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Authors
Gillen, David
Haynes, Matt

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CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

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This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation; and the United States Department Transportation, Federal Highway Administration.

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MOU 3001- EVALUATION METHODS FOR MEASURING THE VALUE OF ITS SERVICES AND BENEFITS FROM IMPLEMENTATION

Measuring the Aggregate Productivity Benefits from ITS Applications: The California Experience

David Gillen and Matt Haynes*

PATH Program
Institute for Transportation Studies
University of California

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* Adjunct Professor and Graduate student respectively, Institute for Transportation Studies, University of California-Berkeley

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EXECUTIVE SUMMARY

There are three comprehensive policies contained in California's Transportation Plan (CTP). These policies are to promote economic vitality through mobility and access, to provide safe, convenient, and reliable transportation, and to provide environmental protection. Transportation applications such as Intelligent Transportation Systems (ITS) offer much in the way of addressing the policies given in the CTP. ITS applications, while encompassing a broad array of transportation strategies, specifically can be described as the use of advanced technologies in electronics and information to improve transportation system performance with regard to vehicles, highways and transit systems.

Because investments in ITS technologies will clearly have widely differing impacts, there is an inherent uncertainty in predicting the impacts of a particular ITS strategy in a given location. If we can better understand to what extent ITS strategies provide benefits to the economic output of a county or region, then decisions to invest in ITS in the future will be better informed. This report uses measures of productivity to assess the impacts that ITS applications have had in California counties.

There have been numerous studies that look at the role that public capital investment has in affecting productivity and economic output. Recent literature has produced widely varying results, and the issue remains unsettled. To further delve into the relationship between public capital and economic output, this research addresses ITS technologies as a component of public capital in the transportation sector. It is important to note that ITS is a very particular type of public capital, broken down into several categories, each with its own specific characteristics.

Traditionally, the impacts of ITS have been studied using purely technical models that measure the effects of ITS on speeds, time savings, and costs. While this sort of analysis is not incorrect, it may be incomplete. What is not addressed it how and whether ITS investments make producers and consumers better off. To study this, two distinct but related economic models were developed to see how ITS fits into the California economy as a whole. The first model is a production function, and the second a productivity model that calculates Total Factor Productivity (TFP).

To study the impacts of ITS on productivity and economic output, a database was constructed for the years 1969-1997. Data was collected for California counties on various economic and transportation statistics as well as levels of ITS implementation in each county. Variables included in this database were consequently used in the two models that were developed to analyze productivity and ITS applications. The two types of ITS applications for which data was collected were ramp meters and changeable message signs.

The results of the production function analysis provide some new results for the public capital literature and for policymakers debating the issue of whether and how much to invest in public capital and particularly ITS. This model is the first attempt to empirically measure the impact of ITS. Previous work has looked at ITS on a project basis or drawn conclusions from simulation results. The results show that highway capital provides local areas (measured by counties) with a competitive advantage creating output gains. Previous research found that the gains were offset by losses in adjacent counties. The net impact was to redistribute economic activity. Our results differ since not all of the gains are obtained from adjacent areas. There is a net positive benefit. This is important for any highway project evaluation since there are benefits that should be included in any benefit cost evaluation.

The impact of ITS applications has not been assessed in an economic model before. This research provides the first results to show ITS applications have a positive impact on economic growth by providing local areas with a competitive advantage. ITS creates economic gains. These gains do not appear to result from shifting economic activity from other jurisdictions. This result, however, needs further investigation.

The second modeling effort was to develop measures of TFP. This productivity measure takes account of the aggregate growth in outputs as well as inputs. New technology affects the economy in several different ways. It can allow us to do old things in new ways and to do new things. Technology is an enabler and it must be combined with personal and industrial strategies to yield new experiences, new products and services to add to the economic and social welfare of California. This research has really focused on the doing old things in new ways, lower costs and improved productivity. To this end our estimates show ITS adds benefits that should be counted in any project evaluation. The benefits are in the form of improvements in productivity. This leads to cost reductions in the delivery of gross county product. This answers a question which arose from our estimates of the production function, if ITS increases output, how does this happen? What we do not yet know is where, in what industries the impacts occur.

This research provides the first evidence of whether and how ITS contributes to economic growth and productivity – an objective established by the California Transportation Plan and ITS in particular. The next set of questions includes, what industries are most affected by ITS applications? Does it matter how many ITS applications are present, in other words, are there diminishing returns to similar ITS projects?[1] Finally, does it matter how ITS projects are combined? This latter question also arose out of our research on production functions as well, and will be a central part of the subsequent research agenda.

[1] Our investigation of ramp meters in the TOPS Report found that adding more pre-set ramp meters yielded few returns and could in fact make you worse off. However, if the technology were added to ramp meters in the form of synchronization the benefits yielded were significant.

1.0 INTRODUCTION

California's Transportation Plan [CTP] was designed to set the course for the future of transportation in California.[2] At the heart of the plan are three comprehensive policies: one that promotes the economic vitality of California by assuring mobility and access for people, goods, services and information; another that provides safe, convenient and reliable transportation; and a third that provides environmental protection and energy efficiency. The Caltrans Strategic Plan in keeping with the CTP creates a vision of a balanced, integrated multimodal transportation network to move people, goods, services and information freely, safely and economically. In order to realize this vision, Caltrans has invested in a program that provides a foundation for the application of advanced technologies to transportation in California. The objective of the program is to accelerate implementation of advanced transportation technology applications. A sub-component of this program is the Intelligent Transportation Systems (ITS) which was the designation given to the multimodal package of transportation innovations but is more narrowly designating the use of advanced technologies in electronics and information *to improve the performance* of vehicles, highways and transit systems.

Among the various categories of ITS applications will be projects dealing with traveler information systems, traffic management systems, vehicle safety systems, public transportation systems and commercial vehicle operations to name a few. In some cases, these projects will require significant capital investments and continuing operations and management expenses, while other projects will represent small capital investments. Some projects will be broadly based in urban areas while others may be specific to a link at a given location such as electronic tolling. The projects will vary in a number of dimensions from size, capital intensity, geographic coverage and user groups effected. The variety and coverage creates a challenge for investment analysis.

Investments in infrastructure and management strategies under the ITS program will generate different types, magnitudes and longevity of payoffs. They will have different levels of costs and both costs and benefits will have risks of varying size. The variability of both benefits and costs will create a degree of uncertainty regarding the evaluation of projects as well concern as to accurate values for benefits and costs. These features create an important challenge since California's transportation needs are designed to be met through public/private partnerships, private initiatives and public investment. In each case the investment dollars will be available through public capital markets only if it can be shown that these projects will meet California's transportation needs now and into the future in an efficient or cost effective way. If these projects do not meet financial and economic tests in a transparent manner, including a compensation for greater risk and uncertainty, the private sector is unlikely to undertake the development of new ATS products in the future. This does not mean all projects must generate at least a market rate of return; indeed, there may be some argument for subsidy. What it does mean is that significant policy issues can only be addressed if the benefits, costs and risks can be

[2] See, California Department of Transportation, New technology and Research Program, *Advanced Transportation Systems Program Plan: 1996 Update*, December 1996

identified for each project. Indeed, the quality of decisions will be threatened by the lack of, or failure to use, aids that help guide the public use of scarce resources.

The purpose of this research was to understand the productivity affects of ITS. An objective of ITS within the California Transportation Plan is to improve the productivity of the [highway] transportation system. In any assessment of ITS applications such a productivity improvement should be included as a benefit of the technology. If markets are competitive and highway services are produced under constant costs (constant returns to scale) such productivity benefits would be fully internalized and would be captured by the welfare measure under the transportation demand curve. However, markets are not fully competitive and there are cost economies in the production of highway transportation services. Therefore, it is important to determine whether and to what extent ITS application affect the economic growth of an area and the competitiveness of industry.

