistics: particulate matter 2.5 ($PM_{2.5}$)

		Mean Daily Max. Level ($\mu g/m^3$)					**Air Quality Index**				
Year	# UZAs	Mean	Median	St. Dev	Min	Max	Mean	Median	St. Dev	Min	Max
1991	–			–					–		
1992	–			–					–		
1993	–			–					–		
1994	–			–					–		
1995	–			–					–		
1996	–			–					–		
1997	–			–					–		
1998	–			–					–		
1999	92	13.62	13.46	3.80	4.49	24.52	48.65	48.90	10.70	18.63	69.81
2000	96	13.16	12.94	3.31	4.01	20.44	47.63	48.03	9.70	16.69	64.72
2001	96	12.76	12.48	3.24	4.02	21.21	46.40	46.50	9.43	16.76	68.35
2002	96	12.26	12.19	3.09	3.93	19.93	45.07	44.41	9.17	16.39	63.73
2003	96	12.00	12.01	2.76	4.17	17.75	44.49	44.78	8.52	17.36	59.22
2004	93	11.74	11.56	2.60	3.68	16.94	43.70	44.37	8.19	15.35	58.43
2005	96	12.39	12.34	2.99	4.08	17.72	45.36	45.52	9.17	16.55	60.15
2006	96	11.35	11.68	2.61	4.08	16.87	42.52	43.90	8.34	16.07	56.60
2007	96	11.56	11.32	2.84	3.34	20.10	43.01	43.90	8.34	13.58	63.18
2008	96	10.73	10.81	2.41	3.54	19.09	40.93	41.55	7.73	14.10	61.79
2009	96	9.69	9.61	1.94	5.07	15.35	37.66	38.10	6.44	21.13	51.40
2010	96	9.71	9.93	2.14	4.41	14.39	37.71	38.58	7.38	18.34	51.81
2011	96	9.80	9.84	1.88	4.67	14.74	37.95	38.32	6.45	19.08	49.93

Source: US Environmental Protection Agency (EPA) - Air Quality System

Table A.8: Particulate matter 2.5 ($PM_{2.5}$) emissions in 2011: short tons (National)

Source Sector	**Total Emissions**		**% of Total**	
Fires	2,123,637		34.9%	
Wildfires		1,125,176		18.5%
Prescribed Fires		903,062		14.8%
Agricultural Field Burning		95,400		1.6%
Dust	1,263,689		20.7%	
Unpaved Road Dust		832,071		13.7%
Paved Road Dust		269,016		4.4%
Construction Dust		162,603		2.7%
Agriculture	896,725		14.7%	
Crops and Livestock Dust		896,538		14.7%
Livestock Waste		187		0.0%
Fuel Combustion	818,406		13.4%	
Residential		392,522		6.4%
Electric Generation		200,197		3.3%
Industrial Boilers		142,320		2.3%
Industrial Boilers (Internal Combustion Engines)		58,164		1.0%
Commercial/Institutional		25,203		0.4%
Mobile	408,014		6.7%	
On-Road		***197,528***		***3.2%***
Non-Road		157,355		2.6%
Locomotives		25,926		0.4%
Commercial Marine Vessels		19,872		0.3%
Aircraft		7,334		0.1%
Industrial Processes	324,458		5.3%	
Not Elsewhere Classified		89,419		1.5%
Mining		73,567		1.2%
Pulp and Paper		33,137		0.5%
Ferrous Metals		28,617		0.5%
Petroleum Refineries		21,352		0.4%
Chemical Manufacturing		19,679		0.3%
Storage and Transfer		18,963		0.3%
Oil and Gas Production		17,382		0.3%
Non-ferrous Metals		15,804		0.3%
Cement Manufacturing		6,538		0.1%
Miscellaneous	251,794		4.1%	
Waste Disposal		164,968		2.7%
Commercial Cooking		84,689		1.4%
Miscellaneous Non-Industrial, Not Elsewhere Classified		2,116		0.0%
Bulk Gasoline Terminals		19		0.0%
Gas Stations		2		0.0%
Solvent	4,059		<1%	
Total	**6,090,782**		**-**	

Source: US Environmental Protection Agency (EPA) - National Emission Inventory (NEI)

Table A.9: Summary statistics: particulate matter 10 (PM_{10})

