WAREHOUSES, TRUCKS AND PM$_{2.5}$: HUMAN HEALTH AND LOGISTICS INDUSTRY GROWTH IN THE EASTERN INLAND EMPIRE

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Abstract

The eastern Inland Empire of Southern California has experienced dramatic growth of the logistics industry since 2000. This paper analyzes the air pollution implications of that expansion. It is found that truck traffic will generate significant air pollution, especially PM$_{2.5}$. The estimated excess mortality associated is 32 to 64 cases per year, with a combined excess mortality and morbidity value of $247$ to $455$ million per year. This represents 44% to 81% of the estimated wages generated by industry growth and $5$ million to $9$ million per distribution facility. These estimates suggest policies should be developed to internalize those costs.
I. INTRODUCTION

The logistics industry organizes, stores and then transports consumer and other goods throughout the United States. It is composed primarily of warehousing and distribution facilities that now typically exceed 500,000 square feet, supported by fleets of trucks that move goods between facilities and other transportation modes. Most of the physical infrastructure of the logistics industry is made up of warehouses and other buildings. Proximity to seaports, air, rail, and road networks are key foundations of the logistics industry and ready access to all forms of transport is increasingly essential. It is also a space intensive industry, making cost of land an important additional location factor.

The valley regions of San Bernardino and Riverside counties in Southern California east of Los Angeles comprise what is known as the Inland Empire. Lying along some of the most extensive road and rail networks in the United States, from an industry perspective the Inland Empire is perhaps an ideal hub for logistics. The region also hosts three air cargo terminals and is proximate to the ports of Los Angeles and Long Beach, which handle approximately 13 million containers per year or one quarter of all imports to the United States. Half of those containers travel via the Inland Empire, which means 34,000 trucks and 100 trains pass through the region each day from the ports (Eventov, 2003; Eventov, 2004c). Volume grew 11.6% in 2004 and is projected to almost double by 2020 (LAEDC, 2003).

This paper analyzes the health effects from fine particles emitted into the atmosphere by heavy-duty diesel trucks that are an important part of the logistics industry expansion in the eastern Inland Empire. Modern warehouses are typically serviced by 300 to 1000 heavy truck trips per day. The sector therefore has the potential to dramatically increase truck traffic, particularly on freeways, and have major effects on air quality because of emissions associated
with diesel fuel combustion. The paper is organized as follows. The next section discusses the environmental effects of diesel emissions from heavy trucks as well as the environmental backdrop against which the truck traffic expansion is occurring. Section 3 presents estimates of the increased truck traffic and fine particle pollution from logistics industry growth. Section 4 incorporates key results from the epidemiological literature on mortality and morbidity consequences of increased particulate exposures, as well as the relevant environmental valuation literature. Section 5 presents our estimated economic costs and Section 6 concludes.

FIGURE 1 ABOUT HERE

Logistics industry growth in the Inland Empire and particularly east of I-15, which is the focus of this paper and highlighted in Figure 1, is a relatively new phenomenon. Prior to the 1990s the Inland Empire was home to only nine logistics centers and all would be considered small by contemporary standards (McLaughlin, 2003). In 2004 there were 43 large (over 500,000 square feet) warehouses and distribution centers and 18 more were planned. During the period 2000-2003, at least 26 were built (Eventov, 2004d) and approximately fifteen more completed construction or were announced by 2004. Allowing for reasonable growth during 2005 and an incomplete inventory, we can say with confidence that during the period 2000 to 2005 forty-five major warehouse and distribution centers were built in the eastern Inland Empire. Most are twenty-four-hour cross-docking facilities used to organize import shipments for distribution nationally (Eventov, 2004b; Herrera, 2005a). In 2004 one-sixth of the commercial development in the nation, or over 10 million square feet, was taking place within the Inland Empire. In early 2005 the industrial vacancy rate was only 2.2%, largely due to demand from the logistics industry. As Tapie Rohm, director of the Inland Empire Center for
Entrepreneurship at the California State University, San Bernardino put it, “Logistics is totally reshaping the Inland Empire” (Eventov, 2003a).

More than 40% of the value of world trade is moved by air and over 70% of all goods purchased via the internet are shipped using expedited air services. But up until 2000 the only commercial airport in the Inland Empire was in Ontario in the western part of the region and virtually all logistics industry growth away from the Southern California coast occurred there. This all changed, however, with the development of the former Norton Air Force Base and March Air Reserve Base for commercial purposes. These facilities made possible air transport and spurred development of several major logistics facilities in the eastern part of the valley.

The eastern Inland Empire also presents an attractive location for companies requiring rail links. BNSF and Union Pacific have rail lines running through the Inland Empire. In 2003 over 495,000 containers were handled by area rail yards and the Southern California Association of Governments predicts that cargo delivered by rail will increase by 160% during 2002 - 2020 (Silva, 2002; SCAG 2003a; 2003b).

Logistics is having important labor market effects in a region hungry for local jobs. It is a relatively labor using industry, with one to four jobs per 10,000 square feet of warehouse space, paying an average of $36,000 per year (Eventov, 2004d; Herrera, 2005b; 2005c; Kirshner, 2002). Approximately 44,000 Inland Empire residents are employed by the logistics industry, with an estimated $300 million annual payroll (Sieroty, 2004). This is expected to increase, which would make the industry the most important employer in the region.

