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# Population Growth and Atmospheric Emissions in California

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

AIR RESOURCES BOARD
Research Division

# POPULATION GROWTH AND ATMOSPHERIC EMISSIONS IN CALIFORNIA

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## Disclaimer

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Abstract

California's population is expected to grow considerably in the coming decades. Estimation of the effects of population growth on atmospheric emissions should help the planning process for attainment of air quality standards. This research estimates the effects of population growth on emissions in two air basins in California: San Joaquin Valley and South Coast. The research utilizes the ARB emissions projection system using carefully selected scenarios of population growth while holding economic growth and regulations constant. The research indicates that as population grows, emissions increase but not as rapidly; if population growth is 10%, the increase in emissions is between 3% and 7%. The estimated impact of population growth is imprecise because of the difficulty of isolating effects of population growth from other factors that affect emissions; further research on this problem is recommended.

## EXECUTIVE SUMMARY

California's population is expected to grow considerably in the coming decades. Estimation of the effects of population growth on atmospheric emissions should help the planning process for attainment of air quality standards by clarifying the benefits of past air quality management programs and by indicating the challenge confronting current management programs. The objectives of this research are to better understand and estimate the net effects of population growth on emissions in California and to estimate the net benefits of air quality programs, which have offset the negative effects of population growth and achieved actual reductions in emissions.

The research utilizes the ARB emissions projection system to calculate a variety of emissions projections using carefully selected scenarios of population growth, economic activities, and regulations. Scenarios that represent different rates of population growth but identical trends in economic activity and regulations provide information about the effects of population growth on emissions. Alternatively, scenarios with identical trends in population growth and economic activity but with different assumptions about regulations provide information on the efficacy of regulations.

Due to uncertain data quality, the research did not consider emissions of small particulate matter ($PM_{10}$) from any source. Because necessary data on growth and control factors were not available, the research also does not consider emissions from on-road mobile sources. The latter limitation is particularly serious, as on-road mobile sources account for over half of most types of emissions. In addition, because the methodology of distinguishing growth of population from growth of economic activity is experimental, the research was limited to two air basins, San Joaquin Valley and South Coast.

Broadly speaking, research indicates that population growth has larger impacts on some sources of emissions and types of pollutants than others. This implies that the overall impact of population growth on emissions depends upon the composition of production and consumption in an area. Thus, impacts of population growth are different in the two air basins examined here. Impact is measured as an elasticity: the percentage change in emissions due to a one-percent increase in population. In all plausible cases, the emissions elasticity with respect to population probably is less than unity, so that emissions increase more slowly than population; but elasticities are greater than zero, so emissions do increase in response to population growth. In most cases, estimated elasticities were in the range from 0.3 to 0.7, indicating that a 10% increase in population produces an increase in emissions of from 3% to 7%. In both air basins the elasticity with respect to population seems to be larger for ROG emissions (closer to the 0.7 end of the range); elasticities are smaller and similar for the other criteria pollutants (closer to the 0.3 end of the range). Recall that these results refer only to emissions from stationary sources and off-road mobile sources; on-road vehicles are excluded.

The hypothetical scenarios also provide evidence on the efficacy of regulatory programs. The impact of regulations depends on the type of regulations implemented and on the structure of economic production and consumption, so the impacts differ somewhat in the two air basins. The largest impacts have been on ROG emissions from 1975 to 1990. (Recall that emissions from on-road mobile sources are excluded from this analysis.) With no new regulations after 1975, ROG emissions in the San Joaquin Valley air basin would have increased by 72% whereas in fact they declined by 36%. In the South Coast air basin from 1975-1990, without new regulations ROG emissions would have declined by 20% (largely due to economic restructuring) whereas in fact they declined by 56%. Regulations also are projected to have large impacts on $NO_x$ emissions, mainly from 1990 to 2010. Without new regulations, $NO_x$ emissions would increase from 1975 to 2010 by 20% and 18% respectively in the San Joaquin Valley and South Coast air basins, whereas in fact they are projected to decline by 8% and 40% respectively.

In conclusion, this research indicates that the projected doubling of California's population by 2040 poses a considerable challenge to efforts to improve air quality. The precise magnitude of this challenge is uncertain because of difficulties in using the ARB emissions projection system for this type of research (i.e. for examining hypothetical scenarios). Foremost among these is the difficulty in isolating the effects of population growth from other factors which also affect emissions, especially economic growth and restructuring. This is a fundamental conceptual problem that requires considerably more research. The most promising direction for research is detailed statistical analysis of past trends in emissions and population growth. Such research is highly recommended, given the importance of the challenge posed by continued population growth.

# POPULATION GROWTH AND ATMOSPHERIC EMISSIONS IN CALIFORNIA

## Introduction

California population is projected to grow considerably in the coming decades. A majority of this growth is due to immigration, either directly from the entry of people or indirectly from the high fertility of immigrants. The balance of the growth is due to high fertility of the native-born population or to migration from other states. To the extent that immigration can be regulated or high fertility discouraged, the population growth rate can be partially controlled. It is well established that population growth negatively affects air quality. The magnitude of this effect, however, is unknown and may require assessment of a set of complex factors. Before a case for mitigation of the negative impacts or for controlling population growth can be made, the effects of population growth on emissions must be estimated.

Estimation of the effects of population growth should help the planning process for attainment of air quality standards. Due to air quality management programs, air quality has steadily improved in the State despite population growth. Estimation of the negative effects of population growth will clarify the positive benefits of past air quality management programs and will indicate the challenge to current management programs posed by continuing population growth.

The objective of this research is to better understand and estimate the net effects of population growth on emissions in California. A second objective is to estimate the net positive benefits of air quality management programs, which have offset the negative effects of population growth and achieved net reductions in emissions.

This report begins, in the next section, with background information on trends in population growth and emissions in California. This is followed by a general description of the methodology used here to examine the effects of population growth on emissions. The next two sections describe problems encountered during the research, involving data quality and isolating population growth from other factors that affect emissions; and describes the solutions adopted to overcome these problems. The final sections present the research results and discuss their implications.

**Background**

In 1993 the Demographic Research Unit in the Department of Finance projected that the population of California would increase from 31 million to about 63 million by 2040.[1] The recent economic recession has slowed the rate of population growth to the extent that the projections made in 1993 may be overestimating the future population. No one, however, doubts that California's population will increase substantially in the next decades, even if it may not actually double in size.

Despite rapid population growth in recent decades, most criteria pollutant emissions in California have declined since 1980. This is because the gains from regulations and cleaner technologies have offset the upward pressures due to population and economic growth. According to Air Resources Board projections[2], in the absence of new regulations and further improvements in technology, the decline in emissions will slow by 2010. After that date, emissions of some of the pollutants would begin to increase because of population and economic growth. It is unclear from ARB projections what the actual impact of population is, net of trends in other factors that affect emissions.

Population growth and changes in technology or regulatory policy are not the only factors that affect emissions. Demographers and environmentalists often categorize other causal factors as "economic activities[3]." Included here are changes in patterns and levels of production and consumption. For example, analyses of global releases of greenhouse gases since 1965 suggest that about one-third of the increase in releases was due to population growth and about two-thirds was due to rising standards of living and levels of consumption.[4] An analogous example from a different area of environmental concern is the increased global demand for food in recent decades; about half the increase in demand was due to population growth, and about half due to rising per capita consumption (including a dietary shift toward more meat consumption in developing regions, especially China).[5] Clearly, economic activities must be taken into account when estimating the net impacts of population growth. The two most important economic factors are per capita income (i.e. level of consumption) and economic restructuring (i.e. disproportionate growth of some industrial sectors relative to others).

Research on the effects of population growth, therefore, requires data or a statistical model that reflect population growth only, with other factors such as regulations, technology, and economic activities held constant. Such data or models are not readily available. The first task of the research project was to find or develop appropriate data and models. Because this work is experimental, the project was limited in scope. The most important limitation was to restrict the analysis to two air basins known to have reasonably complete data; these are the South Coast and the San Joaquin Valley air basins. Once the feasibility of the project was established, the methodology could be extended to all of California.

A general overview of the methodology is presented in the following section, and specific challenges and problems are described in subsequent sections.

## Methodology

The research strategy adopted for this project was to calculate a variety of emissions projections using carefully selected scenarios of population growth, economic activities, and regulations. By comparing alternative projections based on different assumptions about trends in the causal factors, one can determine the implications of the different assumptions. Scenarios that represent different rates of population growth but identical trends in economic activity and regulations provide information about the effects of population growth on emissions. Alternatively, scenarios with identical trends in population growth and economic activity but with different assumptions about regulations provide information on the efficacy of regulations.