This study uses two types of models to understand and measure the productivity effects of ITS applications. For the first model, a production function using county level data for California is estimated. Included in the production function is the number and types of ITS applications in each county. This follows an established methodology which has been used to understand the role of public capital in the economy. ITS is simply a new technology embedded in public capital. The second methodology is to calculate total factor productivity (TFP) measures and determine whether the introduction of ITS applications has a significant impact on a county's productivity.

Section 2 of the report reviews the literature on public capital and its contribution to economic growth and output. In section 3 we review the modeling methods and the functional relationships. The data set which is used in the empirical work is described in section 4. The results of the estimation are described in section 5 and the conclusions are contained in section 6.

2.0 ITS, PUBLIC CAPITAL AND PRODUCTIVITY

Several reviews of the recent literature on public infrastructure and economic growth have been conducted. We summarize briefly the research questions of interest and the approaches which have been followed in investigating quantitatively the links between infrastructure and economic growth.

The basic interest is the link between public infrastructure investments and economic growth. Our research moves forward from this issue by considering the vintage of public capital in the form of the ITS investment. This raises a number of clarifying questions: Do we include all or only some types of public infrastructure? How do we measure investment in public capital stocks? How exactly does public capital affect regional/national income, i.e., what are the mechanisms or linkages by which public investments lead to increased output? How do we measure the magnitude of these effects? In order to measure such impacts, we need to make comparisons either across regions and countries, and/or comparisons over a period of time. The latter raises the problem that there may be all manner of influences on public investment levels and economic output and it is necessary to separate these exogenous influences on economic output to isolate the effect of public investments. Similarly, comparisons across regions or countries must separate out systematic differences in the economic structure of the regions or countries to isolate the differences in economic output explained by differences in public infrastructure spending. Each empirical study, from the pioneering ones to the most recent, must grapple with these considerations.

And if successful, what exactly do these empirical studies tell us? These are macro relationships, i.e., broad or average results of the responsiveness of aggregate economic output to changes in investment in public infrastructure. At best, these provide broad strategic guidance for managing the economy. For example, it might indicate the implications of shifts between public expenditures on social transfer programs and real capital investments. But even this is uncertain; even if public infrastructure is contributing to economic growth, does it automatically follow that still more investment is desirable? Additional analysis is needed to address the optimality of existing infrastructure spending. If it were possible to disaggregate and examine the impacts of different types of public infrastructure (i.e., investment in schools versus roads), this might provide broad guidance towards allocating resources between these sectors.[3] But ultimately, macro studies cannot provide guidance for specific infrastructure investment decisions. These require microeconomic analysis, such as social cost-benefit studies, to estimate whether or not specific public investment decisions will make society wealthier or poorer. That point made, it remains true that ability to better measure the overall or average effect of public infrastructure investments on economic growth would be a useful policy tool for considering expenditure priorities and budget allocations.

The influence of public infrastructure investment, particularly transportation infrastructure, in the economy might be better understood by thinking of it in the context of a general regional economic model.[4] In the regional model, public infrastructure investment first influences regional output directly because expenditures on infrastructure are a part of the economy. What is more important is that public infrastructure is expected to have important indirect or secondary effects. Public infrastructure may be an input in a private firm's production function, and/or it may improve the productivity of other input factors such as labour and private capital. Public infrastructure may also attract inputs from outside the region which would further increase regional economic output.

[3]A few studies have tried to disaggregate public infrastructure by type and examine their differential effects on aggregate output (see Munnell and Cook,1990, and McGuire, 1992, for examples). Other studies have tried to differentiate the impact of infrastructure on types of industries.

[4]Fox (1990) pp.3-13 discusses various linkages between public infrastructure spending and the level of regional/national income.

There are still other effects. The level of income in a region or nation is influenced by various market and socio-political forces that are not controlled by governments. Exogenous events could stimulate the economy, e.g., an inflow of inputs (migration) from outside, and/or an expansion of export markets. These are especially relevant for California. The growth of economic activity stimulates a demand for public infrastructure. This means that the relationship between infrastructure investment and economic growth is not entirely uni-directional. The causality can work both ways.[5]

Another question that arises is a possible relationship between public infrastructure investment and private infrastructure investment, between which complex linkages can exist. Already mentioned is that public infrastructure investments might affect the productivity of private capital (e.g., better public roads make private trucking companies more productive). More complex interrelationships are possible. Suppose the expansion of public infrastructure investment displaces some private sector investment. The net effect on aggregate output depends on the relative magnitudes of changes in public and private investments, <u>and</u> their respective marginal productivity. There could also be behavioural responses by private investors even without full employment. With a planned increased in public spending, even if on infrastructure, could have at least a partially offsetting effect via reduced private investment. In brief, complementarity or substitutability could exist between private and public infrastructure investments. In the presence of complementarity, an increase in public infrastructure would increase the return to private infrastructure investment, and thus encourage more private infrastructure. On the other hand, substitutability leads one type of investment to be replaced by the other. Higher public infrastructure investment could lead to a reduction in private capital investment. This is the so-called “crowding-out” effect.

The links between public infrastructure and private sector productivity raises questions about how to model implied technical change. Does public infrastructure investment affect the productivity of both labour and private capital equi-proportionately (Hicks-neutral technical change, i.e, the efficient combinations of private sector inputs are not changed), or does public infrastructure investments tend to have primarily a labour-saving or private capital-saving effect?

2.1 The Literature on Infrastructure and Economic Growth.

There is a long history and study of emphasis on and study of the role of public infrastructure in economic development. It has been a major theme in economic history and a major theme in the literature on economic development since the 1950s. The recent literature has focused on macro-econometric models which attempt to establish a

[5] Trying to understand this causality has been a major theme of recent contributions to the infrastructure and economic growth literature.

quantitative relationship between public infrastructure investments and the level of income in a region or nation. Most of the literature focuses on macro or economic aggregates; some studies disaggregate somewhat by studying the links between particular types of infrastructure spending and/or the impacts on particular industries. Despite the fact that this recent literature dates only from the late 1980s, the literature is substantial and has been reviewed by a number of authors.[6] We do not undertake a comprehensive literature review here, but it is appropriate to identify a few key contributions which have helped shape this field of inquiry, and also to identify a few articles which are particularly useful in exploring the development of models for British Columbia.

The modern literature largely dates from studies by Aschauer (1989a,b,c,d) who first drew attention to the correlation of nations' economic growth and the percent of government expenditures on infrastructure (Aschauer, 1989c). In a study based on aggregate (annual) time series data of the United States over the period of 1949-1985, he estimated a Cobb-Douglas production function relating real aggregate output of the private sector to non-military public capital (Aschauer, 1989a). The study found that the return to public capital exceeded the return to private capital by a factor of three to four times, and there was a strong positive relationship between public capital and total factor productivity.

Munnell (1990) also used aggregate time series data and a Cobb-Douglas production function. The study focused on private non-farm sector over the 1948-1987 period. Her results were similar to those of Aschauer (1989a). Both studies found that there was a shortage of public capital, i.e., that expansion of public infrastructure would lead to substantial economic growth.

Aschauer's findings captured a great deal of attention. First, it was a conclusion which seemed to solve a major economic puzzle. During the 1970s and 1980s, most industrialized countries, including the United States, had experienced a decline in productivity (and hence national income) growth. There was -- and continues to be -- wide debate about the cause(s) of the productivity slowdown. Aschauer linked this to another recognized trend. Since World War II, and even before, there had been substantial growth of the share of government in national income. But despite the expansion of government spending in the Western world, there was a declining share being spent on public infrastructure. The lagging rate of public investment in transportation and other infrastructure had not gone unnoticed. There was growing concern about possible deterioration of infrastructure and hence a perceived need to increase government spending on infrastructure. Aschauer's analysis provided an

[6]There are several reviews of the literature on public infrastructure investments and economic growth. The ones we found the most useful are: Fox (1990), Gramlich (1994), and Gillen (1996). Another useful overview paper is Munnell (1992).

apparent empirical basis for the need for a major shift in government priorities, a shift toward greater emphasis on infrastructure. For about the last decade, this need for increased infrastructure spending has clashed with the opposite and even stronger pressure on governments which is to reduce spending generally. The debate continues, but the work by Aschauer is a major underlying intellectual force continuing to pressure governments to find ways to increase investments in public infrastructure.