II. THE ENVIRONMENTAL ISSUES

Diesel exhaust is made up of gas and particulates. Gases include hydrocarbons, carbon dioxide, carbon monoxide, nitrogen oxides and sulfur oxides, but particulates are of special concern
because they are associated with a variety of cancers and cardiopulmonary problems that have been shown to increase the risk of mortality. Relative to gasoline engines, heavy-duty diesel trucks, such as those used in the logistics industry, typically emit at least 24 times more fine particulate matter per mile traveled (Kirchstetter et al., 1999). Health effects associated with these particles fall disproportionately on vulnerable populations, such as the young, elderly, and those who already have compromised respiratory systems.

Recently the toxic and especially carcinogenic effects of diesel particulate matter (DPM), much of which comes from trucks, have been highlighted. The State of California and the U.S. Environmental Protection Agency (USEPA) have identified more than 40 toxic pollutants in diesel emissions and in 1998 the California Air Resources Board (CARB) named it a toxic air contaminant (Lippmann et al., 2003; CARB 2000; Ostro and Chestnut, 1998; Hubbell et al., 2001; SCAQMD, 2003).

Particulates are classified according to their diameters. Those less than 2.5 microns (PM$_{2.5}$) pose the greatest threat to human health, because smaller size allows deeper penetration into lung tissues as well as longer float times (as much as several days under dry conditions) and therefore wider deposition. DPM is particularly light, with a mean particle diameter of 0.2 microns, but as much as 20% of DPM can be less than 0.05 microns, which floats longer and penetrates deeper than larger particles. DPM also has a large surface area, making it an ideal carrier for a variety of toxic compounds. DPM typically makes up 10 - 30% of total PM$_{2.5}$ concentrations. The federal limit for PM$_{2.5}$ is 15 µg/m$^3$ average annual concentration and 65 µg/m$^3$ maximum concentration during any 24 hour period. California has a stricter annual average concentration standard of 12 µg/m$^3$. DPM-specific standards do not exist.
The eastern Inland Empire and particularly the I-215, I-10 and I-15 freeway corridors have very high particulate concentrations. In 2003 Riverside and San Bernardino Counties ranked first and second in the nation for total particulate pollution (CARB/American Lung Association, 2004). For example, at the Rubidoux monitoring station in Riverside, during the period 2000 – 2002 the average annual PM$_{2.5}$ concentration was 28.9 µg/m$^3$, which is about 1.75 times the federal limit and more than twice the state standard. Maximum PM$_{2.5}$ concentrations at monitoring stations have been 80 – 100 µg/m$^3$, which are about 1.5 times the federal limit (CARB, 2003). Such concentrations are very common throughout the Inland Empire and have been constant since the late 1990s. USEPA (2002) citing work in Riverside in 1996 by Kleeman et al (2000) notes the Inland Empire had an average DPM concentration of 4.4 µg/m$^3$, which was double the national average (2.1 µg/m$^3$) and much higher than the Southern California average of 2.5 µg/m$^3$ (USEPA, 2002 p. 2-104;2-118 to 2-121; CARB, 2003).

Part of the reason for these high fine particle concentrations is that the eastern Inland Empire experiences the highest truck traffic in Southern California. Table 1 presents California Department of Transportation truck counts at key mileposts for 1998, which we consider prior to the logistics industry explosion in the eastern Inland Empire, and in 2002. Along I-10 east of the I-15, the California Department of Transportation estimates that in 2002 an average of 15,000 to 25,000 trucks traveled each day. This means that trucks pass each point every 3 to 4 seconds. I-215 was used by 5000 to 9000 trucks and I-91 by 10,000 to 15,000 trucks per day (California DOT, 2004). In total in 2002 98,584 trucks passed checkpoints. To estimate a counterfactual, we used 1992 – 2002 data to run milepost-specific AR (1) trend regressions and used those
equations to develop baseline truck traffic estimates for 2005. These estimates are presented in the final column of Table 1. Growth is estimated to be strongest on the eastern part of the I-10.

III. ADDITIONAL TRUCK TRAFFIC AND PARTICULATE EMISSIONS FROM LOGISTICS INDUSTRY GROWTH

We now present estimates of the additional traffic resulting from the logistics industry boom in the eastern Inland Empire and augment those estimates with information from the literature to estimate the contribution toward increased PM$_{2.5}$ concentrations. Estimating truck trips per day per facility is difficult, because of the proprietary nature of information and substantial variability in estimates. Newer facilities in the region were contacted, but none were willing to provide traffic estimates and such data are not published. We therefore base our estimates on secondary sources, including State of New York (2002), which presents a standard development profile for distribution centers locating in New York. For a 500,000 square foot facility on 50 acres, the State of New York estimates 350 truck trips per day. This figure is proportionate to estimates for an AMB Property Corporation center in Redlands (1000 truck trips for a 1.3 million square-foot structure), Wal-Mart distribution centers in Pueblo, Colorado (700 truck trips per day for an 880,000 square foot facility), Connecticut and Delaware (both 1000 truck trips per day for 1.2 million square foot structures) and a grocery distribution center in New York (Hernandez, 2005; Gasiewski, 2004; Pueblo Chieftain, 2004; Boas, 2003; Sholl, 2004).