The Air Resources Board emissions projection model essentially projects baseline emissions using growth factors and control factors. Growth factors represent population growth and/or the trend in economic activity. For example, if 1990 data on emissions are used as the baseline, a growth factor of 1.2 for the year 2010 indicates that emissions will increase 20% from 1990 to 2010 due to population growth and/or changes in economic activity. Control factors reflect changes in regulations and changes in technology mandated by regulations. For example, if 1990 data on emissions are used as the baseline, a control factor of 0.9 for the year 2010 indicates that emissions will decline by 10% from 1990 to 2010 due to the implementation of new regulations. If all causal factors are changing, the projected emissions are simply the product of baseline emissions and the growth and control factors. In the examples above, the product of 1.2 and 0.9 is 1.08, indicating that emissions would increase

8% from 1990 to 2010 due to the combined effects of population growth, changes in economic activities, and implementation of new regulations.

The emissions projection model is highly disaggregated. Five criteria pollutants are projected separately: reactive organic gases (ROG), oxides of nitrogen ($NO_x$), oxides of sulfur ($SO_x$), carbon monoxide (CO), and small particulate matter ($PM_{10}$). Growth factors are the same for all five criteria pollutants, but different control factors are defined for each criteria pollutant. In addition, separate growth and control factors are defined for detailed sources of emissions. For example, the growth factor for manufacturing of apparel represents the change in dollar output in the apparel industry from the base year to the current year (e.g. from 1990 to 1995, or from 1990 to 2010). Most growth factors are measured in terms of changes in dollar output or employment, but a few have unique units (e.g. barrels of oil, number of registered recreational boats). Over 100 growth factors and over 150 control factors are defined for each criteria pollutant. Finally, emissions are projected for each county separately, requiring numerical values of all growth and control factors for each county.

In official ARB projections, emissions from on-road mobile sources are projected by a different methodology. For most counties, vehicle miles traveled by each class of vehicle are projected on the basis of trends in population and per-capita income. For each future date in the projection, vehicle miles traveled are converted into emissions based on a complex model of changes in fleet composition, number of trips, and emissions produced by each trip. Some counties (including those in the South Coast Air Basin) use more sophisticated transportation models to project vehicle miles traveled and emissions from on-road vehicles. Thus, conventional growth factors and control factors do not exist for on-road mobile sources. For consistency with the overall projection model, ARB constructs two sets of numbers for on-road mobile sources, which it calls pseudo-growth factors and pseudo-control factors. These are not comparable to conventional growth and control factors, but when used together they reproduce the more refined projections for on-road mobile sources.

Emissions projections are computed by multiplying base-year emissions by the appropriate growth and control factors. For this research, the base year was 1993 (the latest year for which annual emissions had been estimated for the Emissions Inventory) and emissions were projected forward to 2010 and backward to 1975. Results are expressed as the ratio of emissions in a year relative to emissions in 1975, i.e. as if 1975 were the base year.

The projection scenarios used in this research are defined in terms of growth and control factors. Two types of scenarios are utilized. The first type, called Baseline, uses the actual growth and control factors currently utilized by Air Resources Board. The growth factors represent the combined effects of population growth and changes in economic activities; no effort was made to separate these two factors. Three baseline scenarios were specified:

B1. This scenario used existing growth factors but set all control factors to unity (1.0). This scenario indicates the trend in emissions that would have occurred with the observed and expected rates of growth in California but with no new regulations implemented since 1975.

B2. This scenario used existing control factors but set all growth factors to unity (1.0). This scenario indicates the trend in emissions that would have occurred had there been no growth in California but with the regulations actually adopted and implemented.

B3. This scenario used existing growth and control factors; it represents the actual and expected trend in emissions given the actual growth and regulations observed in California.

Scenario B1 provides an estimate of the impact of growth in California net of any changes in regulations; an alternative estimate of this impact is provided by the comparison of scenarios B2 and B3 (which have identical control factors but different growth factors). This impact is due both to population growth and to changes in economic activity; it represents an upper limit to the possible impacts of population growth alone.

Similarly, scenario B2 provides an estimate of the impact of regulations in California net of any changes in population or economic activity; an alternative estimate of this impact is provided by the comparison of scenarios B1 and B3 (which have identical growth factors but different control factors).

The second type of scenario, called Hypothetical, uses growth factors that were constructed specifically to represent population growth but no exogenous changes in economic activity. The construction of these growth factors is described in a later section of this report. In these scenarios, as in B1 above, control factors were all set to unity (1.0), so that the scenarios provide estimates of the impact of population growth net of any changes in regulations (or economic activity). Two hypothetical scenarios were specified; these are described in a later section.

The sources and quality of the data on growth and control factors used in the Baseline scenarios are discussed in the next section. In the following section, the construction of growth factors for the Hypothetical scenarios is explained.

## Sources and Quality of Data

Many regulations aimed at reducing emissions are imposed and implemented by local air quality management and control boards and vary from one local area to another, so data on control factors come from the local boards. Some regulations apply statewide, and in these cases control factors are computed by Air Resources Board staff in Sacramento. No effort was made in this project to investigate how control factors are computed or to evaluate their accuracy.

Growth factors represent estimates and projections of population size and economic activities for counties. In most cases the data and projections are provided to ARB by a subcontractor, DRI/McGraw-Hill (DRI), and detailed information about the data and projections are proprietary and unavailable. The econometric model used by DRI/McGraw-Hill to produce county-level projections can be described in general terms.[6] Employment and output in detailed industries in the United States are used to estimate output and employment in California; these estimates, in turn, are used to estimate output and employment in specific industries in each county. At each stage of disaggregation, assumptions are made about local trends and competitive advantages based on population projections, real estate prices, labor supply, wages, etc. Initial population data are from the U.S. Census Bureau, but population projections are generated by the econometric model on the basis of projections of employment. To a very large extent, the model projects employment; population simply is assumed to adjust to the supply of jobs and the demand for labor. For this reason, the DRI model cannot be used to compute growth factors that represent only population growth net of any changes in economic activity. The population projection produced by this model differs considerably from the projection produced by the California Department of Finance.

Because details of the DRI model are proprietary, it is impossible to evaluate the quality of data on growth factors.

Fortunately there is an alternative source of data for the South Coast air basin; comparison of the two sources of data cannot indicate which data are "correct," but it does provide a clue about the reliability of estimates of growth factors. The alternative estimates of growth factors in the South Coast air basin (from 1990 to 2010) are provided to ARB by the South Coast Air Quality Management District and the Southern California Association of Governments (which I shall designate SCAG). The SCAG model[7] generally resembles the DRI model in overall logic. National economic trends are used to estimate regional and county trends in employment and output in specific industries based on assumptions about regional and local shares of national production. County and regional population projections are developed independently. The reconciliation of employment and population projections strongly favors the employment projection, so to a large extent population is projected on the basis of supply of jobs and demand for labor.

Growth factors from 2000 to 2010 from the DRI and SCD models are compared in Table 1 next page. Table 1 lists growth factors for a selection of specific sources (called growth codes) for two counties in the South Coast air basin, Los Angeles and Orange. For a number of growth codes, the DRI and SCAG growth factors are quite similar; e.g. growth codes 140, 260, 293, 320, and 420. Recall, however, that growth factors represent growth over a time interval; e.g. a growth factor of 1.12 indicates 12% growth. Thus growth factors that may look similar, such as 1.16 and 1.08 (growth code 270 for Los Angeles), actually represent quite different rates of growth; in this example, one is double the other. In many instances the DRI and SCAG growth factors are quite different; e.g. growth codes 110,133,210,294, and 440. The evidence in Table 1 suggests that estimates of growth factors are not very reliable, and estimates from either model should be viewed skeptically.

In the absence of additional information, it is impossible to determine which model provides more accurate estimates of growth factors. Because of convenience and availability, the DRI estimates of growth factors are used in the Baseline scenarios for both San Joaquin and South Coast air basins.