Aschauer's work did not go uncriticized, quite the contrary, but by and large his basic approach and hypothesis have not been completely refuted. For a variety of technical reasons, most subsequent authors have found reasons why his empirical estimates of the significance of public infrastructure might be overstated, but most have found statistically significant results nonetheless.

Numerous studies have followed Aschauer's original works. The focus of these studies has been on the impact of public infrastructure as a whole, or specific components such as highway, sewer and water on the private sector's economic growth and productivity. This impact is measured by various elasticity estimates. Reported elasticity estimates vary greatly, leading to debates over the magnitude and significance of the impact of public infrastructure on economic growth. Some studies find that public capital contributes in a very significant way to output and productivity growth. Aschauer (1989), Munnell (1990), Berndt and Hansson (1992), and Nadiri and Mamuneas (1994) are examples of such studies. Whereas some other studies, such as Holtz-Eakin (1994), Hulten and Schwab (1991), and Garcia-Mila and McGuire (1992), find a much more modest role for public capital. Gramlich (1994) and Gillen (1996) provide excellent reviews of some of these works. The former focuses more on issues than on particular studies.

Some studies apply Aschauer's approach to the state or local government level. When state-level and metropolitan-level (panel) data and disaggregate the public capital data were used, public capital is found to have a positive effect on output and productivity, but typically of a smaller magnitude than the results found in national level studies. Moreover, the effect of public capital is found to be smaller than that of private capital and labour (see Munnell, 1992 for an example). There is clear evidence that different components of public capital stock make different levels of contributions to economic growth and productivity improvement. Highway investments appear to be more significantly related to output growth and productivity (e.g., Munnell and Cook, 1990).

Duffy-Deno and Eberts (1991) estimate a system of two simultaneous equations, one for regional output and the other for public investment, to examine the effects of public investment and public capital stock on personal income for U.S. metropolitan areas.

They consider the linkage between public investment and personal income works in two directions: public investment influences personal income through its effect on the marginal product of labour, and the level of public investment is partly determined by personal income. They find that the public capital stock has positive and statistically significant effects on per capita personal income.

Lynde and Richmond (1992) examine public capital's contribution to aggregate production output. Their results suggest that public and private capital are *complements*, whereas labour and public capital are *substitutes*. They conclude that public capital infrastructure has an important effect on the productivity of private sectors.

Shah (1992) uses a restricted equilibrium variable cost function to examine the relationship between public infrastructure investment and private sector profitability based on data from for 26 Mexican three-digit manufacturing industries over the 1970-87 period. The estimated variable cost function treats both private capital and public capital as quasi-fixed inputs. The results suggest that Mexican public infrastructure has a small but positive multiplier effect on output, and private sector appears to have earned substantially higher returns from its direct and voluntary investment in physical capital than from its involuntary and indirect investment in public infrastructure. A small degree of complementarity between labor and infrastructure and private capital and infrastructure is observed. The results further suggest that existing levels of private and public capital stocks are below their static equilibrium.

Holtz-Eakin and Schwartz (1994) develop a neoclassical growth model which explicitly incorporates infrastructure in the production function to analyze the empirical importance of public capital accumulation for economic growth. They examine the infrastructure capital in the equilibrium growth path obtained by steady state analysis of their structural model. They did not find any statistically significant effect of the infrastructure investment.

Neil (1996) considers the problem of choosing the rate of investment in infrastructure to maximize steady-state per capita consumption. Under a very restrictive set of assumptions, he derives the optimal tax rate for infrastructure investment to be proportional to elasticity of the output with respect to infrastructure investment. It is assumed that output is determined by a linearly homogeneous function of private capital, labour, and infrastructure. Capital formation is made possible by savings, which is a function of disposable income such that the average propensity to save equals the marginal propensity to save. It is further assumed that the increase in infrastructure stock is determined by taxes for this purpose, and the government balances its budget in each period. The growth rate of labour is assumed to be exogenously determined.

Morrison and Schwartz (1996) estimate a generalised Leontief variable cost function based on state-level data for US manufacturing to analyse the rate of return to infrastructure investment. The rate of return is measured by shadow values which capture the potential cost savings from a decline in variable inputs required to produce a given amount of output when infrastructure investment occurs. The estimated cost function also provides a direct mechanism for examining the impact of infrastructure on productivity measurement. The study finds that infrastructure investment provides a significant return to manufacturing firms and augments productivity growth.

Boarnet (1997) has examined the relationship between transportation investments and local economic development. He has argued, persuasively, that at a system-wide level there are few if any measurable gains from infrastructure investments. However, when examined at a local or regional level, there are areas that gain and some that lose with such investments. When we look at the number of studies above, there is a wide range of output values but those that took care with models and econometric estimation, found results close to zero, meaning there were few measurable positive economic impacts from such investments. Nonetheless, many investments are made to avoid negative spillovers - losing economic activity to neighboring cities, counties or regions. When competition is from neighboring regions, spillovers can be positive from network effects of any improvement in local areas. In a study in Los Angeles, Boarnet found a 1 percent increase in highway infrastructure investments on other California counties. He found some lost and some gained. When aggregated to the state and federal level the net effect was zero - it appears, such investments redistribute economic gains, shifting them from one region to the other.

Oum et al. (1998) have identified an issue that seems to have eluded researchers in this field to this point. They point out that some studies (Aschauer, 1989, and Munnell, 1990) use private sector output as the dependent variable to investigate effects of the government investment on the economy, while most other subsequent studies use GDP or Gross State Products (which includes G as a part of the accounting identity) as the dependent variable. The issue is that the interpretation of the results are fundamentally different depending on which dependent variable is being used. When GDP is the dependent variable, spending on G itself is counted in as a part of GDP in addition to any positive benefits to the private sector economy. In this case, a positive elasticity of G with respect to private sector output is not sufficient to show the need for additional investment on public infrastructure. It is necessary to compare the marginal products of the government infrastructure investments with those of the private sector to determine if an expansion of public infrastructure is called for. On the other hand if private sector output is being used as the dependent variable, a positive coefficient on this variable is all that is required to show the positive contribution of public infrastructure to economic growth.[7]

Sanchez-Robles (1998) examines the effect of public capital on output growth rate based on two cross-country data samples. The first sample includes 57 countries of five

[7] It goes without saying the relative values of the returns to public and private spending should be made.

continents over two time periods: 1970-1985 and 1980-1992. The second sample contains 19 Latin-American countries over the 1970-1985 period. The paper first regresses per capita GDP growth on the share of infrastructure expenditure in national GDP, but fails to find any conclusive evidence with respect to the impact of infrastructure investment on economic growth[8]. The paper then develops an index for infrastructure stock and replaces the expenditure share with this index in the regressions. The index is constructed to capture the capital stock at the beginning of the period, and it is related to the population or the area of the countries (divided by population or by land area) and standardised. The results show that this index has a positive and significant coefficient. The focus of the paper lies on how to measure infrastructure capital better. The paper also provides some interesting discussions on the relationship between public capital and the level and growth rate of output. It also touches on the issue of infrastructure capacity saturation in examining the impact of public capital on economic growth.

Button (1998) examines some of the issues related to the link between public infrastructure investment and economic development from two different perspectives: the endogenous growth approach and the neo-classical approach. He concludes that the body of evidence available so far does not provide strong support for one approach over the other.