Given that distribution centers in the eastern Inland Empire tend to be larger than the development profile prepared by the State of New York, truck traffic should be higher. If truck traffic were proportionate to facility size as appears to be the case, a facility of 800,000 square feet would imply an average of 560 truck trips per day per facility. We use this figure as our main estimate, but also present analysis with the actual State of New York (2002) figure of 350 truck trips per day. The forty-five newest warehouse/distribution centers are therefore estimated
to increase truck traffic in the eastern Inland Empire by 15,750 to 25,200 truck trips per day. These truck trips are expected to be uniformly distributed throughout the day, because distribution centers typically operate 24 hours.

TABLE 2 ABOUT HERE

We know these additional truck trips will be almost completely on freeways rather than streets, but the distribution of the additional traffic flow must be assumed. Column 3 of Table 2 presents our assumptions regarding the distribution of new truck trips generated by logistics facilities established in the eastern Inland Empire since 2000. The new logistics facilities are relatively uniformly scattered around the Inland Empire. We therefore model the additional truck trips as being uniformly distributed across our truck count points. Because total additional truck trips are 24.12% of the 2005 baseline, each truck count point is assumed to experience the same increase. The 2005 baseline distribution of truck counts therefore fully determines the distribution of additional truck trips across count points. Based on this distribution, mean and low estimates of additional truck traffic are presented in columns 4 and 7. A second implication is that effects of each truck trip are limited to one truck count point. This is conservative, because trucks could pass more than one count point as they move from logistics center to national destination. The assumption also, however, avoids the need for assuming ad hoc truck routes for which we may have limited theoretical basis.

These 15,750 to 25,200 additional truck trips per day will produce a variety of pollutants, but we focus only on PM$_{2.5}$ because the health effects are known to be especially important. We also ignore effects of truck traffic outside the heavily populated part of the eastern Inland Empire. These simplifications, of course, bias our health effects estimates downward.
To estimate health effects, we need to model changes in PM$_{2.5}$ concentrations at points of emissions, PM$_{2.5}$ dispersion and damages. PM$_{2.5}$ concentrations at monitoring stations in the region averaged 25.3 to 28.9 µg/m$^3$ during 2000 – 2002. The question is what portion of these concentrations was due to DPM, and for what portion of DPM concentrations are logistics industry trucks responsible? To avoid omitted variable bias it is necessary to adjust for background factors contributing to PM$_{2.5}$ concentrations that are unrelated to truck traffic. Such factors would likely include automobiles, non-vehicle dust and light particles originating from other sources. We do not, however, have a sufficiently comprehensive data set to include those variables in an econometric model. We therefore use our available data combined with research results from the environmental engineering literature.

We begin by dividing the 2000 – 2002 average PM$_{2.5}$ concentration at the monitoring stations closest to each truck count point by the number of trucks per day. This gives the unadjusted PM$_{2.5}$ concentration per truck trip, which at the median is 0.00176 µg/m$^3$. This estimate is similar to that of Lena et al (2002) in their study of Hunts Point, New York that in 1999 had an average measured PM$_{2.5}$ concentration of 25µg/m$^3$, which is very similar to our study area. Using a univariate linear regression they find an additional truck trip per day increases concentrations by 0.0013 µg/m$^3$. That our unadjusted value is somewhat higher is not surprising, because their work focused on urban areas rather than freeways with some of the highest truck traffic in the country. It is notable, though, they do not make any adjustments for other factors that could affect PM$_{2.5}$ concentrations. They then conclude large trucks were responsible for between 26% and 50% of PM$_{2.5}$ concentrations.

We take 0.00176 µg/m$^3$ as the starting point for analyzing the relationship between concentrations and increased truck traffic, but we adjust this value using the environmental
engineering literature. In particular, we take account of (a) the percentage of PM$_{2.5}$ concentrations made up by DPM and (b) the percentage of DPM generated by large trucks. DPM is typically between 23% and 53% of PM$_{2.5}$ concentrations in metropolitan areas (USEPA, 2002; p. 2-120; 9-3) and Fujita (2004) estimates that DPM makes up 35% of PM$_{2.5}$ emissions in the South Coast Air Basin. We therefore take 35% as our percentage of PM$_{2.5}$ concentrations made up by DPM. Fujita (2004) also estimates that in the South Coast Air Basin 67% of the elemental carbon (a key indicator of DPM) comes from large trucks. We therefore take this estimate as our value for the portion of DPM that comes from large trucks. Combining this value with the assumption that DPM makes up 35% of PM$_{2.5}$ emissions implies that large trucks are responsible for 21% of PM$_{2.5}$ concentrations. This value is below the range estimated by Lena et al (2002), which may suggest our estimates are conservative, but more likely simply takes advantage of more recent engineering literature.