As noted earlier, emissions from on-road mobile sources are projected by an entirely different methodology, and pseudo growth and control factors are derived from these projections by ARB for use in the general ARB projection model. These pseudo growth and control factors were not constructed so as to be comparable to actual growth and control factors and are invalid when used separately in artificial scenarios. For example, in the "growth only" (B1 Baseline) scenario where control factors are set to

Table 1

Comparison of growth factors from two sources, DRI/McGraw-Hill (DRI) and South Coast Air Quality Management District (SCAG).

| Growth Codes | Growth Factors 2000-2010 | | | | Source Category |
|---|---|---|---|---|---|
| | Los Angeles | | Orange | | |
| | DRI | SCAG | DRI | SCAG | |
| 110 | 1.08 | .90 | 1.09 | .92 | Agriculture |
| 133 | 1.36 | .64 | 1.28 | .56 | Mining |
| 140 | 1.00 | 1.00 | .94 | 1.00 | Petrol. Prod. |
| 200 | 1.20 | 1.26 | 1.49 | 1.27 | Manufacturing |
| 210 | 1.11 | .96 | 1.16 | .97 | " |
| 220 | 1.17 | 1.13 | 1.19 | 1.12 | " |
| 230 | 1.22 | 1.35 | 1.22 | 1.35 | " |
| 240 | 1.17 | 1.27 | 1.28 | 1.28 | " |
| 260 | .96 | 1.00 | 1.07 | 1.00 | Petrol. Refin. |
| 270 | 1.16 | 1.08 | 1.19 | 1.09 | Manufacturing |
| 290 | .80 | .88 | .85 | .91 | " |
| 291 | 1.03 | 1.18 | 1.15 | 1.17 | " |
| 293 | 1.12 | 1.09 | 1.13 | 1.09 | " |
| 294 | 1.49 | 1.39 | 1.70 | 1.48 | " |
| 298 | 1.35 | 1.48 | 1.41 | 1.52 | " |
| 300 | 1.27 | 1.34 | 1.30 | 1.46 | Services |
| 310 | 1.14 | 1.14 | 1.16 | 1.14 | Electric util. |
| 320 | 1.18 | 1.18 | 1.19 | 1.18 | Petrol. Market. |
| 420 | .97 | .95 | .98 | 1.00 | Railroads |
| 440 | 1.08 | 1.14 | 1.08 | 1.17 | Airports |
| 500 | 1.04 | 1.09 | 1.12 | 1.10 | Consumer prod. |
| 610 | 1.13 | 1.03 | 1.15 | 1.14 | Construction |
| 911 | 1.06 | 1.10 | 1.15 | 1.11 | Archit. Coating |

unity and emissions should increase, projected emissions of ROG and CO from on-road mobile sources actually decline. Similarly, in the "control only" (B2 Baseline) scenario where growth factors are set to unity and emissions should remain constant or decline, projected emissions from on-road mobile sources generally increase.

The pseudo growth and control factors for on-road mobile sources are not incorrect; they simply were constructed for other purposes and are inappropriate for use in the hypothetical scenarios. For this reason, on-road mobile sources are excluded from this research. Estimates of the effects of population growth net of other factors are presented for all other sources (including off-road mobile sources), and for all stationary sources.

The exclusion of on-road mobile sources from the research is unfortunate, as these are major sources of emissions.[8] On the other hand, the effects of population growth on emissions from on-road mobile sources are likely to be rather complex and subtle, and the ARB projection models for most counties are not sufficiently sophisticated to provide realistic estimates of these effects. Population growth leads to dispersion of the population into suburban areas as well as increased densities in the central cities. These changes in population distribution should cause changes in congestion, number of trips, duration of trips, and average speed, all of which affect emissions. The ARB projection model for on-road mobile sources used for most counties does not take such changes in population distribution into account. The Southern California Association of Governments transportation model does take changes in population distribution into account (as do models used in selected other counties), but this model was not available for this research.

One additional restriction was imposed on the scope of this research. Recent research has raised doubts about the quality of data on small particulate matter ($PM_{10}$) and about the assumptions used in ARB projection models regarding $PM_{10}$, so the research is restricted to the other four criteria pollutants. To summarize all restrictions on the research, only two air basins in California are considered and $PM_{10}$ pollutants and on-road mobile sources are excluded from the projections.

One final issue of data quality concerns the mechanical process of specifying growth factors and tranmitting them to ARB, and ARB inputting these growth factors into the model and obtaining output. Clerical errors could occur at any step of the process, in which case the output would not correspond well to the intended input data. One way to check for clerical errors is to compare the intended growth factors with the actual projected emissions for specific source categories. A difficulty here is that the growth codes for which growth factors are specified generally do not correspond directly to the source categories for which output is produced. Many growth codes factor into multiple source categories, and many source categories are affected by multiple growth codes. A few instances in which a single growth factor seems to map into a single source category (e.g. residential fuel combustion, architectural coatings) were examined, and the emissions trend was found to match the growth factor, but such checks are inconclusive.

For a more precise check on quality control, a Test scenario was estimated as well as the Baseline and Hypothetical scenarios described earlier. In the Test scenario, all control factors were set to unity and all growth factors for all sources in each county were set to the rate of population growth (using Department of Finance population projections for counties). For example, the population of Fresno County is projected to increase 166% from 1975 to 2010 (a ratio of 2.66); thus all growth factors for Fresno County for 2010 were set at 2.66 Since all growth factors are identical for all growth codes in each county, projected emissions should increase at exactly the rate of population growth.

Projected emissions from stationary sources are compared to projected population growth in Table 2 next page for the two air basins and each county in these air basins. Projected trends in ROG, $NO_x$, and $SO_x$ emissions (from 1975 to 2010) are very similar or identical to population trends in nearly every county; the only exceptions are ROG in Riverside County and $NO_x$ in Tulare and Riverside Counties. CO projections, on the other hand, differ substantially from population growth in many counties. In Fresno County, for example, the projected growth of population is 2.66 and the projected increase in ROG emissions is 2.63, but the projected increase in CO emissions is ony 1.86.

The discrepancies between emissions and population trends observed in Table 2 can be explained by wildfires ("unplanned fires"). Apparently the projection model ignores the input growth factor for wildfires and assigns a growth factor of unity instead. In many counties wildfires account for a large share of CO emissions from stationary sources[9]; because other stationary sources are unusually slight, wildfires also account for a substantial share of ROG and $NO_x$ emissions in Riverside County and $NO_x$ emissions in Tulare County. Because the same set of growth factors is used for all criteria pollutants, and because these growth factors seem to have "worked" for three of the pollutants (most of the time), clerical errors apparently did not

Table 2

Projected growth of population and of emissions from stationary sources from 1975 to 2010, from the Test scenario.[1]

| County | Pop. | ROG | $NO_x$ | CO | $SO_x$ |
|---|---|---|---|---|---|
| San Joaquin Valley Air Basin | 2.65 | 2.75 | 2.64 | 2.20 | 2.58 |
| Fresno | 2.66 | 2.63 | 2.63 | 1.86 | 2.66 |
| Kern | 2.82 | 2.82 | 2.79 | 1.89 | 2.83 |
| Kings | 2.40 | 2.40 | 2.40 | 2.39 | 2.40 |
| Madera | 3.25 | 3.20 | 3.19 | 2.54 | 3.24 |
| Merced | 2.61 | 2.60 | 2.61 | 2.58 | 2.62 |
| San Joaquin | 2.42 | 2.42 | 2.42 | 2.41 | 2.41 |
| Stanislaus | 2.89 | 2.89 | 2.89 | 2.85 | 2.90 |
| Tulare | 2.39 | 2.31 | 2.13 | 1.90 | 2.40 |
| South Coast Air Basin | 1.90 | 1.86 | 1.84 | 1.28 | 1.72 |
| Los Angeles | 1.57 | 1.56 | 1.56 | 1.20 | 1.57 |
| Orange | 1.84 | 1.84 | 1.83 | 1.44 | 1.84 |
| Riverside | 4.25 | 4.01 | 3.88 | 1.23 | 4.27 |
| San Bernardino | 3.30 | 3.23 | 3.22 | 1.60 | 3.29 |

1. The Test scenario is a projection with all control factors set equal to unity (1.0) and all growth factors in a county set equal to the population growth rate for that county (e.g. in Fresno County, all growth factors for year 2010 set equal to 2.66). Growth factors are expressed as ratios of 2010 to 1975 levels.

occur and growth and control factors were properly assigned in the projections. Projections of CO, however, do not always correspond to intended growth factors because of the internally-assigned factor for wildfires, so all results of CO projections reported below should be interpreted cautiously.

## Isolating the Effects of Population

The ARB emissions projection model utilizes growth and control factors to project baseline emissions. For each county there are over 100 growth factors representing trends in production for specific industries and trends in consumer activities that produce emissions. For this research project, it is necessary to define growth factors that represent only the effects of population growth, not economic changes unrelated to population. How to isolate the effects of population growth net of unrelated economic changes is quite controversial.

The most obvious and simplest approach is to assume that every industry and consumer activity grows at the same rate as population. For example, if population grows by 10%, then agricultural production, petroleum refining, electricity generation, textile manufactures, air travel, and off-road vehicles might all increase by 10%. This simplistic approach is incorrect because of boundaries. We are examining the effects of population growth within specific counties and air basins in California. Some goods consumed by the local population are produced elsewhere, so local population growth leads to industrial expansion elsewhere but not locally. In addition, some goods produced locally are sold elsewhere (i.e. exported out of the county or air basin), so trends in local industry depend in part on population growth elsewhere but not local population growth. For example, population growth in Fresno County does not necessarily cause proportional growth in agricultural production in Fresno County; indeed, to the extent that population growth causes conversion of agricultural land to residential, agricultural production in Fresno County could decline due to local population growth.