The underlying policy issue is whether the government should be investing in public capital, particularly transportation infrastructure, to facilitate economic growth. Cross sectional studies which attempt to measure the marginal contribution of government investment to output offer mixed evidence. This is not surprising since in most cases the increments to capital are quite small in relation to the current stock. Furthermore, the measure of the marginal contribution is not straight forward. The convention is the use the value of the capital stock invested in infrastructure but this ignores issues of the non-homogeneity of the capital stock (differences in types of roadway, for example), variation in utilization rates (congestion) and trade-offs between maintenance and additions to the stock. It also ignores the issue of how the infrastructure is configured (networks) and spillovers between jurisdictions.

2.2 ITS applications, Technology and Economic Growth

ITS is a very particular type of public capital. Described below are the ranges of ITS applications. Our interest is primarily in those ITS applications designed to meet user needs. In particular those applications that both stimulate demand as well as facilitate trade. In the former case, as the system provides greater accessibility, the transactions cost of engaging in trade (purchasing goods and services) are lower. This should be reflected in more economic activity and economic growth. For firms, ITS can lower the costs of doing business both in terms of providing inputs in a timely fashion using newer management technologies such as Just-in-Time delivery as well as in the distribution of products. A transportation system that ensures firms can deliver products to customers in a timely manner, will also stimulate

[8] The share of infrastructure expenditure in GDP has a negative but insignificant coefficient.

economic growth. The issue in all of the ITS technologies is how they meet user needs and how they integrate into firm strategies.

ITS is a package of transportation applications which uses revolutionized computer, electronic, communication, and navigation technologies to increase the performance and productivity of the entire surface transportation system. It also involves data and information sharing among travelers, vehicles, roadways, and transportation management. The development of ITS applications is, as we stated at the outset, designed to improve safety, increase mobility and accessibility of travelers, and enhance system productivity and environmental compatibility.

ITS applications can be defined, as suggested earlier, from two perspectives: deployment and user need. Applications defined from the deployment perspective refer to market packages. Specifically, market packages are groups of improvement strategies that are expected to be deployed together to address a transportation or air quality objective or problem. Market packages are deployment-oriented. They deal with the specific service requirements of traffic managers, transit operators, travelers, and other ITS stakeholders. The National ITS Architecture identifies fifty-three market packages. They are grouped under seven subsystems including:

1. Advanced Traveler Information Systems (ATIS)
2. Advanced Traffic Management Systems (ATMS)
3. Emergency Management (EM)
4. Advanced Vehicle Safety Systems (AVSS)
5. Advanced Public Transportation Systems (APTS)
6. Commercial Vehicle Operation (CVO)
7. ITS Planning

ITS applications defined from the perspective of users' needs are strategies and technologies that are related to specific *user needs*. User services meet the safety, mobility, accessibility, environmental and other transportation needs of a specified user or group of users. Deployment of a user service may require several technologies that are shared with other user services.

2.2.1 Advanced Travel Information Systems (ATIS)

Advanced Travel Information Systems (ATIS) is a package of user services which provide transportation users with timely travel information. Applications under the ATIS include:

- pre-trip travel information;
- en-route driver information;
- route guidance;
- ride matching and reservations;
- traveler service information;
- traffic control;
- en-route transit information;
- personalized public transit; and
- electronic payment services.

Pre-Trip Travel Information service provides real-time information on accidents, road construction, alternative routes and modes, traffic speeds along given routes and modes, parking availability, event and transit schedules, fares, transfers, ride-sharing services, and weather conditions. Users can access the information before departure, select travel time, mode, and routes, and estimate arrival time.[9] All types of vehicle drivers, transit passengers, and other travelers who plan to make trips are primary users. Individuals who are interested in traffic and weather information also benefit from the service.

En-Route Driver Information service conveys the above mentioned information to travelers who are on the road to their destinations through audio and visual technologies and in-vehicle signing. This service can increase the safety and convenience of vehicle drivers and improve the efficiency of vehicle operation. En-route drivers and travelers are the primary users of this service. Information generated from all the ATIS market packages and "Virtual TMC and Smart Probe Data" package is required to support this user service.

Route Guidance provides travelers with simple instructions on how to reach destinations using information provided by en-route driver information service. A route guidance service processes data on route traffic condition, selects an alternative route, and provides appropriate instruction. Audio technology is used as a main tool to convey directions to users so that the drivers are not distracted. A visual display will also be used in this service. En-route drivers, especially those who are not familiar with a specific geographic area, will benefit from this service. This user service can be linked to multi-modal traffic management for incident response and transportation demand management.

This user service also enables commuters to find a match for ridesharing using information on travel origins and destinations. The service allows for single-trip rideshare matching and en-route pickups. It can be operated independently and could potentially ease traffic congestion and maximize the utility of transportation facilities if more people carpool. A market package related to this user service is Dynamic Ridesharing. The success of the user service and market package depends on high concentrations of trips with the same or similar origins and destinations. Commuters and other travelers who are interested in carpooling will be the primary users of this service.

ATMIS supplies information for planning a trip before departure or getting around while a trip is already underway. The information service is accessible from home and office. With some limitations, users can also use the service while traveling. Combined with pre-trip and en-route information systems, travelers can capture information on location, availability of food, lodging, parking, automotive services, hospitals, and community facilities. When fully deployed and integrated with other business and financial services, the service will collectively link users, sponsors, and providers. Furthermore, it will support financial transactions like automatic billing for purchases.

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[9] The full implementation of the Pre-Trip Travel Information requires deployments of several market packages such as Broadcast Traveler Information, Interactive Traveler Information, Information Service Provider Based Route Guidance, Yellow Pages and Reservation, and Dynamic Ridesharing.

Traffic Control service is mainly provided by Transportation Management Centers (TMCs). Based on information on roadway conditions, TMCs manage and coordinate traffic movement on the transportation network system. The service will improve operation efficiency of transportation network and provide better transportation service to users. With the service, users can travel faster with less stress.[10]

En-Route Transit Information service provides information to public transit users. The information provided is similar to pre-trip travel information. It helps transit users make effective transfer decisions and itinerary modifications while a trip is underway.[11]

Electronic payment technologies (e.g. Electronic Toll Collection) allows travelers to use electronic cards or tags for payments of transportation services including tolls, transit fares, and parking. The service can reduce travel time delays and inconvenience. It has a potential to integrate all modes of transportation including road pricing options.

2.2.2 Advanced Traffic Management Systems (ATMS)

Advanced Traffic Management Systems (ATMS) is a package of technologies that enable the integration of freeway and surface arterial operations. The primary intention of ATMS is to manage travel corridors and areas efficiently while retailing local community goals. Applications under the ATMS are:

- en-route driver information;
- traffic control;
- incident management;
- travel demand management;
- emissions testing and mitigation; and
- electronic payment services.

Using advanced detection and verification technologies, this service offers mitigative actions for traffic incidents, adverse road conditions, road construction activities, and special events. The service will reduce the time for incident detection and clearance, therefore reducing traffic congestion caused by incidents. Incident Management service can be integrated with many ATIS user services to enhance the performance of transportation system and to improve travelers' mobility. Market packages that are required to implement this user service are Surface Street Control, Freeway Control, Incident Management System, Virtual TMC and Smart Probe Data, and HAZMAT Management.

Travel Demand Management (TDM) service intends to reduce traffic congestion and air pollution by promoting the use of higher occupancy vehicles (HOV), transit modes, non-

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[10] The implementation of this user service requires deployments of a number of market packages including Network Surveillance, Probe Surveillance, Surface Street Control, Freeway Control, HOV and Reversible Lane Management, Traffic Information Dissemination, Regional Traffic Control, Traffic Network Performance Evaluation, Virtual TMC and Smart Probe Data, Multi-Modal Coordination, and In-Vehicle Signing.

[11] This user service requires a range of market packages under APTS, such as Transit Vehicle Tracking, Transit Fixed-Route Operations, Demand Response Transit Operations, and Transit Passenger and Fare Management, as well as packages of ATIS including Broadcast Traveler Information, Interactive Traveler Information, and Dynamic Ridesharing.

motorized alternatives, or non-travel options. TDM strategies include enforcing HOV lane use, parking control and incentives, road access pricing and prioritizing schemes.