		Mean Daily Max. Level ($\mu g/m^3$)					Air Quality Index				
Year	# UZAs	Mean	Median	St. Dev	Min	Max	Mean	Median	St. Dev	Min	Max
1991	91	30.90	30.46	7.26	18.00	55.05	27.81	27.10	5.68	16.59	44.99
1992	92	27.97	27.75	5.74	16.86	45.40	25.41	25.22	4.80	15.51	39.88
1993	92	27.32	26.45	5.74	14.90	43.86	24.78	24.23	4.80	13.73	37.29
1994	93	26.88	26.07	5.93	12.55	43.21	24.47	23.80	5.06	11.45	37.87
1995	93	26.02	25.26	6.00	15.38	42.63	23.68	23.30	5.04	14.22	36.73
1996	94	25.26	24.43	5.65	15.00	42.95	23.07	22.45	4.85	13.89	37.07
1997	92	25.42	24.47	5.85	12.54	53.27	23.16	22.52	4.88	11.56	44.44
1998	89	25.73	25.61	5.71	14.17	48.72	23.45	23.36	4.81	13.08	41.00
1999	88	26.33	24.55	6.51	14.08	45.75	23.92	22.69	5.41	13.03	39.41
2000	91	25.76	24.64	6.06	14.97	48.93	23.49	22.65	5.12	13.81	41.63
2001	91	25.14	23.62	5.75	15.40	42.18	22.93	21.72	4.89	14.21	36.43
2002	90	24.47	22.80	6.62	14.41	43.62	22.32	21.10	5.69	13.24	38.09
2003	90	24.61	24.00	6.42	14.73	43.01	22.41	21.95	5.42	13.64	37.47
2004	89	23.45	22.55	5.67	13.45	39.22	21.43	20.72	4.90	12.39	34.07
2005	88	24.32	23.87	5.86	12.85	46.14	22.20	21.98	4.96	11.92	39.16
2006	86	24.74	23.29	7.67	14.90	66.98	22.44	21.46	6.14	13.78	52.58
2007	86	24.36	23.57	6.80	14.32	59.19	22.19	21.77	5.60	13.20	47.89
2008	86	22.64	20.93	6.33	11.81	48.68	20.65	19.28	5.35	10.91	40.49
2009	86	20.36	19.17	5.43	10.96	42.97	18.69	17.60	4.76	10.17	37.08
2010	87	20.44	20.15	4.97	10.48	34.76	18.78	18.66	4.41	9.72	30.64
2011	88	20.48	19.54	5.93	8.54	40.95	18.78	18.05	5.23	7.85	35.34

Source: US Environmental Protection Agency (EPA) - Air Quality System

Table A.10: Particulate matter 10 (PM_{10}) emissions in 2011: short tons (National)

Source Sector	**Total Emissions**		**% of Total**	
Dust	10,969,412		53.0%	
Unpaved Road Dust		8,329,439		40.2%
Construction Dust		1,509,686		7.3%
Paved Road Dust		1,130,287		5.5%
Agriculture	4,502,007		21.8%	
Crops and Livestock Dust		4,501,667		21.8%
Livestock Waste		339		0.0%
Fires	2,531,444		12.2%	
Wildfires		1,325,991		6.4%
Prescribed Fires		1,063,159		5.1%
Agricultural Field Burning		142,295		0.7%
Fuel Combustion	950,077		4.6%	
Residential		395,692		1.9%
Electric Generation		272,538		1.3%
Industrial Boilers		186,449		0.9%
Industrial Boilers (Internal Combustion Engines)		63,250		0.3%
Commercial/Institutional		32,148		0.2%
Industrial Processes	861,531		4.2%	
Mining		483,920		2.3%
Not Elsewhere Classified		149,591		0.7%
Storage and Transfer		51,248		0.2%
Pulp and Paper		41,482		0.2%
Ferrous Metals		34,856		0.2%
Chemical Manufacturing		25,065		0.1%
Petroleum Refineries		24,368		0.1%
Non-ferrous Metals		20,032		0.1%
Oil and Gas Production		18,929		0.1%
Cement Manufacturing		12,039		0.1%
Mobile	594,233		2.9%	
On-Road		***370,826***		***1.8%***
Non-Road		165,337		0.8%
Locomotives		27,926		0.1%
Commercial Marine Vessels		21,519		0.1%
Aircraft		8,626		0.0%
Miscellaneous	283,085		1.4%	
Waste Disposal		191,962		0.9%
Commercial Cooking		88,846		0.4%
Miscellaneous Non-Industrial, Not Elsewhere Classified		2,253		0.0%
Bulk Gasoline Terminals		22		0.0%
Gas Stations		2		0.0%
Solvent	4,559		<1%	
Total	**20,696,348**		**-**	

Source: US Environmental Protection Agency (EPA) - National Emission Inventory (NEI)

Table A.11: Summary statistics: sulfur dioxide (SO_2)