The three values, (1) PM$_{2.5}$ concentrations per truck trip, (2) percentage of PM$_{2.5}$ concentrations from DPM and (3) percentage of DPM concentrations coming from large trucks are multiplied to obtain a coefficient of 0.000416, which we use to convert increases in truck traffic into changes in concentrations. In addition, we suppose that due to on-going technological change, monitored PM$_{2.5}$ concentrations would have remained at 2000-2002 average levels without logistics industry growth.

TABLE 3 ABOUT HERE

With these and the previous assumptions related to the spatial distribution of additional truck traffic presented in Table 2, we estimate that with an average of 560 truck trips per facility per day the new centers increase concentrations by 4.2% to 10% compared with the 2000-2002 average concentration, with a mean of 6.6% or 1.75 µg/m$^3$. The largest increases are predicted to
occur on I-10 east of the I-215 Freeway. If we instead assume 350 trucks per facility per day, PM$_{2.5}$ concentrations are estimated to increase between 2.6% and 6.3% compared with the 2000-2002 average concentration. This implies a mean increase of 1.09 µg/m$^3$ or 4.2%.

IV. 4. HEALTH COSTS OF DIESEL PARTICULATE MATTER AND THE VALUE OF A STATISTICAL LIFE

The health effects of diesel exhaust have been investigated at length in recent years and as was already discussed results show increases in both morbidity and mortality. Though scientific uncertainty exists, the evidence leads most organizations, including the USEPA, World Health Organization and the National Institute for Occupational Safety and Health to link diesel exhaust with human mortality (USEPA, 2002; SCAQMD, 2003; Kagawa, 2002). There are also immediate morbidity effects like chronic cough and bronchitis (Braun-Fahrlander, 1997).

Cancer is an especially important health risk associated with exposure to DPM. In their diesel risk reduction plan of 2000, the California Air Resources Board concluded that exposures to DPM of 1 µg/m$^3$ (about one-quarter of the concentration in the Eastern Inland Empire) cause excess cancer cases in the range of 130 to 2400 per million. A review by a scientific panel recommended a unit risk for DPM of 300 excess cancers per million people per 1 µg/m$^3$ increase in PM$_{2.5}$. The Los Angeles air basin cancer risk is double the California average of 500 per million and DPM is believed to account for 71% of the risk from air pollution (California Air Resources Board, 2000; SCAQMD, 2000; Figdor, 2002).

Long-term cohort studies are currently underway to fully assess the effects on children, but as a result of studies conducted in Southern California by Peters et al (1999a; 1999b) and Gauderman et al (2000; 2002), it is known that children experience a decrease in respiratory function and lung capacity when chronically exposed to particulate matter. The unknown remains the lasting effect this exposure will have into adulthood. Recent studies have looked
deeper into effects on pregnancy, birth and infant mortality. Research suggests that exposure to particulate matter may trigger pre-term birth (Ritz et al, 2002), reduce birth weight (Bobak and Leon, 1999) and increase infant mortality (Schwartz, 2004).

The work by Dockery et al (1993) and Pope et al (1995) are key epidemiological references and were used to set the national long-term PM$_{2.5}$ standards that were adopted in 1997. Krewski, et al (2000) refined both those estimates. Dockery et al (1993) analyzed cross-section data from approximately 8000 adults in six cities in the 1970s and found that a 1.0 µg/m$^3$ increase in PM$_{2.5}$ increased overall mortality by 1.40%. The reanalysis by Krewski et al (2000) changed this result relatively little, increasing it to 1.51%. Pope et al (1995) analyzed a panel of data for over half a million adults in 50 metropolitan areas during the period 1982-89. They found a 1.0 µg/m$^3$ increase in PM$_{2.5}$ increased overall mortality by 0.69%. Hubbell et al (2001) used the Krewski et al (2000) reanalysis of those data for their work on heavy-duty vehicles.

Subsequently, Pope et al (2002) utilized data that expanded the follow-up time used in Pope et al (1995) and took advantage of better PM$_{2.5}$ measurement and statistical techniques. They find that at the mean total mortality increases by 0.4% for a 1.0 µg/m$^3$ increase in PM$_{2.5}$ for the period 1979 – 83. Using data from 1999-2000 the effect was a stronger 0.6% per 1.0 µg/m$^3$ increase in PM$_{2.5}$. Ostro and Chestnut (1998) use a 0.35% increase in mortality for a 1.0 µg/m$^3$ increase in PM$_{2.5}$ and SCAQMD (2003) uses a 0.4% figure.

Because the techniques and data set used by Pope et al (2002) are better than previous efforts, we take our marginal (and average) mortality risk from that source. We utilize a figure of 0.5% for a 1.0 µg/m$^3$ increase in PM$_{2.5}$, which is the mean of their two sets of estimates. Because more recent data suggest stronger effects, we consider this estimate conservative. This figure is then applied to the California baseline mortality rate of 75.78 per 1000 population
A particularly important aspect of conservatism is the assumption of constant marginal mortality risk. A standard damage model would suggest that as concentrations rise marginal damages should also increase (Kolstad, 2000). As Riverside and San Bernardino are the two counties with the highest PM$_{2.5}$ concentrations in the US, it is likely that marginal risks would be higher than in the variety of cities analyzed by Pope et al (2002).