A second approach, exemplified in the DRI and South Coast models of economic and population dynamics (and other "computable general equilibrium" models, or CGE[10]), is to assume that population and economic trends cannot be separated because population adjusts to the demand for labor. Growth factors estimated by CGE models vary, with some industrial and consumer sectors growing more rapidly than others. There are two difficulties with this approach. The first is that it is empirically incorrect. It is true that there is considerable migration into and out of California in response to economic trends and the demand for labor. But the majority of population growth is due to natural increase and immigration, which occur for reasons largely unrelated to economic trends. Immigration into California is influenced mostly by economic circumstances in the sending country and is not highly sensitive to the demand for labor in California. Birth and death rates also are largely insensitive to the demand for labor in California.

The second difficulty with CGE models is that the economic trends that drive them largely reflect factors unrelated to population. The variation in growth factors across industrial and consumer sectors is due partly to shifting tastes associated with rising incomes and partly to the ongoing restructuring of the global economy. Thus growth factors estimated by DRI isolate the effects of economic trends, not population trends; this is essentially the opposite of what we want for this research.

Almost certainly, exogenous county population growth[11] induces relatively rapid increases (i.e. large growth factors) in some industrial and consumer sectors and slower increases (small growth factors) in other sectors. Very little research directly addresses this topic. Two studies, however, provide useful clues that have been used here to define growth factors. One study used ARB data on emissions in 1980 and 1990, with detailed sources of emissions aggregated into 13 broad source categories.[12] A simple statistical model was used to estimate the effect of population growth in counties from 1980 to 1990 on emissions of each criteria pollutant from each of the 13 source categories, net of the effects of per capita income and regulatory efforts (represented by control factors). The results are a set of population elasticities; for example, the population elasticity for ROG emissions from off-road mobile equipment (e.g. farm tractors, construction equipment) is 0.421, indicating that a 10% increase in population is associated with a 4.21% increase in ROG emissions from equipment. The elasticities indicate that some broad source categories are more responsive than others to population growth; for example, residential and commercial activities, solvent use, and off-road vehicles are fairly responsive, while industrial and agricultural processes and waste burning are relatively unresponsive.

Using the results from that study, an elasticity has been assigned to each of the more than 100 growth codes by linking each growth code to the most appropriate of the 13 broad source categories; the growth codes and elasticities are shown in Appendix Table A-1 as Hypothetical Scenario 1. The elasticities are the same for all counties. Growth factors were constructed for each growth code and county using the following formula:

$$GF = 1.0 + ((P - 1.0)*E)$$

where GF is the growth factor for a specific growth code and county, E is the elasticity for that growth code, and P is the population growth for that county relative to 1975 (e.g. 1.20 represents 20% growth since 1975). The population trends used in this calculation, based on Department of Finance projections, are shown in Appendix Table A-2.

The second relevant study of population and economic activity was research conducted by economists at Resources For The Future (RFF) in the early 1970s for the U.S. Commission on Population and the American Future.[13] The RFF economists used U.S. Census Bureau population projections and detailed consumption functions for specific commodities (which they had estimated from consumer survey data) to project the demand for various types of goods.[14] They then used an elaborate input-output matrix to convert the demand for goods into projections of industrial output for detailed industries. By comparing the projections of industrial output associated with alternative population projections, it is possible to compute approximate population elasticities for specific industries. These elasticities indicate the percentage growth in output in specific industries associated with a one-percent increase in population. For example, the output elasticity with respect to population implied by the RFF data is .55 for construction, .35 for chemicals, .64 for rubber and plastics, .46 for paper products, and .41 for services. These elasticities were used to modify the elasticities from Hypothetical Scenario 1; the resulting elasticities are shown in Appendix Table A-1 as Hypothetical Scenario 2 (H2). These elasticities were used to construct growth factors as described above.

The variation in RFF elasticities supports the contention that population growth affects some industrial sectors more than others. The overall elasticity for manufacturing (.41) is somewhat greater than the elasticity calculated in the first study for industrial processes (about .2), but in both cases the elasticities are rather small, suggesting that industrial output increases at a slower rate than population in a high-income, advanced industrial society. The similarity of elasticities in the two studies is remarkable given the very different methodologies employed.

The RFF research did not end with calculations of industrial output associated with population projections. The RFF economists estimated emissions of criteria pollutants associated with the industrial output by utilizing information about production technologies and making assumptions about future technologies. By comparing the emissions associated with different population projections (with economic growth and technology identical in each projection, and thus held constant), it is possible to estimate approximate population elasticities. The emission elasticities with respect to population in the RFF study are .29 for hydrocarbons, .42 for sulfur oxides, .26 for carbon monoxide, and .29 for nitrogen oxides.[15] We shall see how these compare to the elasticities calculated here using ARB data and alternative projection scenarios.

**Emissions Elasticities with Respect to Population**

Trends in emissions from stationary sources in the two air basins are shown in Table 3 for the three Baseline and two Hypothetical projection scenarios. Trends in emissions from all sources except on-road mobile sources are shown in Table 4. In both tables, trends are expressed as ratios of emissions in 1990 or 2010 relative to emissions in 1975; e.g. a ratio of 1.79 indicates that emissions increased by 79% since 1975. Trends in population also are shown for comparison.

Close inspection of the Baseline scenarios reveals a number of anomalies. In the "growth only" (B1) scenario for the San Joaquin Valley Air Basin, for example, $NO_x$ emissions from stationary sources increase substantially whereas $NO_x$ emissions from "all" sources[16] increase only very slowly. This occurs because the ARB growth factors indicate a very rapid decline in train traffic in the San Joaquin Valley (an off-road mobile source), and trains produced some 40% of $NO_x$ emissions in 1975 (but trains are a minor source of emissions of other criteria pollutants). The decline in train emissions offsets the increase in $NO_x$ emissions from stationary sources. Another anomaly in the trends for the San Joaquin Valley Air Basin is the very rapid increase in ROG emissions under the B1 scenario, much more rapid than population increase. This occurs because of a very large increase in oil and gas production and extraction between 1975 and 1990, and then a gradual decline in oil and gas production through 2010. This may be an accurate projection, but it certainly does not indicate changes due to population growth. Finally, the trend in CO emissions in the San Joaquin Valley Air Basin is modest, but also misleading. About half of the CO emissions are due to waste burning of agricultural debris and rangelands and forest management; these sources increase between 1975 and 1980 and then remain constant through 2010. Another 25% of CO emissions are due to uncontrolled fires, which are projected as constant from 1975 to 2010. Again, these are trends

Table 3

Trends in population and emissions from stationary sources[1] from 1975 to 1990 and to 2010 under alternative projection scenarios.

| Scenario | Population[2] | Projected Emissions ROG | $NO_x$ | CO | $SO_x$ |
|---|---|---|---|---|---|
| San Joaquin Valley Air Basin | | | | | |
| B1. Baseline, Growth Only | | | | | |
| 1990 | 1.56 | 1.79 | 1.69 | 1.31 | 1.05 |
| 2010 | 2.75 | 1.78 | 2.21 | 1.49 | 1.45 |
| B2. Baseline, Control Only | | | | | |
| 1990 | 1.00 | 0.49 | 1.00 | 1.00 | 1.00 |
| 2010 | 1.00 | 0.42 | 0.89 | 1.00 | 1.00 |
| B3. Baseline, Growth & Control | | | | | |
| 1990 | 1.56 | 0.61 | 1.72 | 1.31 | 1.05 |
| 2010 | 2.75 | 0.57 | 2.04 | 1.49 | 1.45 |
| H1. Hypothetical Elasticities 1 | | | | | |
| 1990 | 1.50 | 1.39 | 1.25 | 1.08 | 1.15 |
| 2010 | 2.65 | 2.41 | 1.86 | 1.27 | 1.50 |
| H2. Hypothetical Elasticities 2 | | | | | |
| 1990 | 1.50 | 1.14 | 1.20 | 1.07 | 1.16 |
| 2010 | 2.65 | 1.49 | 1.67 | 1.24 | 1.53 |
| South Coast Air Basin | | | | | |
| B1. Baseline, Growth Only | | | | | |
| 1990 | 1.32 | 0.74 | 0.70 | 0.99 | 0.47 |
| 2010 | 1.70 | 1.02 | 1.02 | 1.10 | 0.67 |
| B2. Baseline, Control Only | | | | | |
| 1990 | 1.00 | 0.47 | 0.76 | 1.00 | 0.91 |
| 2010 | 1.00 | 0.34 | 0.28 | 1.00 | 0.82 |

Table 3 (cont.)