		Mean Daily Max. Level (ppb)					**Air Quality Index**				
Year	# UZAs	Mean	Median	St. Dev	Min	Max	Mean	Median	St. Dev	Min	Max
1991	79	18.77	18.87	12.16	2.02	62.87	24.45	26.13	14.18	2.77	62.68
1992	77	18.38	17.48	12.38	0.87	75.36	23.90	24.15	13.86	1.21	74.05
1993	79	17.58	16.41	11.37	1.87	56.28	23.10	23.14	13.41	2.61	58.27
1994	79	15.59	14.92	9.47	0.70	44.39	20.86	20.63	11.98	0.99	54.63
1995	79	13.22	12.54	8.16	0.25	41.88	17.94	17.20	10.46	0.35	50.07
1996	79	13.27	12.37	7.96	0.68	35.22	17.91	17.58	10.22	0.93	44.79
1997	77	13.62	13.28	8.06	0.01	34.37	18.42	18.41	10.34	0.01	44.96
1998	76	13.50	12.64	7.87	0.27	34.20	18.41	17.79	10.27	0.38	45.85
1999	77	12.71	12.80	7.25	1.61	32.51	17.35	18.09	9.51	2.26	42.77
2000	77	11.96	11.60	7.21	0.24	28.88	16.32	16.41	9.41	0.27	38.14
2001	76	11.63	11.27	6.79	0.86	31.65	15.97	15.82	9.01	1.19	42.28
2002	75	10.88	10.24	6.84	0.88	31.71	14.91	14.57	8.99	1.14	41.86
2003	77	10.45	9.54	6.65	0.70	29.32	14.34	12.88	8.81	0.95	38.02
2004	76	10.15	9.27	6.85	0.63	33.76	13.88	13.09	8.94	0.76	40.77
2005	75	10.42	9.49	6.57	0.87	30.58	14.30	13.27	8.67	1.18	38.64
2006	74	9.07	8.31	5.81	0.90	22.41	12.44	11.86	7.68	1.12	29.48
2007	74	8.76	7.99	6.04	1.00	28.54	11.90	11.30	7.73	1.42	31.05
2008	73	7.56	5.61	5.35	0.13	23.68	10.19	7.46	6.83	0.18	26.58
2009	73	5.94	5.02	4.34	0.93	23.67	7.89	6.66	5.51	0.79	25.96
2010	74	5.29	4.14	3.97	0.54	18.31	7.01	5.17	5.28	0.60	21.23
2011	78	4.84	3.66	4.16	0.61	27.34	6.16	4.68	5.14	0.41	28.08

Source: US Environmental Protection Agency (EPA) - Air Quality System

Table A.12: Sulfur dioxide (SO_2) emissions in 2011: short tons (National)

Source Sector	**Total Emissions**		**% of Total**	
Fuel Combustion	5,424,306		84.0%	
Electric Generation		4,607,653		71.3%
Industrial Boilers		429,469		6.6%
Industrial Boilers (Internal Combustion Engines)		159,458		2.5%
Commercial/Institutional		118,547		1.8%
Residential		109,179		1.7%
Industrial Processes	667,150		10.3%	
Not Elsewhere Classified		138,929		2.2%
Chemical Manufacturing		133,342		2.1%
Non-ferrous Metals		102,887		1.6%
Petroleum Refineries		86,156		1.3%
Oil and Gas Production		74,136		1.1%
Cement Manufacturing		60,056		0.9%
Pulp and Paper		32,035		0.5%
Ferrous Metals		28,594		0.4%
Storage and Transfer		8,972		0.1%
Mining		2,043		0.0%
Fires	195,494		3.0%	
Wildfires		95,837		1.5%
Prescribed Fires		83,255		1.3%
Agricultural Field Burning		16,402		0.3%
Mobile	156,599		2.4%	
Commercial Marine Vessels		100,235		1.6%
On-Road		***29,465***		***0.5%***
Aircraft		13,642		0.2%
Locomotives		8,529		0.1%
Non-Road		4,729		0.1%
Solvent, Dust, Agriculture & Miscellaneous	17,406		<1%	
Total	**6,460,955**		**-**	

Source: US Environmental Protection Agency (EPA) - National Emission Inventory (NEI)