The value of reducing mortality risk has been the focus of study for more than thirty years and is hotly debated. In the USEPA’s estimate of the benefits from the 2000 Clean Air Act reauthorization, a value of $4.8 million in 1990 dollars was used, which is approximately $7 million in 2005 dollars (USEPA, 1999). Meta-analysis by Viscusi and Aldy (2003) put the best estimate at $6.7 million. Alberini et al (2004) evaluate whether willingness to pay to avoid the risk of dying declines with age and health status. They find those with cardiovascular and respiratory illness and cancer typically place higher values on their lives than healthier individuals. They also find limited support for the hypothesis that value decreases with age, but only among those over 70 years and the results were statistically significant only when data from Canada and the U.S. were pooled. These results indicate willingness to pay about 25% lower than for those below age 70. Analysis of U.S. data did not yield significant effects.

Given this literature, we utilize a value of a statistical life (VOSL) of $6.7 million from Viscusi and Aldy (2003), but apply a 25% reduced value (i.e. $5.0 million) to those over age 70 as suggested by Alberini et al (2004) and Ostro and Chestnut (1998). Inland Empire Economic Partnership (2006) and Public Policy Institute of California (2002) estimate that 10.5% of the Inland Empire population is over age 65 and Census Bureau (2002) estimates that nationally about 9.0% of the population is over the age of 70. As we do not have Inland Empire-specific estimates of the over 70 population and there is only a small difference with the over 65 year old
population estimate, we use Census Bureau (2002) and suppose 9.0% of the total mortality is valued at $5.0 million and the remainder at $6.7 million. No increases to our baseline VOSL are made for younger people, because there is no literature to support such a step.

This VOSL is almost certainly conservative. The studies summarized in Viscusi and Aldy (2003) are largely based on risks of sudden death. We know that DPM exposure has a variety of cardiopulmonary and carcinogenic risks, but few could be labeled as sudden death. More accurately, risks would be described as lingering illness and death, which is almost certainly valued more highly than sudden death. At the present time, though, no literature on the value of avoiding such a risk profile exists. iii

In valuation studies that combine morbidity and mortality, increased mortality generally makes up 90% to 95% of overall health damages (USEPA, 1999; Hubbell et al, 2001; Ostro and Chestnut, 1998). For example, 92% of the estimated Clean Air Act health benefits were due to decreased mortality (USEPA, 1999; H-30). Utilizing these results, we assume morbidity is 8.7% of estimated mortality, which corresponds to 8% of overall value. This estimate is also conservative, because the total value and weight of morbidity would likely be higher if valuation literature existed for damage and risk profiles similar to those associated with PM$_{2.5}$ exposure.

To estimate damages from the concentration increases in Table 3, we must know the populations affected and the levels of effects experienced, which depend on the spatial distribution of populations and the dispersion of fine particles. We know from the literature that fine particles disperse in the atmosphere and are diluted as they move away from pollution sources. Concentrations are therefore declining functions of distance from sources. The literature also suggests that effects reach zero at approximately one kilometer from sources (Fraser, 2004; Nazemi, 2002; D. Cocker private communication). There is no consensus,
however, regarding the functional relationship between PM$_{2.5}$ concentrations and distances from sources, so we consider two possibilities, with both assuming effects are negligible beyond $\frac{1}{2}$ kilometer on each side of freeways.$^\text{iv}$

FIGURE 2 ABOUT HERE

The first case assumes PM$_{2.5}$ exposures are linear decile functions of distance from pollution sources, with 10% of the population experiencing full exposure, 10% experiencing 90% of full exposure, etc. The second case is more conservative and supposes exposures take a logarithmic functional form, with the most exposed population decile experiencing only 90% of full exposure. As shown in Figure 2, with logarithmic decay exposures decline more rapidly as distance from pollution sources increase.

TABLE 4 HERE

The eastern Inland Empire populations exposed to the increased PM$_{2.5}$ concentrations from logistics industry growth are shown as polygons along freeways in Figure 1. As shown in Table 4, in total there are over 175,000 people living within $\frac{1}{2}$ kilometer of Eastern Inland Empire freeways. Based on the 2000 census the area immediately adjacent to I-10 is home to 45,046 people, near the 91 Freeway are 57,889 persons, by the 60 Freeway live 39,148 people, within $\frac{1}{2}$ km of I-215 are 29,209 and 4222 persons live along I-15. We do not have information on the population distributions within each polygon and therefore assume a uniform distribution within $\frac{1}{2}$-kilometer bands on each side of freeways.

V. RESULTS

TABLE 5 ABOUT HERE

TABLE 6 ABOUT HERE
Tables 5 and 6 summarize our results. We find the health implications of the logistics industry expansion in the eastern Inland Empire are likely to be significant. Assuming 560 truck trips per facility per day, depending on the pattern of dispersion, industry growth is expected to cause premature mortality of 32 to 64 persons per year. The value of this premature mortality is estimated to be $209 to $419 million, with morbidity worth approximately $18 to $36 million. With 350 truck trips per facility per day, predicted excess mortality is 20 to 40 persons per year. Total health costs are estimated to be $143 to $285 million.