2.2.3 Advanced Public Transportation Systems (APTS)

Advanced Public Transportation Systems (APTS) is a group of user services that apply various technologies to improve the efficiency and effectiveness of transit operation and user mobility. User services under this subsystem are:

- traffic control;
- travel demand management;
- public transportation management;
- en-route transit information;
- personalized public transit;
- public travel security; and
- electronic payment services.

This service provides the capabilities of automated planning and scheduling for transit services using information on real-time vehicle and facility status, passenger loading, bus running time, and mileage accumulated. The service can potentially improve the efficiency of transit operations and maintenance. Transit operators and paratransit providers are the primary users of this service. This service can be integrated with traffic control service to ensure transfer connections in inter-modal transportation. It is supported by the market packages of Transit Vehicle Tracking, Transit Fixed-Route Operations, Demand Response Transit Operations, Transit Security, Transit Maintenance, and Multi-Modal Coordination.

With the capacities supported by the Transit Vehicle Tracking and Transit Security market packages, this service creates a secure environment for public transit users and operators. Transit users are protected by on-board security systems that perform surveillance and warn of potentially hazardous situations. An automated vehicle location system helps transit operators and police to locate vehicles quickly and take appropriate actions in the case of emergency.

2.2.4 Commercial Vehicle Operations (CVO)

Commercial Vehicle Operations (CVO) consists of technologies that enhance the efficiency, productivity, and safety of goods movement. CVO applications include:

- incident management;
- commercial vehicle electronic clearance (pre-clearance);
- automated roadside safety inspection;
- on-board safety monitoring;
- commercial vehicle administrative process;
- hazardous material incident response; and
- commercial fleet management.

This user service allows point-to-point non-stop commercial vehicle operations while satisfying regulatory requirements, such as the issuance of licenses and permits, records keeping, tax collections, inspections, and weighing across multiple jurisdictions including domestic and international borders. Market packages required for the implementation of this service are Electronic Clearance, Commercial Vehicle Administrative Processes, International Border Electronic Clearance, and Weight-in-Motion.

This user service provides the carriers with the capabilities to select and purchase annual or temporary credentials electronically. The use of this service could enable participating interstate carriers to electronically capture mileage, fuel purchase, trip, and vehicle data by state. It could reduce paperwork for fuel taxes and registration. The service has a potential for synergy with commercial vehicle pre-clearance service. It is supported by Electronic Clearance, Commercial Vehicle Administrative Processes, and International Border Electronic Clearance, etc market packages.

This service also offers the same capabilities and functions as Public Transportation Management service. It can perform automated planning and scheduling for commercial goods movements using information on real-time vehicle and facility status, etc. The service will improve the efficiency of commercial fleet operations and maintenance.

2.3 SUMMARY

This brief summary of ITS technologies provides a description of the potential sources and underlying drivers of user benefits or efficiency gains that would show up as changes in economic growth or improvements in productivity in the California economy. Different ITS applications and combinations of applications will have different effects. Sufficient variability in these applications across the counties of California will provide some information on the direction and extent of these impacts.

There are several ways in which the impacts of ITS applications can operate. ITS can reflect a service to meet user needs, as described above, but it also represents a change in technology for the transportation system. The productivity of the transportation system; that is, the ability to increase output with no increase in inputs or to produce the same output using fewer inputs, is affected. Therefore, even if there are no added services to 'meet user needs' the economy may still grow at a faster rate because other factors, the infrastructure capital for example, has been more effective. This is the technological change referred to earlier as Hicks neutral. Does the introduction of ITS applications affect the productivity of both labour and private capital equi-proportionately (Hicks-neutral technical change, i.e, the efficient combinations of private sector inputs are not changed), or do ITS investments tend to have primarily a labour-saving or private capital-saving effect? The models developed below are designed to answer all of these questions.

This research represents the first attempt to measure this change due to ITS investments. In the past, financial models were used to assess ITS applications. In our view this is incorrect. The objective of ITS was, among other things, to enhance the economic well-being of Californians. This requires of measure of economic welfare or economic performance. The models in section 4 are designed to provide this analysis.

3.0 MODELING METHODOLOGY

There are several ways of exploring the impacts of ITS applications on California. A purely technical model would look for increased speeds, timesavings, operating cost savings or combinations of these. While not incorrect, these approaches are incomplete. The fundamental question is how and whether the investments in ITS make California consumers and producers better off. This requires an economic model of how ITS fits into the California economy, meeting user needs described earlier. We use two approaches to answer this question. The first, a production function model, is derivative of the role and impact of public capital on economic growth. This literature was surveyed in section 2. The second model is a productivity model in which total factor productivity (TFP) is calculated and then examined statistically to determine whether ITS applications contribute to higher levels of TFP. In this case the productivity changes in a county, measured by the increase in county output relative to input use, is calculated for each year (1969-97 inclusive). This measure is a gross indicator of the productivity changes in the sense it includes all influences and factors to productivity change. In order to take account of different physical and economic environmental conditions, we regress a set of explanatory variables on the TFP calculation to distinguish the separate contributions of each of the influence. ITS will be one of the factors, but as we have indicated, the influence can be both direct in the form of lower costs, as well as indirect in the form of technological change which can alter the productivity of other factors of production.

3.1 Production Approach to ITS Impacts

This section contains two parts. The first is a review of major methodological issues which arise in the literature on macro-econometric studies of public infrastructure and economic growth. The second part sets out a conceptual framework to examine more closely the links between public infrastructure, ITS applications and economic growth, and the implications for formulating models of this type.

3.1.1 Major Methodological Issues Arising in the Literature

There are a number of methodological as well as measurement issues. We identify three major methodological issues which have emerged in this literature: (1) the choice of a production function approach versus estimating cost functions; (2) the problem of non-stationarity, i.e., the problem that time series data may involve time trends which give rise to spurious correlation among variables and hence misleading inferences; and (3) the issue of establishing causality between infrastructure investment, ITS applications and economic growth. A fourth issue is partly methodological but mostly a measurement issue: the appropriate measure of infrastructure inputs. This is also addressed in the following section.

3.1.1.1 Production versus Cost Functions.

Most of the early studies used time series data in an aggregate production function framework to examine the relationship between national or state level output or productivity growth and public sector capital. Recent studies have focused more on sub-national (regional, provincial, state, etc) level data. This could take advantage of the availability of cross-section or panel data. The Cobb-Douglas production function has been the most frequently used form in empirically based studies. Alternatively, the translog function is a more general formulation, but in application it may be difficult to estimate because it involves a large number of parameters; this is particularly the case when additional infrastructure or technology variables are introduced or when the function is applied to the noisy spatial data that are used to estimate regional production functions. The choice of functional form should depend on its appropriateness in relation to the questions of concern, and also quite often, on the limitations imposed by data and other analytical features of the research design.

Recently, there has also been a shift from the traditional production function framework to the use of a cost function approach. The cost function approach has a number of conceptual advantages over the production function approach. Estimating a production function is prone to multi-collinearity problems because input quantities are more likely to be correlated with each other than with factor prices. The cost function approach relies on changes in relative prices to reflect the choices among inputs. Furthermore, a cost function facilitates the explicit exploration of cost efficiency, i.e., measuring the effect of a change in public capital stock on production costs at a given output level. It should be noted, however, that cost functions require the assumption of an optimal mix of inputs. While debatable, this is more plausible for application to individual firms (micro data) than applied to aggregate or even industry-level data. The cost function approach is used mostly in industry-specific studies. This is less aggregated than economy-wide studies, but it is not really using micro-level data. For example, Lynde and Richmond (1992) estimate a translog cost function to examine the impact of public capital on the cost of production in the U.S. non-financial corporate sector. Morrison and Schwartz (1996) use a generalized Leontief variable cost function to examine the role of state infrastructure in determining state level manufacturing industry's performance.[12] They find that infrastructure investment provides a significant return to manufacturing firms and augments productivity growth.