Table A.13: Mean carbon monoxide (CO) concentration by UZA, 2011

UZA	**CO (ppm)**	**UZA**	**CO (ppm)**
Anchorage, AK	1.1601	Cincinnati, OH-KY-IN	0.4055
Spokane, WA-ID	0.9127	Atlanta, GA	0.4043
Los Angeles - Long Beach - Santa Ana, CA	0.8883	Raleigh - Durham, NC	0.3855
Laredo, TX	0.7669	Memphis, TN-MS-AR	0.3849
Winston - Salem, NC	0.7000	New York - Newark, NY-NJ-CT	0.3837
Hartford, CT	0.6923	Columbus, OH	0.3825
Philadelphia, PA-NJ-DE-MD	0.6733	Stockton, CA	0.3820
Cleveland, OH	0.6723	Virginia Beach, VA	0.3820
San Diego, CA	0.6336	Jackson, MS	0.3804
Little Rock, AR	0.5960	Pensacola, FL-AL	0.3736
Minneapolis - St. Paul, MN	0.5882	Grand Rapids, MI	0.3713
Washington, DC-VA-MD	0.5848	Tulsa, OK	0.3650
Houston, TX	0.5846	Allentown - Bethlehem, PA-NJ	0.3648
Jacksonville, FL	0.5707	Dallas - Fort Worth - Arlington, TX	0.3625
Albuquerque, NM	0.5624	Dayton, OH	0.3531
Chicago, IL-IN	0.5623	Albany, NY	0.3497
New Orleans, LA	0.5615	Milwaukee, WI	0.3416
Colorado Springs, CO	0.5562	Honolulu, HI	0.3414
Worcester, MA-CT	0.5510	Boston, MA-NH-RI	0.3291
Las Vegas, NV	0.5298	Poughkeepsie - Newburgh, NY	0.3287
Rochester, NY	0.5243	Akron, OH	0.3271
El Paso, TX-NM	0.5233	Seattle, WA	0.3147
Pittsburgh, PA	0.5192	Indianapolis, IN	0.3147
Denver - Aurora, CO	0.5129	Baton Rouge, LA	0.3125
Salt Lake City, UT	0.5029	Brownsville, TX	0.3125
Birmingham, AL	0.5019	Columbia, SC	0.3048
St. Louis, MO-IL	0.4980	Austin, TX	0.3032
Richmond, VA	0.4864	Riverside - San Bernardino, CA	0.2662
Omaha, NE-IA	0.4753	Kansas City, MO-KS	0.2354
Providence, RI-MA	0.4744	Beaumont, TX	0.1738
San Jose, CA	0.4714	Bakersfield, CA	-
Buffalo, NY	0.4710	Cape Coral, FL	-
Springfield, MA-CT	0.4659	Charleston - North Charleston, SC	-
San Francisco - Oakland, CA	0.4656	Corpus Christi, TX	-
Fresno, CA	0.4624	Eugene, OR	-
Bridgeport - Stamford, CT-NY	0.4598	Greensboro, NC	-
Detroit, MI	0.4561	Knoxville, TN	-
Phoenix - Mesa, AZ	0.4555	Louisville, KY-IN	-
Baltimore, MD	0.4525	Madison, WI	-
Charlotte, NC-SC	0.4499	Miami, FL	-
Oklahoma City, OK	0.4454	New Haven, CT	-
Boise, ID	0.4279	Orlando, FL	-
Wichita, KS	0.4216	Oxnard, CA	-
Nashville - Davidson, TN	0.4214	Portland, OR-WA	-
Toledo, OH-MI	0.4213	Salem, OR	-
McAllen, TX	0.4208	San Antonio, TX	-
Tucson, AZ	0.4206	Sarasota - Bradenton, FL	-
Sacramento, CA	0.4176	Tampa - St. Petersburg, FL	-
		Mean	*0.4693*

Note: Mean pollution concentrations are the mean values of the daily maximum pollution levels over 2011.