We estimate that on average each of the 45 facilities will generate about 320 jobs. A total of approximately 14,400 jobs should be created by the expansion. Assuming 560 truck trips per facility per day, the health costs per job created are therefore in the range of $16,000 to $29,000, which is 44% to 81% of the average annual salary of workers in the logistics industry. Health costs per distribution facility are estimated to be $5.0 to $9.3 million.

VI. CONCLUSION

This paper combined data on logistics industry expansion and traffic volumes with information from the environmental engineering, epidemiology and valuation literatures to estimate the mortality and morbidity effects of industry growth. A number of assumptions were needed to make the necessary inferences, but this is peculiar neither to this paper nor the context analyzed. Fortunately, a variety of quantitative literature is available, but it is also recognized that estimates derived from other settings transfer imperfectly to the eastern Inland Empire. As discussed in the previous sections, at every juncture we have therefore chosen conservative assumptions to avoid overstating costs.

We find that considering only localized effects, as a result of the logistics industry boom PM$_{2.5}$ concentrations will rise by between 1.1 and 2.59 µg/m$^3$ or 4.2% to 10.0% compared with
the 2000-2002 average annual concentrations. We then utilize the best available measures from the literature to estimate mortality effects. Assuming constant marginal health damages (perhaps our most conservative assumption), we conclude that the logistics industry expansion will cause 32 to 64 cases of excess mortality and morbidity valued at $247 to $455 million per year.

These estimates are so significant because of the confluence of a variety of factors. First, the logistics industry expansion in the Eastern Inland Empire is very large – effects in this case are not marginal. Second, there are over 175,000 people living very close to area freeways, implying high levels of exposure. Finally, though per-unit costs are likely to be higher than the literature suggests due to higher morbidity, pain and suffering, even using conservative values each premature death has a very high value in the US. These facts combine to generate local health costs that may approach $0.5 billion per year.

Is growth of the logistics industry worth the cost? We are not able to truly answer this question, because it is possible that the increased economic output could exceed the health costs associated with the expansion. We know, though, that a major reason logistics industry growth has been welcomed is to bring jobs to the eastern Inland Empire. These jobs on average pay $36,000 per year, but we find that local health costs per year per job are likely to be at least half that value. Perhaps more to the point, it should be asked whether the logistics industry itself would be willing to pay the full external costs of its actions. For example, would each facility be willing to pay a charge of $5 to $9 million per year to cover the health costs it is estimated to impose on the community? We are not in a position to say yea or nay, but economic efficiency dictates that mechanisms should be put in place so those enjoying the benefits of logistics industry growth also pay the full costs – including external health costs – of their actions.
There are several potential limitations to our analysis. We were unable to econometrically adjust for non-truck PM$_{2.5}$ sources and therefore estimated increased concentrations using research from the environmental engineering literature. Second, the generation of local jobs could *ceteris paribus* reduce air pollution from automobiles as per-person commute distances decline, perhaps even reducing total emissions. This outcome is possible, but unlikely because heavy-duty diesel trucks emit so much more PM$_{2.5}$ per mile traveled than cars. People may also move away as they notice pollution concentrations rising near freeways, which would reduce damages. We have not taken the possibility of this averting behavior into account. Finally, in the long-run housing prices and rents should reflect increased air pollution along freeways. People living in such zones will therefore trade off health risks against lower housing costs. If information is imperfect (as is likely), the efficiency of such adjustments will, of course, be reduced. This is especially true for those who are poor and non-English speakers, who are most likely to live close to freeways.
References


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Source: author estimate based on California Department of Transportation, [www.dot.ca.gov/hq/trafops/saferesr/trafdata/index.htm](http://www.dot.ca.gov/hq/trafops/saferesr/trafdata/index.htm)
Table 2 Additional Logistics Industry Truck Traffic in 2005 Assuming Average Traffic of 560 and 350 Truck Trips/day/facility

<table>
<thead>
<tr>
<th>Freeway</th>
<th>Vehicle Count Point</th>
<th>Assumed % of additional Truck Trips Passing Indicated Milepost</th>
<th>Mean Estimate (560 trips/facility/day)</th>
<th>Low Estimate (350 trips/facility/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>ETIWANDA AVE.</td>
<td>21%</td>
<td>5311</td>
<td>22.62% 24.12% 3319</td>
</tr>
<tr>
<td>10</td>
<td>MOUNTAIN VIEW AVE.</td>
<td>25%</td>
<td>6230</td>
<td>31.46% 24.12% 3894</td>
</tr>
<tr>
<td>10</td>
<td>YUCAIPA BOULEVARD</td>
<td>16%</td>
<td>4121</td>
<td>39.62% 24.12% 2576</td>
</tr>
<tr>
<td>215</td>
<td>RIVERSIDE, SPRUCE ST.</td>
<td>13%</td>
<td>3190</td>
<td>25.56% 24.12% 1994</td>
</tr>
<tr>
<td>215</td>
<td>IOWA AVE.</td>
<td>10%</td>
<td>2619</td>
<td>25.98% 24.12% 1637</td>
</tr>
<tr>
<td>91</td>
<td>RIVERSIDE, LA SIERRA AVE.</td>
<td>15%</td>
<td>3729</td>
<td>22.60% 24.12% 2331</td>
</tr>
<tr>
<td>Regional Average</td>
<td>16.67%</td>
<td>4200</td>
<td>27.97% 24.12% 2625</td>
<td></td>
</tr>
</tbody>
</table>