3.1.1.2 NON-STATIONARITY.

As the literature progressed, the problem of non-stationarity of the data has become of increasing concern (e.g., see Aaron, 1990; Hulten and Schwab, 1991; and Tatom, 1991). Many economic time series are non-stationary, i.e., data series will tend to 'drift' in similar directions over time. If so, this renders conventional techniques of statistical inference invalid (Lynde and Richmond, 1993). When the data are not stationary, the common trends in the output and public infrastructure data series may lead to a spurious correlation. Therefore, it is necessary to remove this common trend to eliminate spurious correlation and then determine the true relationship between the two variables. Attempts have been made to deal with the presence of non-stationarity in time series data. For example, Aschauer (1990) attempts to correct for the non-stationarity of GNP and non-military public investment by deflating both series by the net private capital stock.[13]

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[12]See Diewert (1974) for details on the desirable properties of the generalized Leontief function.

[13] This approach, however, was later shown to be ineffective by Harmatuck (1996).

A common approach to deal with non-stationary series is to take "first differences," i.e., to use the change in a variable from one time period to the next, rather than the absolute level of the variables. This technique is widely used but it poses a particular problem for studying the link between public infrastructure and economic growth. Taking first differences focuses on the period to period changes in the variables. But arguably, this is focusing on more of a short run relationship between the variables than the long run relationship. For some data series there is little difference, but the whole point of studying infrastructure and economic growth is to try and establish long term relationships.

Another approach is to incorporate a time trend to account for non-stationarity. This assumes that residuals from deterministic time trends are stationary. But there is at least some evidence in the infrastructure literature that first-differencing may be more often appropriate than deterministic de-trending (Harmatuck, 1996).

Tests can be conducted to examine not only whether variables grow over time, that is, the extent to which they are non-stationary, but also whether they grow together over time and converge to their long-run relationship, that is, the extent to which they are co-integrated. Engle and Granger (1987) have developed tests of cointegration to determine if regressions of non-stationary series ought to be based upon levels of variables, differences, or a combination of both. In most cases, a linear combination of two non-stationary series, such as the disturbances from a linear regression equation, is non-stationary if the dependent and independent variables are non-stationary. Hamilton (1994) provides a good discussion on the concept and various tests of co-integration.

3.1.1.3 Causality.

The causality issue has been raised by a number of researchers, such as Eisner (1991), Munnell (1992), and Gramlich (1994). As noted earlier, while researchers and policy-makers are looking for a causal link between infrastructure investment and economic growth, it is likely that the causality can also work in the other direction. However, at present there is no theoretical or empirical consensus regarding the nature of the causality and the best approach to deal with the issue.

Most of the recent empirical studies have focussed on the effect of infrastructure investment on economic production. Much less effort has been devoted to empirical testing of causality. There have been some efforts to include public capital as an endogenous variable in a production growth model (see Hulten and Schwab, 1993, for an example). These efforts have provided limited evidence for the endogeneity of public capital. Gramlich (1994) provides a good discussion on this issue.

Talley (1996) provides a theoretical framework that links productivity and transportation infrastructure, allowing for a two-way causal relationship. Transportation infrastructure investment is specified to affect a region's economic production, and at the same time, the latter is specified to affect a region's level of infrastructure investment, thereby considering the simultaneous nature of the two. That is, there is a circularity between transportation infrastructure investment and economic production. The model explicitly demonstrates the two-way linkage between transportation infrastructure investment and economic production. However, it requires rather detailed information, and has not been applied empirically.

Granger-causality tests, proposed by Granger (1969) and popularized by Sims (1972), might be a useful tool for testing the causal relationship between public infrastructure and economic growth. Granger-causality states that if an event Y is the cause of another event X, then the event Y should precede the event X. It is defined that if y can help forecast x, then y is said to Granger-cause x. Hamilton (1994) offers a clear description of the method. It should be noted that the concept of Granger-causality reflects a statistical relationship, but it does not always reflect the true causation.[14] For example, stock prices and interest rates are often found to be good predictors of many key economic time series such as GNP. This does not mean that these stock prices or interest rates actually *cause* GNP to move up or down. Instead, the values of these series reflect the market's best information as to where GNP might be headed. In such cases, Granger-causality tests should not be used to infer a direction of causation. Nevertheless, there are circumstances in which Granger-causality may offer useful evidence about the direction of true causation.

A number of studies have used the Granger test to examine the direction of causality between public infrastructure and output, but the results are not always encouraging. For example, Holtz-Eakin (1992) found some ambiguity in the direction of causation. Eberts and Forgarty (1987) used the Granger test to examine the causal relationship between public and private capital. They found that among 40 U.S. cities, the preponderant effect was for public to lead private capital, although in some cases the reverse was found to be true. Boarnet (1997) also used this test in his study of the impact of public capital investment on county level economic growth.

3.1.2 THE INTERPRETATION AND MEASUREMENT OF PUBLIC INFRASTRUCTURE CAPITAL.

In the short run, capital inputs (and sometimes labour inputs) are fixed whereas variable inputs adjust according to changes in output level. In the long run, however, all inputs become variable. To examine how public infrastructure affects the private sector, one needs to work in a long-run framework.

The impact of new capital infrastructure investment on economic growth and productivity may not be observed immediately, other than the employment generated during the construction stage. The economy would experience an adjustment process before it can properly utilise new infrastructure. This process can also be viewed from another angle: public infrastructure is an input in production processes, and is expected to increase (or decrease) as output increases (or decreases). However, this adjustment is not likely to be instantaneous. Therefore, dis-equilibrium is expected in the short-run. Any inference drawn during this adjustment period regarding the relationship between public infrastructure and economic growth could be misleading. Therefore, some sort of lag structure or other mechanism is necessary to incorporate more than one year's investments as the relevant measure.

[14] In fact, it may even indicate the opposite direction (see Example 11.1 in Hamilton, 1994).

In most studies of the relationship between public infrastructure and economic growth or productivity, public infrastructure is measured by the (constant) dollar value of the infrastructure (capital) stock. That is, rather than use current expenditures, these are converted to constant dollars and compiled over time, less an assumed depreciation rate, to arrive at a figure for the accumulated *stock* of infrastructure capital. The economic contribution of infrastructure capital lies in the *flow* of services it provides, which depend not only the stock, but also on how efficiently it is used.

There are various ways to increase capital service flow. Capital expansion through additional infrastructure investment and better utilisation of existing infrastructure through efficiency improvement are two of the most obvious options. The former would result in an increase in capital stock, while the latter would not. Suppose both approaches would lead to the same (increased) output level. A study linking capital stock to output would find a positive relationship if the capital expansion option is adopted. However, the same study would probably not be able to find any significant relationship if the second option is adopted since there would be no change in the capital stock level. This suggests that using capital stock as a measure of the input from infrastructure might yield potentially misleading results.

By using the capital stock to measure the level or size of infrastructure, it is implicitly assumed that service flows from the infrastructure are in direct proportion to the capital stock. This may not always be true. The flow of services can be influenced by (1) the rate of utilisation of the capital stock; and/or (2) the degree of maintenance and rehabilitation of the stock. Another issue is whether or not investment expenditures rather than a capital stock measure should be used. These points are discussed in turn.