Table A.14: Mean nitrogen dioxide (NO_2) concentration by UZA, 2011

UZA	**NO2 (ppb)**	**UZA**	**NO2 (ppb)**
Denver - Aurora, CO	41.1561	Rochester, NY	18.6077
Philadelphia, PA-NJ-DE-MD	35.3749	Riverside - San Bernardino, CA	18.5709
El Paso, TX-NM	33.8065	Honolulu, HI	18.0726
Salt Lake City, UT	32.8446	Pittsburgh, PA	17.7894
Chicago, IL-IN	32.3500	Virginia Beach, VA	17.5390
New Orleans, LA	32.3325	Cincinnati, OH-KY-IN	17.2920
Little Rock, AR	31.5261	Dallas - Fort Worth - Arlington, TX	17.0438
Nashville - Davidson, TN	30.6546	Milwaukee, WI	16.5388
Worcester, MA-CT	29.7356	Baton Rouge, LA	16.4761
Baltimore, MD	29.3034	Poughkeepsie - Newburgh, NY	15.3530
Richmond, VA	28.9062	Atlanta, GA	15.0202
Albuquerque, NM	28.7833	Memphis, TN-MS-AR	14.8213
Pensacola, FL-AL	28.1399	Columbia, SC	14.7050
Cleveland, OH	27.7944	Omaha, NE-IA	13.6124
Detroit, MI	26.9292	Stockton, CA	13.4555
Toledo, OH-MI	26.6838	Beaumont, TX	13.1448
Bridgeport - Stamford, CT-NY	26.4665	Charleston - North Charleston, SC	12.5985
Allentown - Bethlehem, PA-NJ	25.9145	San Antonio, TX	11.1165
Bakersfield, CA	24.8289	Tulsa, OK	9.1531
Miami, FL	24.8262	Sarasota - Bradenton, FL	6.8405
San Diego, CA	24.3978	Austin, TX	5.7979
Laredo, TX	24.1896	Akron, OH	-
Minneapolis - St. Paul, MN	24.0411	Albany, NY	-
McAllen, TX	23.0660	Anchorage, AK	-
Houston, TX	23.0276	Birmingham, AL	-
Washington, DC-VA-MD	22.9993	Brownsville, TX	-
Phoenix - Mesa, AZ	22.8794	Cape Coral, FL	-
Las Vegas, NV	22.8601	Colorado Springs, CO	-
Charlotte, NC-SC	22.3362	Columbus, OH	-
Hartford, CT	22.2890	Corpus Christi, TX	-
San Jose, CA	22.2785	Dayton, OH	-
New Haven, CT	21.6829	Eugene, OR	-
Boston, MA-NH-RI	21.4999	Grand Rapids, MI	-
St. Louis, MO-IL	21.3352	Greensboro, NC	-
Buffalo, NY	21.1787	Indianapolis, IN	-
San Francisco - Oakland, CA	20.8895	Kansas City, MO-KS	-
Tucson, AZ	20.7164	Knoxville, TN	-
Fresno, CA	20.4430	Los Angeles - Long Beach - Santa Ana, CA	-
Raleigh - Durham, NC	20.0605	Louisville, KY-IN	-
Jacksonville, FL	19.9518	Madison, WI	-
New York - Newark, NY-NJ-CT	19.9278	Oklahoma City, OK	-
Sacramento, CA	19.6549	Oxnard, CA	-
Winston - Salem, NC	19.1647	Portland, OR-WA	-
Springfield, MA-CT	18.9924	Providence, RI-MA	-
Boise, ID	18.8074	Salem, OR	-
Wichita, KS	18.7345	Seattle, WA	-
Jackson, MS	18.7135	Spokane, WA-ID	-
Orlando, FL	18.6806	Tampa - St. Petersburg, FL	-
		Mean	*21.6914*

Note: Mean pollution concentrations are the mean values of the daily maximum pollution levels over 2011.

Table A.15: Mean ozone (O_3) concentration by UZA, 2011

UZA	**O3 (ppm)**	**UZA**	**O3 (ppm)**
Richmond, VA	0.0520	Poughkeepsie - Newburgh, NY	0.0419
Fresno, CA	0.0508	San Diego, CA	0.0417
Greensboro, NC	0.0508	Cleveland, OH	0.0416
Bakersfield, CA	0.0499	Tampa - St. Petersburg, FL	0.0415
Winston - Salem, NC	0.0494	New Haven, CT	0.0415
Colorado Springs, CO	0.0491	Worcester, MA-CT	0.0415
Laredo, TX	0.0490	Charleston - North Charleston, SC	0.0414
Philadelphia, PA-NJ-DE-MD	0.0487	Little Rock, AR	0.0414
Kansas City, MO-KS	0.0484	Baton Rouge, LA	0.0413
Denver - Aurora, CO	0.0478	Las Vegas, NV	0.0408
Salt Lake City, UT	0.0475	Omaha, NE-IA	0.0407
Atlanta, GA	0.0473	Buffalo, NY	0.0406
Minneapolis - St. Paul, MN	0.0472	Stockton, CA	0.0402
New York - Newark, NY-NJ-CT	0.0472	Jackson, MS	0.0402
Albuquerque, NM	0.0471	Akron, OH	0.0401
Charlotte, NC-SC	0.0466	Miami, FL	0.0399
Virginia Beach, VA	0.0466	Pensacola, FL-AL	0.0398
Toledo, OH-MI	0.0466	Phoenix - Mesa, AZ	0.0397
Boise, ID	0.0465	Nashville - Davidson, TN	0.0391
Tucson, AZ	0.0465	Springfield, MA-CT	0.0390
Los Angeles - Long Beach - Santa Ana, CA	0.0464	Beaumont, TX	0.0390
Orlando, FL	0.0462	St. Louis, MO-IL	0.0390
Providence, RI-MA	0.0461	Oklahoma City, OK	0.0389
Cincinnati, OH-KY-IN	0.0461	Milwaukee, WI	0.0387
Raleigh - Durham, NC	0.0459	Knoxville, TN	0.0386
Bridgeport - Stamford, CT-NY	0.0459	Honolulu, HI	0.0386
McAllen, TX	0.0458	Sarasota - Bradenton, FL	0.0385
Birmingham, AL	0.0458	Grand Rapids, MI	0.0382
Baltimore, MD	0.0458	Boston, MA-NH-RI	0.0381
Columbia, SC	0.0457	New Orleans, LA	0.0381
Columbus, OH	0.0457	Cape Coral, FL	0.0375
Houston, TX	0.0451	Corpus Christi, TX	0.0373
Dayton, OH	0.0449	Chicago, IL-IN	0.0373
Wichita, KS	0.0444	Portland, OR-WA	0.0370
Austin, TX	0.0444	Allentown - Bethlehem, PA-NJ	0.0368
Dallas - Fort Worth - Arlington, TX	0.0443	Albany, NY	0.0365
Sacramento, CA	0.0443	San Jose, CA	0.0362
Washington, DC-VA-MD	0.0439	Memphis, TN-MS-AR	0.0359
Jacksonville, FL	0.0437	Eugene, OR	0.0355
Detroit, MI	0.0435	Brownsville, TX	0.0346
El Paso, TX-NM	0.0435	Salem, OR	0.0345
Hartford, CT	0.0431	Louisville, KY-IN	0.0321
Oxnard, CA	0.0430	Seattle, WA	0.0320
Madison, WI	0.0430	Riverside - San Bernardino, CA	0.0319
Rochester, NY	0.0428	Pittsburgh, PA	0.0311
Indianapolis, IN	0.0425	San Francisco - Oakland, CA	0.0306
Spokane, WA-ID	0.0422	Tulsa, OK	0.0281
San Antonio, TX	0.0421	Anchorage, AK	0.0254
		Mean	*0.0419*