Trends in population and emissions from stationary sources[1] from 1975 to 1990 and to 2010 under alternative projection scenarios.

| Scenario | Population[2] | Projected Emissions | | | |
|---|---|---|---|---|---|
| | | ROG | $NO_x$ | CO | $SO_x$ |
| B3. Baseline, Growth & Control | | | | | |
| 1990 | 1.32 | 0.37 | 0.55 | 0.99 | 0.32 |
| 2010 | 1.70 | 0.37 | 0.38 | 1.10 | 0.33 |
| H1. Hypothetical Elasticities 1 | | | | | |
| 1990 | 1.35 | 1.20 | 1.14 | 1.06 | 1.16 |
| 2010 | 1.90 | 1.51 | 1.36 | 1.15 | 1.40 |
| H2. Hypothetical Elasticities 2 | | | | | |
| 1990 | 1.35 | 1.23 | 1.17 | 1.06 | 1.11 |
| 2010 | 1.90 | 1.57 | 1.44 | 1.16 | 1.27 |

1. Trends in population and emissions are expressed as ratios relative to 1975 levels; e.g. 1.56 represents a 56% increase from 1975.

2. Population trends are based on DRI/McGraw-Hill data in the Baseline scenarios and Department of Finance data in the Hypothetical scenarios.

Table 4

Trends in population and emissions from all sources except on-road mobile sources[1] from 1975 to 1990 and to 2010 under alternative projection scenarios.

| Scenario | Population[2] | Projected Emissions ROG | $NO_x$ | CO | $SO_x$ |
|---|---|---|---|---|---|
| San Joaquin Valley Air Basin | | | | | |
| B1. Baseline, Growth Only | | | | | |
| 1990 | 1.56 | 1.72 | 1.05 | 1.21 | 1.02 |
| 2010 | 2.75 | 1.74 | 1.20 | 1.46 | 1.27 |
| B2. Baseline, Control Only | | | | | |
| 1990 | 1.00 | 0.53 | 0.99 | 1.00 | 1.00 |
| 2010 | 1.00 | 0.44 | 0.78 | 0.86 | 0.94 |
| B3. Baseline, Growth & Control | | | | | |
| 1990 | 1.56 | 0.64 | 1.04 | 1.22 | 1.02 |
| 2010 | 2.75 | 0.60 | 0.92 | 1.35 | 1.27 |
| H1. Hypothetical Elasticities 1 | | | | | |
| 1990 | 1.50 | 1.38 | 1.19 | 1.14 | 1.16 |
| 2010 | 2.65 | 2.37 | 1.66 | 1.45 | 1.52 |
| H2. Hypothetical Elasticities 2 | | | | | |
| 1990 | 1.50 | 1.14 | 1.14 | 1.11 | 1.14 |
| 2010 | 2.65 | 1.49 | 1.45 | 1.35 | 1.45 |
| South Coast Air Basin | | | | | |
| B1. Baseline, Growth Only | | | | | |
| 1990 | 1.32 | 0.80 | 1.03 | 1.40 | 0.80 |
| 2010 | 1.70 | 1.08 | 1.18 | 1.60 | 0.92 |

Table 4 (cont.)

Trends in population and emissions from all sources except on-road mobile sources[1] from 1975 to 1990 and to 2010 under alternative projection scenarios.

| Scenario | Population[2] | Projected Emissions ROG | $NO_x$ | CO | $SO_x$ |
|---|---|---|---|---|---|
| B2. Baseline, Control Only | | | | | |
| 1990 | 1.00 | 0.50 | 0.86 | 1.00 | 0.88 |
| 2010 | 1.00 | 0.36 | 0.46 | 0.92 | 0.81 |
| B3. Baseline, Growth & Control | | | | | |
| 1990 | 1.32 | 0.44 | 0.93 | 1.41 | 0.62 |
| 2010 | 1.70 | 0.43 | 0.60 | 1.41 | 0.59 |
| H1. Hypothetical Elasticities 1 | | | | | |
| 1990 | 1.35 | 1.20 | 1.13 | 1.13 | 1.11 |
| 2010 | 1.90 | 1.49 | 1.32 | 1.31 | 1.28 |
| H2. Hypothetical Elasticities 2 | | | | | |
| 1990 | 1.35 | 1.22 | 1.15 | 1.14 | 1.09 |
| 2010 | 1.90 | 1.55 | 1.38 | 1.35 | 1.23 |

1. Trends in population and emissions are expressed as ratios relative to 1975 levels; e.g. 1.56 represents a 56% increase from 1975.

2. Population trends are based on DRI/McGraw-Hill data in the Baseline scenarios and Department of Finance data in the Hypothetical scenarios.

that are unrelated to population growth.

Anomalies also appear in Baseline projections for the South Coast Air Basin. The trend in CO emissions from stationary sources is flat because uncontrolled fires (which produce 65% of stationary sources emissions) are assumed to remain constant and because declines in emissions from oil and gas production and range management burning offset increases from other stationary sources. ROG, $NO_x$, and $SO_x$ emissions from stationary sources all decline in the "growth only" scenario because of a massive decline in oil and gas production and extraction (by over 95%), especially in 1990; production recovers somewhat by 1995 and then remains nearly constant through 2010.[17] Oil and gas production accounted for about 50% of $NO_x$ emissions and about 70% of $SO_x$ emissions from stationary sources in 1975.

The trends noted above are called "anomalies" because they reflect unusual industrial trends and assumptions about trends which are unrelated to population growth. The demise of the oil and gas extraction and production industry in the South Coast, especially in 1990, and the parallel surge in oil and gas extraction and production in the San Joaquin Valley, cannot be attributed to population trends. Nor can the demise of the train industry in the San Joaquin Valley be attributed to population trends. Similarly, assumptions about waste burning and uncontrolled fires in these Baseline projections seem unrelated to population trends. For these reasons, the Baseline scenarios (as presented here) cannot be used to compute the effects of population growth on emissions.

It is possible to omit anomalous sources from the Baseline scenarios and report trends in emissions from selected sources only. Two problems confront such an approach. First, it is not entirely clear which sources are anomalous; the unusual trends noted above are obvious, but other trends may also be anomalous but in less obvious ways. Secondly, this omits most of the major sources of emissions and focuses attention on only a small part of the air quality "problem." Nevertheless the 1975-2010 trends in emissions from selected sources[18] have been calculated under the Baseline "growth only" (B1) scenario; these are shown in the top panel of Table 5. These trends appear to be more plausible than those for "all" sources shown in Table 4.

The Baseline "growth only" scenario for selected sources may be used to calculate emissions elasticities with respect to population (i.e., the effect of population growth on emissions). These elasticities, shown in the bottom panel of Table 5, are computed simply by comparing the increase in emissions to the increase in population. For example, in the case of ROG

Table 5

Trends in population and emissions from selected sources only[1] from 1975 to 2010 under the Baseline "growth only" (B1) scenario, and emissions elasticities with respect to population.

| Air Basin | Population | Projected Emissions | | | |
|---|---|---|---|---|---|
| | | ROG | $NO_x$ | CO | $SO_x$ |
| Trends[2] 1975-2010 | | | | | |
| San Joaquin Valley | 2.75 | 2.34 | 1.98 | 2.36 | 1.80 |
| South Coast | 1.70 | 1.62 | 1.73 | 1.76 | 1.89 |
| Elasticities | | | | | |
| San Joaquin Valley | | 0.77 | 0.56 | 0.78 | 0.46 |
| South Coast | | 0.89 | 1.04 | 1.09 | 1.27 |

1. The selected sources include all stationary-source fuel combustion except oil and gas production and petroleum refining; "other" waste burning; all solvent use; all industrial processes; petroleum marketing; and several off-road mobile sources (off-road vehicles, mobile equipment, and utility equipment).

2. Trends in population and emissions are expressed as ratios relative to 1975 levels.

emissions from selected sources in the San Joaquin Valley Air Basin, the trend in emissions from 1975 to 2010 is 2.34 (134% increase) while the trend in population is 2.75; the emissions elasticity with respect to population, therefore, is 1.34/1.75 or 0.77. The elasticity for CO is comparable (0.78), while the elasticities for $NO_x$ and $SO_x$ are somewhat smaller (0.56 and 0.46 respectively). These elasticities indicate that emissions increase in response to population growth (and economic changes), but they do not increase as rapidly as population. Emissions elasticities with respect to population are larger in the South Coast air basin than in the San Joaquin Valley air basin, and for three criteria pollutants the elasticities are greater than 1.0; that is, emissions increase faster than population.