Author calculations based on California Department of Transportation, [www.dot.ca.gov/hq/trafops/saferesr/trafdata/index.htm](http://www.dot.ca.gov/hq/trafops/saferesr/trafdata/index.htm)
### Table 3 Estimated Logistics Industry Shares of PM$_{2.5}$ Concentrations in December 2005 at Key Mileposts Assuming 560 and 350 Truck Trips/Facility/Day

<table>
<thead>
<tr>
<th>Freeway</th>
<th>Vehicle Count Point</th>
<th>Average PM$_{2.5}$ Concentration 2000 - 2002 at nearest monitoring station (µg/m$^3$)</th>
<th>Estimated % Of 2000-2002 Average Concentration</th>
<th>Estimated Increased Concentrations Due to Logistics Industry Growth (µg/m$^3$)</th>
<th>Estimated % Of baseline 2005 Concentration Due to Logistics Industry Growth</th>
<th>Estimated Increased Concentrations Due to Logistics Industry Growth (µg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>ETIWANDA AVENUE</td>
<td>25.3</td>
<td>8.74%</td>
<td>2.21</td>
<td>5.46%</td>
<td>1.38</td>
</tr>
<tr>
<td>10</td>
<td>MOUNTAIN VIEW AVENUE</td>
<td>25.9</td>
<td>10.02%</td>
<td>2.59</td>
<td>6.26%</td>
<td>1.62</td>
</tr>
<tr>
<td>10</td>
<td>YUCAIPA BOULEVARD</td>
<td>25.9</td>
<td>6.62%</td>
<td>1.72</td>
<td>4.14%</td>
<td>1.07</td>
</tr>
<tr>
<td>215</td>
<td>RIVERSIDE, SPRUCE STREET</td>
<td>28.9</td>
<td>4.60%</td>
<td>1.33</td>
<td>2.87%</td>
<td>0.83</td>
</tr>
<tr>
<td>215</td>
<td>IOWA AVENUE</td>
<td>25.9</td>
<td>4.21%</td>
<td>1.09</td>
<td>2.63%</td>
<td>0.68</td>
</tr>
<tr>
<td>91</td>
<td>RIVERSIDE, LA SIERRA AVENUE</td>
<td>26.8</td>
<td>5.79%</td>
<td>1.55</td>
<td>3.62%</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>Regional Average</td>
<td>26.5</td>
<td>6.66%</td>
<td>1.75</td>
<td>4.16%</td>
<td>1.09</td>
</tr>
</tbody>
</table>

## Table 4 Populations Subject to Increased PM$_{2.5}$ Concentrations

<table>
<thead>
<tr>
<th>Freeway</th>
<th>Vehicle Count Point</th>
<th>Increased PM$_{2.5}$ w/ 560 Trucks/Day (µg/m$^3$)</th>
<th>Population Affected by Additional Trucks Passing Count Point (000s)</th>
<th>Portion of Figure 1 Population Polygon Assumed to be Affected by Increased Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>ETIWANDA AVE.</td>
<td>2.21</td>
<td>38.01</td>
<td>100% of I-15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75% of I-10</td>
</tr>
<tr>
<td>10</td>
<td>MOUNTAIN VIEW AVE.</td>
<td>2.59</td>
<td>5.63</td>
<td>12.5% of I-10</td>
</tr>
<tr>
<td>10</td>
<td>YUCAIPA BLVD.</td>
<td>1.72</td>
<td>5.63</td>
<td>12.5% of I-10</td>
</tr>
<tr>
<td>215</td>
<td>SPRUCE ST.</td>
<td>1.33</td>
<td>39.14</td>
<td>100% of I-60</td>
</tr>
<tr>
<td>215</td>
<td>IOWA AVE.</td>
<td>1.09</td>
<td>29.21</td>
<td>100% of I-215</td>
</tr>
<tr>
<td>91</td>
<td>LA SIERRA AVE.</td>
<td>1.55</td>
<td>57.89</td>
<td>100% of I-91</td>
</tr>
</tbody>
</table>

Source: Author estimates. Population polygons developed by Pei-Yi Lee of University of California, Riverside
Table 5 Estimated Annual Health Costs of Logistics Industry Expansion in the Eastern Inland Empire – Linear PM$_{2.5}$ Exposure Decay