Note: Mean pollution concentrations are the mean values of the daily maximum pollution levels over 2011.

Table A.16: Mean particulate matter (PM_{10}) concentration by UZA, 2011

UZA	**PM$_{10}$** ($\mu g/m^3$)	**UZA**	**PM$_{10}$** ($\mu g/m^3$)
Philadelphia, PA-NJ-DE-MD	40.9511	Spokane, WA-ID	19.0820
Bakersfield, CA	35.8130	Colorado Springs, CO	19.0678
El Paso, TX-NM	33.4541	Orlando, FL	18.9793
Baton Rouge, LA	32.8663	Minneapolis - St. Paul, MN	18.7444
Richmond, VA	30.6310	Memphis, TN-MS-AR	18.5698
Fresno, CA	29.9890	Dayton, OH	18.4775
New Orleans, LA	29.2672	Rochester, NY	18.2470
Oklahoma City, OK	28.9218	Charleston - North Charleston, SC	18.2017
Albuquerque, NM	28.8178	Indianapolis, IN	17.9159
Toledo, OH-MI	27.7875	Virginia Beach, VA	17.6222
Corpus Christi, TX	27.0431	San Jose, CA	17.5088
Honolulu, HI	26.9971	Madison, WI	17.4237
Knoxville, TN	26.8860	Miami, FL	17.4152
Sacramento, CA	26.3150	Allentown - Bethlehem, PA-NJ	17.3649
Little Rock, AR	25.9398	Charlotte, NC-SC	17.2323
Denver - Aurora, CO	25.4816	Laredo, TX	16.8430
Jacksonville, FL	25.3883	San Francisco - Oakland, CA	16.7624
New Haven, CT	25.1864	Sarasota - Bradenton, FL	16.6740
New York - Newark, NY-NJ-CT	25.0714	Austin, TX	16.3982
Cleveland, OH	24.9222	Worcester, MA-CT	16.2500
Birmingham, AL	24.5283	Nashville - Davidson, TN	15.7257
Louisville, KY-IN	23.9558	Tulsa, OK	15.5981
Kansas City, MO-KS	23.5260	Bridgeport - Stamford, CT-NY	15.3655
Salt Lake City, UT	23.4483	Cape Coral, FL	15.2959
Columbus, OH	23.2562	Raleigh - Durham, NC	15.2222
Milwaukee, WI	23.2280	Washington, DC-VA-MD	15.2092
San Diego, CA	23.1082	Omaha, NE-IA	14.9560
St. Louis, MO-IL	22.9275	Anchorage, AK	14.5906
Chicago, IL-IN	22.5411	Winston - Salem, NC	14.2173
Wichita, KS	22.4218	Grand Rapids, MI	13.9667
Brownsville, TX	22.4164	Providence, RI-MA	13.9160
Dallas - Fort Worth - Arlington, TX	22.3541	Baltimore, MD	13.5750
Tucson, AZ	21.8989	Boston, MA-NH-RI	13.1834
Las Vegas, NV	21.3234	Poughkeepsie - Newburgh, NY	12.9201
Houston, TX	20.6841	Pittsburgh, PA	12.6254
Columbia, SC	20.5660	Eugene, OR	12.0000
Jackson, MS	20.4818	Springfield, MA-CT	11.4866
Tampa - St. Petersburg, FL	20.4417	Hartford, CT	11.0612
Cincinnati, OH-KY-IN	20.2941	Greensboro, NC	10.1404
Boise, ID	20.0198	Seattle, WA	8.5373
Pensacola, FL-AL	20.0193	Akron, OH	-
Detroit, MI	19.9529	Albany, NY	-
Phoenix - Mesa, AZ	19.5637	Beaumont, TX	-
Atlanta, GA	19.5502	Buffalo, NY	-
Stockton, CA	19.5209	Oxnard, CA	-
McAllen, TX	19.4358	Portland, OR-WA	-
Los Angeles - Long Beach - Santa Ana, CA	19.4174	Riverside - San Bernardino, CA	-
San Antonio, TX	19.2870	Salem, OR	-
		Mean	*20.4803*