The emissions trends under the Hypothetical scenarios (shown in Tables 3 and 4) do not incorporate anomalies because they were calculated without reference to industrial or economic trends. The Hypothetical scenarios, therefore, may be used directly to calculate emissions elasticities with respect to population; these elasticities are shown in Table 6. Numerous elasticities are presented in Table 6, and it is necessary to simplify and generalize the results. In all cases, elasticities computed from 1975-1990 and 1975-2010 trends are very similar, so the time period of the projection can be disregarded; this helps simplify the table. Unfortunately, in other respects the results defy simplification.

The two hypothetical scenarios produce quite different estimates of elasticities for ROG emissions in the San Joaquin Valley air basin: about 0.8 in H1 and 0.3 in H2. This occurs because of the very different growth elasticities for petroleum production (growth codes 140-153, shown in Appendix Table A-1) used in the two scenarios -- 1.0 in H1 and 0.2 in H2 -- and because petroleum production is a major source of ROG emissions in the San Joaquin Valley air basin. The growth elasticity for petroleum production used in H1 was estimated by a statistical model from a relatively small sample (California counties with any petroleum production) and thus is unreliable; the data base for H2 seems more reliable in this case. Elasticities for other criteria pollutants in Table 6 besides ROG are reasonably similar under the two scenarios. Overall, the H2 elasticities seem more credible than the H1 elasticities in Table 6.

Elasticities calculated for stationary sources and for "all" sources are reasonably similar in the cases of ROG and $SO_x$ emissions in both air basins, but they differ substantially for $NO_x$ emissions in the San Joaquin Valley air basin and for CO emissions in the South Coast air basin. This occurs because off-road mobile sources produce a greatly disproportionate share of

Table 6

Emissions elasticities with respect to population, calculated from Hypothetical scenarios.

| Air Basin / Source / Scenario | ROG | $NO_x$ | CO | $SO_x$ |
|---|---|---|---|---|
| **San Joaquin Valley** | | | | |
| Stationary Sources | | | | |
| H1 | | | | |
| 1990 | 0.78 | 0.50 | 0.16 | 0.30 |
| 2010 | 0.85 | 0.52 | 0.16 | 0.30 |
| H2 | | | | |
| 1990 | 0.28 | 0.40 | 0.14 | 0.32 |
| 2010 | 0.30 | 0.41 | 0.15 | 0.32 |
| "All" Sources[1] | | | | |
| H1 | | | | |
| 1990 | 0.76 | 0.38 | 0.28 | 0.32 |
| 2010 | 0.83 | 0.40 | 0.27 | 0.32 |
| H2 | | | | |
| 1990 | 0.28 | 0.28 | 0.22 | 0.28 |
| 2010 | 0.30 | 0.27 | 0.21 | 0.27 |
| **South Coast** | | | | |
| Stationary Sources | | | | |
| H1 | | | | |
| 1990 | 0.57 | 0.40 | 0.17 | 0.46 |
| 2010 | 0.57 | 0.40 | 0.17 | 0.44 |
| H2 | | | | |
| 1990 | 0.66 | 0.49 | 0.17 | 0.31 |
| 2010 | 0.63 | 0.49 | 0.18 | 0.30 |
| "All" Sources[1] | | | | |
| H1 | | | | |
| 1990 | 0.57 | 0.37 | 0.37 | 0.31 |
| 2010 | 0.54 | 0.36 | 0.34 | 0.31 |
| H2 | | | | |
| 1990 | 0.63 | 0.43 | 0.40 | 0.26 |
| 2010 | 0.61 | 0.42 | 0.39 | 0.26 |

1. "All" sources are all except on-road mobile sources.

$NO_x$ emissions in the San Joaquin Valley air basin and of CO emissions in the South Coast air basin. In other words, the elasticities in Table 6 reflect the economic and consumption structures of the air basins in the base year of the projections.

Despite these complexities, certain general conclusions can be drawn from the figures in Table 6. In nearly all cases, elasticities are modest in size, nearly always less than 0.6. This indicates that while emissions increase with population growth, emissions increase much slower than the rate of population growth. In most cases, the effect of population growth on emissions is less for CO emissions, although this could be due to an artifact of the projection model (as demonstrated by the Test scenario). Under the H2 scenario the effect of population growth on emissions is quite similar for ROG, $NO_x$, and $SO_x$ emissions in the San Joaquin Valley air basin; but the effect of population is relatively greater for ROG emissions and relatively smaller for $SO_x$ emissions in the South Coast air basin, reflecting differences in industrial structures in the two air basins.

The elasticities from the Hypothetical scenarios in Table 6 cannot be compared to the elasticities from the Baseline "growth only" scenario in Table 5 because of the differences in sources. For the sake of comparison, emissions trends for 1975-2010 and elasticities under the Hypothetical (H2) scenario were calculated using the same selected sources of emissions used in constructing Table 5; these elasticities under the H2 scenario for emissions from selected sources are shown in Table 7.

The effects on elasticities of omitting "troublesome" or "anomalous" sources and focusing only on selected sources of emissions can be seen by comparing the elasticities in Table 7 with those for the 2010 H2 "all" sources projection in Table 6. The elasticities from selected sources in Table 7 are larger than the elasticities from "all" sources in Table 6, especially for ROG emissions in the San Joaquin Valley air basin (elasticities of 0.63 and 0.30 respectively); but in most cases the difference is small. With that one exception, the elasticities from selected sources are good approximations to the elasticities from "all" sources, at least under the Hypothetical scenario.

Elasticities from selected sources are substantially smaller under the Hypothetical scenario (Table 7) than under the Baseline "growth only" scenario (Table 5). The differences are moderate in the San Joaquin Valley air basin, ranging from 0.14 for ROG (elasticities of 0.63 compared to 0.77) to 0.40 for CO (0.38 compared to 0.78). The differences are larger and more variable in the South Coast air basin, ranging from 0.25 for ROG (0.64

Table 7

Trends in population and emissions from selected sources from 1975 to 2010 under the Hypothetical (H2) scenario, and emissions elasticities with respect to population.

| Air Basin | Population | Projected Emissions | | | |
|---|---|---|---|---|---|
| | | ROG | $NO_x$ | CO | $SO_x$ |
| Trends[1] 1975-2010 | | | | | |
| San Joaquin Valley | 2.65 | 2.04 | 1.50 | 1.62 | 1.49 |
| South Coast | 1.90 | 1.58 | 1.41 | 1.39 | 1.37 |
| Elasticities | | | | | |
| San Joaquin Valley | | 0.63 | 0.30 | 0.38 | 0.30 |
| South Coast | | 0.64 | 0.46 | 0.43 | 0.41 |

1. Trends in population and emissions are expressed as ratios relative to 1975 levels.

compared to 0.89) to 0.86 for $SO_x$ (0.41 compared to 1.27). The elasticities from the Hypothetical scenario represent the effects of population growth only, while the elasticities from the Baseline "growth only" scenario represent the combined effects of population growth and changes in production and consumption. Therefore it was expected that the former would be smaller than the latter, and the elasticities from the two scenarios can be interpreted as lower-limit and upper-limit estimates of the "true" elasticities.

There is no way of knowing, from the data available here, which estimate (i.e. which scenario) is closer to the "truth." If we take the midpoint between the two sets of estimates (i.e. the average), we obtain elasticities in the San Joaquin Valley air basin of 0.70 for ROG, 0.43 for $NO_x$, 0.58 for CO, and 0.38 for $SO_x$. These figures indicate that all emissions increase slower than population, and that the effects of population are greatest on ROG emissions and least on $SO_x$ emissions; a 10% increase in population produces a 7.0% increase in ROG emissions and a 3.8% increase in $SO_x$ emissions in the San Joaquin Valley air basin. The same procedure gives elasticities in the South Coast air basin of 0.76 for ROG, 0.75 for $NO_x$, 0.76 for CO, and 0.84 for $SO_x$; here population growth has about the same effect on all emissions, and this is larger than the effect of population growth on emissions in the San Joaquin Valley air basin.

Emissions elasticities with respect to population were estimated by Resources For The Future (RFF) economists for the entire United States in the early 1970's. Estimates for the United States should be larger than estimates for local counties or air basins because of different boundaries. Some impacts of population growth are not counted at the local level because the emissions occur in a different local area, but most of these "import/export" impacts would be counted in a study of the entire country. Nevertheless the RFF elasticities estimated for the United States are somewhat smaller than the elasticities estimated here, falling in a range from 0.26 to 0.42 (with $SO_x$ at the upper end and all other pollutants at the lower end). These differences in elasticities can be attributed to the large differences in methodology and to differences in the scope of sources considered. Perhaps the similarity of results is more remarkable than the differences.