Utilisation of capital stocks. Using the capital stock as the measure of its influence on economic output implicitly assumes that the actual flow of capital services is a fixed proportion of the capital stock, regardless of variations in the intensity of using that capital stock. This can be thought of as capital being 'used up' purely with the passage of time rather than actual rate of usage. Alternatively, the capital stock may permit different rates of using up the capital, depending on how intensively it is utilised. This issue was addressed by Oum, Tretheway, and Zhang (1991) and Oum and Zhang (1991) for firm-level analysis, and their discussions also apply to macro-level analysis as well. Oum and Zhang (1991) proposed replacing the capital stock measure with a measure of utilised capital, that is, the capital stock adjusted by a utilisation rate.[15] Holleyman (1996) attempts to deal with the issue. He defines an effective amount of net highway infrastructure stock by assuming that an industry's utilisation of the highways is equal to its share of national truck transportation costs. Specifically, he defines an adjustment (weighting) factor equal to the share of total industries' truck transportation cost in the nation's total transportation freight bill, and then applies this share to the net highway infrastructure stock to estimate the amount of services that particular industry derives from the highway network. Boarnet (1997) provides another example as to how to deal

[15] Aschauer (1989a, b) also included capacity utilization in estimating the production function. However, his reason for including the variable was to control for the influence of the business cycle as well as to measure the effect of capacity utilization on productivity.

with this issue. He includes a congestion measure in an aggregate production function to explicitly examine the effectiveness of highway expansion versus congestion reduction.

Maintenance and capital service flow. Proper maintenance improves service flows from infrastructure and maintains or even prolongs its service life. Some maintenance and repairs are exactly that: routine expenditure which maintains the capital stock only for the current period. Of course, forgoing even routine maintenance will have an adverse affect on the capital stock, reducing its usefulness and/or its expected life. Some maintenance expenditures may have an effect over several time periods. If so, this represents added value to the infrastructure and such expenditures should be "capitalized" and recorded as a capital improvement rather than treated as an annual expense. However, there are questions to be investigated concerning what portion of maintenance expenditures be capitalized and over what time period. There are both economic and accounting issues, i.e., what treatment of expenditures is appropriate by economic criteria and whether or not current accounting practice corresponds to this economic criteria.

3.2 Modeling Production with ITS Applications

Our approach in modeling the impact of ITS applications on productivity is based on the idea that public capital generally, but ITS applications specifically, are productive at a scale smaller than the state level. It may be the case that the affects of public capital are localized and those of ITS applications are even more so. It therefore seems appropriate to use the smallest geostatistical unit of observation possible. We can always aggregate if need be.

An added reason to use county level data is to evaluate the re-distribution hypothesis versus the net economic growth hypothesis. We know from the aggregate studies, even those at the state level, that there is tenuous evidence of whether public capital adds more to economic growth than private capital. Furthermore, there is evidence that clusters of economic activity tend to occur where there are major highways or transportation activity centers (e.g. major highway intersections, airports, ports). These centers of activity may be cannibalized from other areas. The role of ITS in this case is increasingly important since it provides opportunities for greater mobility and accessibility. There will be two forces at work. One to re-distribute activity to the lower transaction cost area and the other to increase the aggregate level of economic activity by providing the county with a competitive and comparative advantage.

A method of exploring the shifting effect of public capital was used by Holtz-Eakin (1994) and Boarnet (1997). The impact on neighboring counties can be captured by including a measure of public capital and ITS infrastructure in neighboring counties. The simplest first assumption is to include only direct neighboring counties and not secondary or third level linkages. This approach is included in the specification below.

It is necessary to specify the production function of the economy in a specific functional form in order to estimate it empirically and address the issues discussed in the previous section. Our preferred model is to use a translog function with both time effects and province-specific effects but if estimation becomes troublesome a simpler log-linear model will be used. The translog form (Christensen, Jorgenson and Lau, 1973) provides a second order approximation to the true production function, and has been widely used in practice. It allows for variable returns to scale and variable input substitutability depending on the data points. The translog production function can be written as:

$$
\begin{aligned}
\ln Y_{i,t} = {} & \alpha_0 + \beta_1 \ln L_{i,t} + \beta_k \ln K_{i,t} + \beta_h \ln H_{i,t} + \beta_g \ln G_{i,t} \\
& + 1/2\, \beta_{ll} (\ln L_{i,t})^2 + 1/2\, \beta_{kk} (\ln K_{i,t})^2 + 1/2\, _{hh} (\ln H_{i,t})^2 + 1/2\, \beta_{gg} (\ln G_{i,t})^2 \\
& + \gamma_{lk} \ln L_{i,t} \bullet \ln K_{i,t} + \gamma_{lh} \ln L_{i,t} \bullet \ln H_{i,t} + \gamma_{lg} \ln L_{i,t} \bullet \ln G_{i,t} \\
& + \gamma_{kh} \ln K_{i,t} \bullet \ln H_{i,t} + \gamma_{kg} \ln K_{i,t} \bullet \ln G_{i,t} + \gamma_{hg} \ln H_{i,t} \bullet \ln G_{i,t} \\
& + \lambda_{i,t}\, ITS_{i,t} + \delta \ln(X^*Hi,t) + \delta_p\, CD + \phi_t\, TIME + \varepsilon
\end{aligned}
$$

Where the subscripts i and t index each variable for a given county in a given year and Y is output at the county level (or GDP), L labour, K private capital, H highway capital, G other government capital, CD are county dummies, TIME is a time effect, and ε is an error term. The X* is a neighborhood matrix with elements $x_{i,j}$ where x is 1 if the counties are contiguous and 0 otherwise and, x_{ii} is 0. The ITS variable measures the time point of introduction and the number of ITS applications in a given country. It will take the value zero for all time periods for some counties and a positive and growing value in other counties as ITS projects are introduced. Ramp meters are a good example of the type of ITS project that can be evaluated.

The marginal products of private capital, highway capital, and other government capital can be derived by taking the derivative of the equation with respect to the variable of interest..

The above equation relates output to government capital and ITS specific capital. As mentioned early, it is most likely that the causality goes in both directions. Therefore, we also specify government capital as a function of output and private capital as follows:[16]

$$\ln H = \alpha_{h0} + \alpha_{hy} \ln Y + \alpha_{hk} \ln K + \nu_h$$

$$\ln G = \beta_{g0} + \beta_{gy} \ln Y + \beta_{gk} \ln K + \nu_g$$

These equations will be estimated in a simultaneous system.

3.3 TFP Approach to ITS Impacts

[16] It is necessary to add other variables in the models in order to explain the level of highway stock (H) and government's other capital stock (G). The added variables will also help meet the identification condition of the parameters in this simultaneous system of equations.

Productivity measurement has generally been implemented using partial productivity measures. These include popular indexes such as output per worker, or per hour of labor. Others that have been used are output per machine hour or per machine, output per expenditure on public capital or unit measure of public capital. The obvious problem with these measures are they do not take account of the contribution of the nature, type (vintage) and extent of the other factors that can clearly contribute to the productivity of the factor input that is being considered. As a means of correcting this shortcoming economists have developed an index that considers all input factors simultaneously and all outputs. The index, termed total factor productivity or TFP, aggregates outputs on the basis of their revenue contribution and inputs on the basis of their relative importance to total costs.

The initial TFP measure was constructed as:

$$\ell n\left(TFP_k \big/ TFP_l \right) = \sum_i \left(\frac{R_{ik} + R_{il}}{2} \right) \ell n\left(Y_{ik} \big/ Y_{il} \right) - \sum_i \left(\frac{S_{ik} + S_{il}}{2} \right) \ell n\left(X_{ik} \big/ X_{il} \right)$$

where k and l are adjacent time periods, the Y's are the output indices and the X's the input indices. R's are the revenue shares and the S's are the cost shares. This measure of TFP has been shown to be an exact index procedure that corresponds to a homogenous translog production function which contains no implicit restrictions of separability or neutral technological change.