Note: Mean pollution concentrations are the mean values of the daily maximum pollution levels over 2011.

Table A.17: Mean particulate matter ($PM_{2.5}$) concentration by UZA, 2011

UZA	**PM$_{2.5}$** ($\mu g/m^3$)	**UZA**	**PM$_{2.5}$** ($\mu g/m^3$)
Fresno, CA	14.7353	San Antonio, TX	9.8201
Houston, TX	13.6428	Bridgeport - Stamford, CT-NY	9.7725
Little Rock, AR	13.6188	Philadelphia, PA-NJ-DE-MD	9.6739
Richmond, VA	13.4978	New Haven, CT	9.6572
Los Angeles - Long Beach - Santa Ana, CA	12.7736	Beaumont, TX	9.5785
Cincinnati, OH-KY-IN	12.1892	Greensboro, NC	9.5482
San Diego, CA	12.1236	Winston - Salem, NC	9.5403
Chicago, IL-IN	11.9760	Grand Rapids, MI	9.4511
Birmingham, AL	11.8784	Milwaukee, WI	9.4091
Atlanta, GA	11.8618	Corpus Christi, TX	9.4016
Phoenix - Mesa, AZ	11.8362	Buffalo, NY	9.3816
Sacramento, CA	11.7366	Worcester, MA-CT	9.3480
Las Vegas, NV	11.7226	Raleigh - Durham, NC	9.2402
Akron, OH	11.6745	San Francisco - Oakland, CA	9.1786
Indianapolis, IN	11.6619	Virginia Beach, VA	9.1284
Columbus, OH	11.6413	San Jose, CA	9.0921
Tucson, AZ	11.6127	Wichita, KS	9.0753
Knoxville, TN	11.4914	Hartford, CT	8.9502
El Paso, TX-NM	11.4571	Austin, TX	8.8862
Columbia, SC	11.4551	Stockton, CA	8.8760
Cleveland, OH	11.3715	Kansas City, MO-KS	8.8473
Dayton, OH	11.3055	Boston, MA-NH-RI	8.8348
Baton Rouge, LA	11.1479	Charleston - North Charleston, SC	8.8168
Minneapolis - St. Paul, MN	11.0948	Sarasota - Bradenton, FL	8.7923
Baltimore, MD	11.0877	Orlando, FL	8.6965
Pensacola, FL-AL	11.0661	Poughkeepsie - Newburgh, NY	8.6892
Louisville, KY-IN	11.0342	Springfield, MA-CT	8.4719
McAllen, TX	10.9410	Jackson, MS	8.3943
Bakersfield, CA	10.8970	Omaha, NE-IA	8.3873
Honolulu, HI	10.8469	Albany, NY	8.3774
Allentown - Bethlehem, PA-NJ	10.8456	Portland, OR-WA	8.3722
Charlotte, NC-SC	10.8373	Salt Lake City, UT	8.0067
Tampa - St. Petersburg, FL	10.8293	Spokane, WA-ID	7.8830
Brownsville, TX	10.7444	Cape Coral, FL	7.8819
Jacksonville, FL	10.5336	Albuquerque, NM	7.7662
New York - Newark, NY-NJ-CT	10.5244	Boise, ID	7.6898
Miami, FL	10.5106	Riverside - San Bernardino, CA	7.6354
St. Louis, MO-IL	10.4733	Eugene, OR	7.3631
Oklahoma City, OK	10.2650	Memphis, TN-MS-AR	7.3008
Madison, WI	10.2437	Denver - Aurora, CO	7.1070
Washington, DC-VA-MD	10.2423	Seattle, WA	7.0978
New Orleans, LA	10.1667	Pittsburgh, PA	7.0854
Oxnard, CA	10.1659	Laredo, TX	6.6668
Dallas - Fort Worth - Arlington, TX	9.9700	Salem, OR	6.1802
Rochester, NY	9.9389	Colorado Springs, CO	5.8739
Nashville - Davidson, TN	9.9371	Tulsa, OK	5.6400
Providence, RI-MA	9.9040	Toledo, OH-MI	5.6119
Detroit, MI	9.8519	Anchorage, AK	4.6654
		Mean	*9.7969*