**Impacts of Regulatory Efforts**

The principal focus of this research project is population growth, so the estimates of emissions elasticities with respect to population have been discussed at length. The figures in Tables 3 and 4 also provide information about the effects of regulatory efforts (control factors), however, and these deserve some discussion. On-road mobile sources are excluded from the analysis, and most other sources are regulated by air districts, not the state ARB; thus we shall discuss each air basin separately.

In the San Joaquin Valley air basin up to 1990, only ROG emissions were regulated; other criteria pollutants were unaffected by regulations. ROG emissions declined very considerably between 1975 and 1990 because of regulatory efforts; without regulations "all" ROG emissions would have increased by 72% (B1 scenario in Table 4), whereas in fact with regulations they actually declined by 36% (B3 scenario). This impact was due entirely to stationary sources (same scenarios in Table 3). The projections to 2010 indicate that anticipated regulations will have no further impact on ROG emissions and little impact on CO and $SO_x$ emissions. Anticipated regulations are projected to have a modest impact on "all" $NO_x$ emissions by 2010; without regulations "all" $NO_x$ emissions would increase by 20% (B1 scenario in Table 4), whereas in fact with regulations they are projected to decline by 8% (B3 scenario). The anticipated regulations affect mainly stationary sources, but also off-road mobile sources slightly.

In the South Coast air basin up to 1990, regulations had diminished ROG emissions sharply and $NO_x$ and $SO_x$ emissins slightly. Without regulations, "all" ROG emissions would have declined by 20% from 1975 to 1990 due to structural changes in the economy (B1 scenario in Table 4); in fact, with regulations they actually declined by 56% (B3 scenario). The impact of regulations on "all" $NO_x$ emissions was more modest; emissions actually declined by 7%, whereas without regulations they would have increased by 3%. Looking forward to 2010, anticipated regulations will continue to reduce ROG and $SO_x$ emissions and will have a sharp impact on $NO_x$ emissions. Without regulations, "all" $NO_x$ emissions would increase 18% from 1975 to 2010; in fact, with regulations they are projected to decline by 40%. These impacts of regulations are due entirely to stationary sources.

**Caveats**

Before summarizing the substantive results of this research, it is worthwhile to recall the caveats, qualifications, and limitations of the research. The purpose of the research was to estimate the effects of population growth on emissions using alternative projection scenarios. This approach is innovative, and to test its feasibility the research was limited to two air basins, San Joaquin and South Coast. Further limitations were imposed because of data availability; $PM_{10}$ emissions and emissions from on-road mobile sources are excluded from the research.

The ARB emissions projection system utilizes growth and control factors. The growth factors currently used by ARB (supplied by DRI/McGraw-Hill) incorporate both population growth and economic changes. Alternative growth factors for the South Coast Air Basin, supplied by the Southern California Association of Governments, often diverge substantially from the DRI growth factors; both sets of growth factors must be considered unreliable and must be used with caution.

In addition, for some specific industries/sources, economic changes are so large that any effects of population growth are obscured; anomalous results are obtained for these industries/sources, such as sharp drops in emissions in the "growth only" scenario. These industries/sources were excluded from the projection in order to estimate effects of population growth, but this greatly reduced the scope of the research. For some criteria pollutants, the sources not excluded account for only about 20% of total emissions (including emissions from on-road mobile sources); the research leaves us 80% ignorant of the impacts of population growth.

It proved to be extremely difficult to specify growth factors that reflect population growth but not economic change. The solution used here is innovative but imprecise; estimates of the effects of population growth on emissions vary widely between air basins, types of emissions, and assumptions about the relationship between population and economic growth. These results can only be interpreted as experimental and suggestive approximations.

### Conclusions and Recommendations

This report is rather long and technical, so it is worthwhile to summarize the main results. California's population is growing rapidly, posing a challenge to efforts to improve air quality. The primary purpose of the research was to estimate the effects of population growth on emissions. The research utilizes the ARB emissions projection system to calculate a variety of emissions projections using carefully selected scenarios of population growth, economic activities, and regulations. Scenarios that represent different rates of population growth but identical trends in economic activity and regulations provide information about the impact of population growth on emissions. Impact is measured as an elasticity: the percentage change in emissions due to a one-percent increase in population.

Broadly speaking, the results indicate that populaton growth has larger impacts on some sources of emissions and types of pollutants than others. This implies that the overall impact of population growth on emissions depends upon the composition of production and consumption in an area; impacts of population growth are different in the two air basins examined here. In all plausible cases, the emissions elasticity with respect to population probably is less than unity, so that emissions increase more slowly than population; but elasticities are greater than zero, so emissions do increase in response to population growth. In most cases, estimated elasticities were in the range from 0.3 to 0.7, indicating that a 10% increase in population produces an increase in emissions of from 3% to 7%. In both air basins the elasticity with respect to population seems to be larger for ROG emissions (closer to the 0.7 end of the range); elasticities are smaller and similar for the other criteria pollutants (closer to the 0.3 end of the range).

A secondary purpose of the research was to estimate the efficacy of regulatory programs in responding to the challenges posed by past population and economic growth. Hypothetical projection scenarios with identical trends in population growth and economic activity but with different assumptions about regulations provide information on the efficacy of regulations. The impact of regulations depends on the type of regulations implemented and on the structure of economic production and consumption, so the impacts differ somewhat in the two air basins. The largest impacts have been on ROG emissions from 1975 to 1990. (Recall that emissions from on-road mobile sources are excluded from this analysis.) With no new regulations after 1975, ROG emissions in the San Joaquin Valley air basin would have increased by 72% whereas in fact they declined by 36%. In the South Coast air basin from 1975-1990, without new regulations ROG emissions would have declined by 20% (largely due to economic restructuring) whereas in fact they declined by 56%. Regulations also are projected to have large impacts on $NO_x$ emissions, mainly from 1990 to 2010. Without new regulations, $NO_x$ emissions would increase from 1975 to 2010 by 20% and 18% respectively in the San Joaquin Valley and South Coast air basins, whereas in fact they are projected to decline by 8% and 40% respectively.

Because the results obtained here are so uncertain, tentative, and limited in scope, one immediately wonders what further research is needed. The original question remains interesting and important; California's population is growing, and it would be useful to know what impact this will have on emissions and air quality. The essential research on impacts of population growth involves estimating growth factors that more clearly and precisely isolate population growth from economic changes.

One approach to estimating appropriate growth factors would be to replicate the Resources For the Future research of the 1970's, using current data for California. This would be an enormous undertaking, requiring the estimation of dozens of consumption functions and the construction of a large, detailed input-output model of the California economy. Probably the results obtained would not justify the effort required.

A better approach would be to extend the statistical research on emissions that served as the basis for the growth factors in the hypothetical H1 scenario. That research utilized data from a cross-section of counties. Sources of emissions were aggregated into 13 broad categories so that all counties had reliable data. An alternative approach that would permit analyses of detailed sources of emissions would be to identify those counties with substantial emissions from each specific source and pool time series data on population and emissions from those selected counties. For each detailed source, a pooled cross-section of time series would be analyzed to estimate the effect of population growth on emissions from that specific source, holding other factors constant. This research would provide more reliable estimates of elasticities for more detailed sources than were available here for the Hypothetical (H1) scenario; these could be used to define growth factors and to estimate emissions from the ARB projection system.

The statistical research suggested above would apply to all sources. For on-road mobile sources, other approaches would be useful as well. Several transportation models exist that would permit simulation studies of the dynamics of population growth, such as geographic dispersion of population, changes in densities, and congestion. These topics cannot usefully be examined with ARB models of mobile sources emissions (e.g. EMFAC). The transportation model at Southern California Association of Governments would be useful, as would Tranus (available at UC Davis) or TRIPS[19].

## Endnotes

1. See California Department of Finance (1993).

2. See California Air Resources Board (1993).

3. This categorization of factors is based on the IPAT model developed by ecologists Paul Ehrlich and John Holdren (1971). A more sophisticated categorization is presented by Stern, Young, and Druckman (1992).

4. See Bongaarts (1992).

5. See Brown (1974). For more recent and precise data specifically on arable land area and livestock production (with similar conclusions), see Harrison (1993).

6. See DRI/McGraw-Hill (1994).

7. See Southern California Association of Governments (1996).

8. For example, on-road mobile sources accounted for the following shares of total emissions in California in 1990: 47% of ROG, 70% of CO, 56% of NOx, and 28% of Sox (based on Emissions Inventory data provided by ARB).

9. In the B3 ("growth and control") scenario, for example, the share of all stationary CO emissions due to wildfires in 1990 is 40% in Fresno County, 18% in the whole San Joaquin Valley air basin, and 68% in the South Coast air basin.