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>ETIWANDA AVENUE</td>
<td>38,007</td>
<td>114.70 (17.51)</td>
<td>9.98</td>
<td>71.68 (10.95)</td>
<td>6.24</td>
</tr>
<tr>
<td>10</td>
<td>MOUNTAIN VIEW AVENUE</td>
<td>5631</td>
<td>19.93 (3.04)</td>
<td>1.73</td>
<td>12.46 (1.90)</td>
<td>1.08</td>
</tr>
<tr>
<td>10</td>
<td>YUCAIPA BOULEVARD</td>
<td>5631</td>
<td>13.19 (2.01)</td>
<td>1.15</td>
<td>8.24 (1.26)</td>
<td>0.72</td>
</tr>
<tr>
<td>215</td>
<td>RIVERSIDE, SPRUCE STREET</td>
<td>39,148</td>
<td>70.97 (10.84)</td>
<td>6.17</td>
<td>44.36 (6.77)</td>
<td>3.86</td>
</tr>
<tr>
<td>215</td>
<td>IOWA AVENUE</td>
<td>29,209</td>
<td>43.47 (6.64)</td>
<td>3.78</td>
<td>27.17 (4.15)</td>
<td>2.36</td>
</tr>
<tr>
<td>91</td>
<td>RIVERSIDE, LA SIERRA AVENUE</td>
<td>57,889</td>
<td>122.68 (18.73)</td>
<td>10.67</td>
<td>76.67 (11.71)</td>
<td>6.67</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>175,515</td>
<td>$384.94 (58.78)</td>
<td>$33.49</td>
<td>$240.59 (36.74)</td>
<td>$20.93</td>
</tr>
<tr>
<td>Based on Average Concentration Increase Across 6 Points</td>
<td>175,515</td>
<td>$418.90 (63.96)</td>
<td>$36.44</td>
<td>$261.81 (39.98)</td>
<td>$22.78</td>
<td></td>
</tr>
</tbody>
</table>

Based on Average Concentration Increase Across 6 Points

Author calculations using references cited in text
Table 6 Estimated Annual Health Costs of Logistics Industry Expansion in the Eastern Inland Empire – Logarithmic PM$_{2.5}$ Exposure Decay

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>ETIWANDA AVENUE</td>
<td>38,007</td>
<td>62.25 (9.50)</td>
<td>5.42</td>
<td>38.91 (5.94)</td>
<td>3.38</td>
<td>560 Truck Trips/Facility/Day</td>
</tr>
<tr>
<td>10</td>
<td>MOUNTAIN VIEW AVENUE</td>
<td>5,631</td>
<td>10.82 (1.65)</td>
<td>0.94</td>
<td>6.76 (1.03)</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>YUCAIPA BOULEVARD</td>
<td>5,631</td>
<td>7.16 (1.09)</td>
<td>0.62</td>
<td>4.47 (0.68)</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>215</td>
<td>RIVERSIDE, SPRUCE STREET</td>
<td>39,148</td>
<td>38.52 (5.88)</td>
<td>3.35</td>
<td>24.07 (3.68)</td>
<td>2.09</td>
<td>350 Truck Trips/Facility/Day</td>
</tr>
<tr>
<td>215</td>
<td>IOWA AVENUE</td>
<td>29,209</td>
<td>23.59 (3.60)</td>
<td>2.05</td>
<td>14.75 (2.25)</td>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>RIVERSIDE, LA SIERRA AVENUE</td>
<td>57,889</td>
<td>66.58 (10.17)</td>
<td>5.79</td>
<td>41.61 (6.35)</td>
<td>3.62</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>175,515</td>
<td>$208.92 (31.90)</td>
<td>$18.18</td>
<td>$130.57 (19.73)</td>
<td>$11.36</td>
<td></td>
</tr>
<tr>
<td>Based on regional average</td>
<td>175,515</td>
<td>$227.35 (34.71)</td>
<td>$19.78</td>
<td>$142.09 (21.70)</td>
<td>$12.36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Author calculations using references cited in text
* First author is corresponding author, though authorship is shared. The John Randolph Haynes and Dora Haynes Foundation financed this work through a faculty fellowship while the first author was on the faculty of the University of Redlands. Their generous support is gratefully acknowledged. We would also like to thank one anonymous reviewer, participants in the second Ad Hoc Workshop of Environmental Economists of Western Oregon., Pei-Yi Lee, who provided GIS input and David Cocker, both of University of California, Riverside, who generously advised on particulate dispersion patterns. The first author would also like to thank the University of Redlands and Portland State University for providing homes and acting as sponsors for this research.

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Ouderkirk: Ecos Consulting, Portland, Oregon. E-mail bradouderkirk@msn.com

i Facilities in the High Desert are omitted from this total.

ii It is notable that a recent environmental health literature focuses on DPM as a distinct carcinogenic pollutant. We examine the relationship between overall PM$_{2.5}$, of which DPM is one part, and health outcomes, because of serious scientific uncertainty and because focusing exclusively on cancer risk could omit potentially important health outcomes (CARB, 1998; 2000 and USEPA, 2002; 2-125).

iii The authors would like to thank Trudy Cameron of the University of Oregon for this insight.

iv We thank Jo Albers of Oregon State University for encouraging us to pursue two cases.

Abbreviations
CARB: California Air Resources Board
DPM: Diesel Particulate Matter
USEPA: United States Environmental Protection Agency