Note: Mean pollution concentrations are the mean values of the daily maximum pollution levels over 2011.

Table A.18: Mean sulfur dioxide (SO_2) concentration by UZA, 2011

UZA	SO2 (ppb)	UZA	SO2 (ppb)
New Haven, CT	27.3390	Charleston - North Charleston, SC	2.6469
Cleveland, OH	14.2865	Las Vegas, NV	2.6304
Cincinnati, OH-KY-IN	12.6315	Philadelphia, PA-NJ-DE-MD	2.5473
Sacramento, CA	12.1069	Hartford, CT	2.3661
Allentown - Bethlehem, PA-NJ	11.9261	Indianapolis, IN	2.3104
Los Angeles - Long Beach - Santa Ana, CA	11.2758	Wichita, KS	2.2195
Jacksonville, FL	10.7282	Dallas - Fort Worth - Arlington, TX	2.1866
Houston, TX	10.6799	Charlotte, NC-SC	2.1521
Phoenix - Mesa, AZ	9.9600	Grand Rapids, MI	2.1473
Detroit, MI	9.8960	Providence, RI-MA	2.1344
Tucson, AZ	9.2273	Boise, ID	2.0275
Denver - Aurora, CO	7.9405	Little Rock, AR	2.0152
Virginia Beach, VA	7.7752	Pittsburgh, PA	2.0075
Chicago, IL-IN	7.6771	Tulsa, OK	1.9504
Akron, OH	7.5838	El Paso, TX-NM	1.9011
Dayton, OH	7.3948	Portland, OR-WA	1.8784
Beaumont, TX	7.3767	Richmond, VA	1.7488
Baton Rouge, LA	7.2650	San Diego, CA	1.7254
Oklahoma City, OK	6.5779	San Jose, CA	1.7123
Birmingham, AL	6.4955	Winston - Salem, NC	1.6468
Poughkeepsie - Newburgh, NY	6.2247	Kansas City, MO-KS	1.6356
Jackson, MS	6.1714	New York - Newark, NY-NJ-CT	1.4545
New Orleans, LA	5.6454	Fresno, CA	1.3781
Baltimore, MD	5.6217	Toledo, OH-MI	1.3398
Raleigh - Durham, NC	5.5440	Milwaukee, WI	1.2536
Nashville - Davidson, TN	5.4416	Albuquerque, NM	1.1545
Buffalo, NY	5.3064	Memphis, TN-MS-AR	1.1438
Columbia, SC	4.9869	Corpus Christi, TX	1.1371
Atlanta, GA	4.8149	Rochester, NY	0.6497
Stockton, CA	4.7837	Omaha, NE-IA	0.6071
Riverside - San Bernardino, CA	4.3061	Anchorage, AK	-
Boston, MA-NH-RI	4.1218	Austin, TX	-
Miami, FL	4.1033	Bakersfield, CA	-
Oxnard, CA	3.9917	Brownsville, TX	-
Bridgeport - Stamford, CT-NY	3.8922	Cape Coral, FL	-
Worcester, MA-CT	3.8848	Colorado Springs, CO	-
Seattle, WA	3.7752	Columbus, OH	-
Pensacola, FL-AL	3.7690	Eugene, OR	-
Honolulu, HI	3.7645	Knoxville, TN	-
Salt Lake City, UT	3.5483	Louisville, KY-IN	-
McAllen, TX	3.5031	Madison, WI	-
Minneapolis - St. Paul, MN	3.0384	Orlando, FL	-
Washington, DC-VA-MD	3.0369	Salem, OR	-
Albany, NY	2.9263	San Antonio, TX	-
Springfield, MA-CT	2.9140	Sarasota - Bradenton, FL	-
San Francisco - Oakland, CA	2.7783	Spokane, WA-ID	-
Greensboro, NC	2.7054	St. Louis, MO-IL	-
Laredo, TX	2.6830	Tampa - St. Petersburg, FL	-
		Mean	*4.8351*

Note: Mean pollution concentrations are the mean values of the daily maximum pollution levels over 2011.