10. Berck et al. (1991) describe CGE models in general and demonstrate an application to water use in agriculture. The DRI model for air quality is described in DRI/McGraw-Hill (1994), Vol. II.

11. Population growth is considered exogenous here if it occurs "on its own," independent of economic trends. Growth due to natural increase (i.e. high fertility) and immigration is largely exogenous. Interstate migration may be partly exogenous, e.g. retired persons migrating in search of a gentle climate.

12. The study is described by Cramer (1998).

13. See Ridker (1972) for details.

14. They made projections from 1970 to 2000 and to 2020. The "low economic growth" projections to 2000 were used here for the

calculations of population elasticities (see Ridker, 1972, Table 2). Note that their projection time frame (1970-2000) is very similar to the one used here (1975-2010), although they made their projection at the beginning of the time period and the one here is made at the middle.

15. See Ridker (1972), Table 7.

16. For convenience, emissions from all sources except on-road mobile sources are referred to as emissions from "all" sources. As explained earlier, mobile sources are excluded from consideration here, so "all" refers to all sources considered in this research.

17. The trends in oil and gas production/extraction under the Baseline "growth only" (B1) scenario are worth noting in detail because they are so erratic; there may be problems with data quality. ROG emissions from oil and gas extraction in the two air basins (in thousands of tons per year) are as follows (where SJV is the San Joaquin Valley air basin and SC is the South Coast air basin):

| | SJV | SC |
|---|---|---|
| 1975 | 86.4 | 173.3 |
| 1980 | 149.6 | 102.3 |
| 1985 | 190.1 | 135.1 |
| 1990 | 221.0 | 8.3 |
| 1995 | 198.2 | 39.1 |
| 2000 | 181.6 | 36.7 |
| 2005 | 181.6 | 35.5 |
| 2010 | 181.6 | 34.8 |

18. The selected sources include all stationary-source fuel combustion except oil and gas production and petroleum refining; 'other' waste burning; all solvent use and industrial processes; petroleum marketing; and several off-road mobile sources (off-road vehicles, mobile equipment, and utility equipment).

19. See Cameron (1991).

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Appendix Table A-1

Growth codes used in all scenarios, and population elasticities used in the Hypothetical Scenarios.

| Code | Source | Elasticity H1 | Elasticity H2 |
|---|---|---|---|
| 100 | Resource development/agriculture | 0 | 0 |
| 101 | Range improvement | 0 | 0 |
| 110 | Agriculture | 0 | 0 |
| 111 | Pesticide | 0 | 0 |
| 120 | Forestry | 0 | 0 |
| 130-134 | Mining | 0 | 0 |
| 140-153 | Petroleum production | 1.0 | 0.2 |
| 200 | Manufacturing: total | 0.2 | 0.4 |
| 210 | Manuf: food & kindred | 0.2 | 0.4 |
| 220 | Manuf: lumber & wood | 0.2 | 0.4 |
| 230 | Manuf: paper & allied | 0.2 | 0.3 |
| 240 | Manuf: chemical & allied | 0.2 | 0.3 |
| 260-269 | Petroleum refining | 0.2 | 0.2 |
| 270 | Manuf: mineral products | 0.2 | 0.3 |
| 271 | Manuf: glass products | 0.2 | 0.3 |
| 272 | Manuf: cement | 0.2 | 0.3 |
| 280 | Manuf: metallurgical | 0.2 | 0.4 |
| 290 | Other manufacturing | 0.2 | 0.4 |
| 291 | Manuf: apparel | 0.2 | 0.6 |
| 292 | Manuf: furniture | 0.2 | 0.5 |
| 293 | Manuf: fabricated metals | 0.2 | 0.5 |
| 294 | Manuf: machinery | 0.2 | 0.5 |
| 295 | Manuf: transportation equip | 0.2 | 0.4 |
| 296 | Manuf: rubber & plastics | 0.2 | 0.3 |
| 297 | Manuf: tobacco | 0.2 | 0.4 |
| 298 | Manuf: instruments | 0.2 | 0.4 |
| 299 | Manuf: transp equip aircraft | 0.2 | 0.4 |
| 300 | Services | 0.7 | 0.6 |
| 310-317 | Electric utilities | 0.2 | 0.4 |
| 320 | Petroleum marketing | 0.7 | 0.8 |
| 322 | Gasoline service stations | 0.7 | 0.8 |
| 330 | Other services | 0.7 | 0.6 |
| 332 | Printing and publishing | 0.2 | 0.4 |
| 400 | Transportation: trucking, busing | 0.9 | 0.9 |
| 410 | On-road travel, unpaved roads | 0.7 | 0.9 |
| 411 | Farm road travel | 0.2 | 0 |
| 412 | Timber production travel | 0.2 | 0 |
| 420 | Rail transport | 0.2 | 0.2 |
| 430 | Ship transport | 0.2 | 0.2 |

Table A-1 (cont.)

Growth codes used in all scenarios, and population elasticities used in the Hypothetical Scenarios.

| Code | Source | Elasticity H1 | Elasticity H2 |
|---|---|---|---|
| 440-444 | Air travel | 0.2 | 0.2 |
| 451 | On-road travel, paved roads | 0.7 | 0.9 |
| 485 | On-road trucks | 0.9 | 0.9 |
| 491-493 | Motorcycles | 0.9 | 0.9 |
| 500 | Domestic consumer products | 0.7 | 0.8 |
| 510 | Residential: cooking, heating etc | 0.7 | 0.8 |
| 520 | Recreational activities | 0.9 | 0.8 |
| 521 | Off-road motor vehicles | 0.8 | 0.8 |
| 531-533 | Automobiles | 0.9 | 0.9 |
| 541-543 | Automobiles | 0.9 | 0.9 |
| 551-553 | Automobiles | 0.9 | 0.9 |
| 561-563 | Trucks | 0.9 | 0.9 |
| 571-573 | Trucks | 0.9 | 0.9 |
| 581-583 | Trucks | 0.9 | 0.9 |
| 591-593 | Trucks | 0.9 | 0.9 |
| 600 | Industrial equipment, construction | 0.4 | 0.5 |
| 601-603 | Trucks | 0.9 | 0.9 |
| 610 | Construction | 0.4 | 0.5 |
| 611 | Buses | 0.9 | 0.9 |
| 620 | Natural sources | 0 | 0 |
| 625 | Waste disposal landfill | 0.3 | 0.3 |
| 630 | Government | 0.7 | 0.6 |
| 631 | National security | 0.2 | 0.2 |
| 632-635 | Airplanes | 0.2 | 0.2 |
| 811-818 | Equipment | 0.4 | 0.5 |
| 821-822 | Boats | 0.2 | 0.2 |
| 831-832 | Boats | 0.2 | 0.2 |
| 841-842 | Off-road automobiles | 0.8 | 0.8 |
| 851-852 | Lawn & garden utility vehicles | 0.7 | 0.8 |
| 900 | Unspecified activities | 1.0 | 1.0 |
| 911-912 | Architectural coating | 1.0 | 1.0 |
| 923 | Structural fires | 0.7 | 0.8 |

Appendix Table A-2

Estimated and projected population and growth ratios (relative to 1975); counties in two air basins in California.[1]

| County | Population (000) | | | Growth Ratio | |
|---|---|---|---|---|---|
| | 1975 | 1990 | 2010 | 1990 | 2010 |
| San Joaquin Valley Air Basin | | | | | |
| Fresno | 465.6 | 673.7 | 1237.4 | 1.45 | 2.66 |
| Kern | 368.6 | 549.6 | 1037.7 | 1.49 | 2.82 |
| Kings | 70.5 | 102.4 | 168.9 | 1.45 | 2.40 |
| Madera | 52.8 | 89.6 | 171.8 | 1.70 | 3.25 |
| Merced | 120.3 | 180.5 | 313.6 | 1.50 | 2.61 |
| San Joaquin | 321.2 | 484.4 | 778.4 | 1.51 | 2.42 |
| Stanislaus | 231.8 | 376.1 | 670.0 | 1.62 | 2.89 |
| Tulare | 218.4 | 314.7 | 521.2 | 1.44 | 2.39 |
| South Coast Air Basin | | | | | |
| Los Angeles | 7278.1 | 8898.4 | 11441.9 | 1.22 | 1.57 |
| Orange | 1688.4 | 2423.8 | 3104.1 | 1.44 | 1.84 |
| Riverside | 565.7 | 1195.8 | 2406.7 | 2.11 | 4.25 |
| San Bernardino | 793.8 | 1440.7 | 2621.5 | 1.81 | 3.30 |

1. The 1975 figures were calculated by linear interpolation between 1970 and 1980. Growth ratios are the ratio of population in 1990 or 2010 to population in 1975.