The measure of TFP illustrated above can be used to make time series and cross-sectional comparisons of TFP. In cross sectional comparisons indices k and l are interpreted as different economic agents such as firms or states rather than different time periods. A problem does arise if we have a panel of data in which the data are both time series and cross sectional; for example having information for several firms over a ten to twenty year period. In this case we require the development of a *multilateral TFP index* that allows bilateral comparisons across economic agents as well as over time. This index is constructed as:

$$\ell n\left(TFP_k \big/ TFP_l \right) = 1\!\big/\!2 \sum_i \left(R_i^k + \overline{R}_i \right) \bullet \left(\ell n Y_i^k - \ell n \overline{Y}_i \right) - 1\!\big/\!2 \sum_i \left(R_i^l + \overline{R}_i \right) \bullet \left(\ell n Y_i^l - \ell n \overline{Y}_i \right)$$
$$- 1\!\big/\!2 \sum_i \left(S_n^k + \overline{S}_n \right) \bullet \left(\ell n X_n^k - \ell n \overline{X}_n \right) + 1\!\big/\!2 \sum_i \left(S_n^l + \overline{S}_n \right) \bullet \left(\ell n X_n^l - \ell n \overline{X}_n \right)$$

where $\overline{R}$ is the revenue share averaged over all firms and time periods and similarly for S on the input side. All bilateral comparisons are base-firm and base year invariant.

This equation can be derived from a translog transformation structure by taking the difference between each firm's transformation function and the function resulting from arithmetic averaging of the transformation function across all observations.

A measure of TFP can provide a single index for use in comparisons across time, multiple agencies, and even for comparison with private enterprises. TFP measures total output produced per unit input[17]. The concept calls for the aggregation of input data (labor, private capital, public capital, transportation capital and ITS applications) to try and examine the source of improved efficiency for a given geographic area. Since there are many important output measurements to be considered (the make of gross product of a geostatistical unit such as agriculture, miming, forestry, manufacturing, retail and wholesale trade and government service), TFP makes it possible to evaluate all of these. The acceptance of TFP is reflected in its increasing use for recent research purposes.

The first two issues are to be investigated using a calculation of TFP and a subsequent regression of TFP on a set of explanatory variables that would allow us to identify the separate contribution of ITS to the TFP measure. The calculated measure of TFP is a 'gross' measure of productivity since it looks simply at the growth in outputs over the growth in inputs. It may be possible to examine the TFP measure for a county or point in time when ITS applications were introduced and the change in TFP could be attributed to the introduction of ITS. This may result in an overestimate of the contribution of ITS to area productivity growth and secondly, it would not be possible to distinguish different types of ITS or their combination unless one had a large and expansive data set with a significant variation in ITS technologies across relatively small geographic areas.

In order to distinguish the separate contribution of ITS and a particular type of ITS implemented we take the calculated TFP measure for each geographic area in each year and regress it on a set of variables that would influence the change in productivity. In doing it this way we net out the influence of other variables and obtain a more accurate measure of the separate contribution of ITS to efficiency and economic growth. If significant, this would be included in any benefit-cost evaluation that might be undertaken.

The variables included in this second stage regression would be output level in the county, miles of highway, proportions of economic activity in different economic sectors as forestry, mining, manufacturing, retail and wholesale services etc. and, the date of introduction and growth in ITS projects in the county.

Out production function and TFP calculation is developed on a database (described in detail in the following section) for all counties in California for the period 1969 through 1997.

4.0 DATA DESCRIPTION

The data used for this report comes from a variety of sources, and includes information on characteristics of California counties for the years 1969-1997. There are a total of 58 counties in California, ranging in size from a population of around two thousand to a

[17] ibid, pg. 434

population of nearly ten million (See Appendix A-1). The data collected were used in the two models described above in section 3.

Over the 29 year period from 1969-97, California's total population grew from 19.7 million in 1969 to 32.2 million in 1997, for an average increase of 2.2% per year (See Appendix A-2). By comparison, the Gross State Product (GSP) grew at an average of 4.1% per year (using real 1999 dollars).

Over this time period, the transportation system also underwent significant change. Most new road construction in California was completed before 1969, both on local and state levels. In the years since 1969, there has been less emphasis on constructing new roads than there has been on widening and maintaining existing roads. The corresponding road mile growth rate for all roads in California for the years 1969-97 was 0.6% per year. However, this decrease in the rate of expansion of the road and highway network has not translated into slowed growth in travel. California's per-capita VMT on state highways increased a total of nearly 64% from 1969-97, and total state highway VMT increased nearly threefold.

For the 1969-97 time period, total travel on California state highways increased significantly, at an average rate of nearly 5.8% per year **(See Appendix A-7)**. These statistics reflect largely the increase in capacity utilization that has occurred on California roadways, as the system works to accommodate more traffic for each road mile that exists.

To adequately measure the effect ITS applications have on the operations of the road network, data was gathered and complied for each county in California. However, due to the tremendous variation in the size and scale of California's counties, difficulty arises when trying to directly compare one county with another. Yet, by employing TFP techniques, we were able to obtain a direct measure by which to compare the productivity of the transportation system in each county with that in others.

4.1 DESCRIPTION OF DATA

For our TFP analysis, data was collected for many different variables which serve to depict the economic and travel related conditions in California counties for the described years. The first process of data collection was to identify that data which was necessary to analyze the productivity of the California transportation system. As in any TFP analysis, the data must either represent an output of the system or an input to it. Thus, there needed to be a set of outputs that provided a comprehensive idea of the outputs of the highway system, as well as a set of inputs that would provide the basis for TFP measurement. In addition to outputs and inputs, additional variables were collected for regression with the TFP results.

The 29 year period from 1969-97 was selected for several reasons. First, those years represented a significant longitudinal time period, long enough so the aggregate effects of introduced ITS technologies would be fully realized. Second, since ITS technology has been deployed only on a limited scope in many areas of California, and since much of this deployment has occurred recently, it was important to have data as recent as possible. Because of this need for recent data, we were able to collect data up until 1997. Finally, the 29 year period was chosen because data collection restrictions made collecting years prior to 1969 and more recent than 1997 very difficult to impossible.

What follows is a summary of the actual data collected, where it was collected from, and its use in the analysis that took place. Data was collected for three categories for the TFP analysis: outputs, inputs, and regression variables. For inputs and output, it was necessary to collect both a quantity measure for a specific input as well as a cost measure for the same input. For example, one of the input variables for public capital was the length of the state highway system in California. The quantity measure used for this variable was then state highway road miles, and the price measure was state highway capital outlay expenditures. The following variables are described below, along with the corresponding quantity and price measures associated with them.

4.2 Output Variables

The three main output variables, shown below in Table 1, provide a comprehensive look at the gross economic productivity of each individual county. The output variables give data on county income and gross product. With this information, it is possible to compare the level of output across counties in the TFP analysis.

Table 1: TFP Output Variables

Variable	Quantity	Price
1. Aggregate Income	Employment	Total county income
2. Sector Income	Employment	County income by sector
3. County Product	Population	GCP

Included in the set of outputs is data for county population, employment, personal income, gross county product, and personal income divided by sector. This data provided the structure for forming the three output variables that were then used in undertaking the TFP analysis.

The first two output variables include data on population, employment, and personal income. Population and employment data for California counties for the years 1969-97 was obtained through the Regional Economic Information System (REIS) database, which is updated and maintained by the Bureau of Economic Analysis (BEA). Also obtained through the REIS database was data for total personal income by county, as well as personal income in counties by sector. The individual sectors are listed in Table 2 below, along with the corresponding average percent of county total income for all counties for the 1969-97 period.

County personal income, both aggregate and by sector, are used as output prices in the TFP analysis. The corresponding output quantity for aggregate personal income and sector income is county employment. As mentioned above, personal income data was obtained from the BEA's REIS database.

Table 2: Individual Sector Income			
Sector	**Average Percent of Total Income**	**Sector**	**Average Percent of Total Income**
Agricultural Services, Forestry, Fishing, Other	0.7	Retail Trade	7.2
Mining	0.4	Finance, Insurance, Real Estate	5.3
Construction	4.2	Services	20.0
Manufacturing	13.2	Government and Govt. Enterprises	11.6
Transportation and Public Utilities	4.7	Other Income (including county adjustment factors)	28.2
Wholesale Trade	4.5	**Total**	**100**

4.2.1 Gross State Product and Gross County Product

The final output variable, county product, incorporates Gross State Product (GSP) data, obtained from the BEA website and the *California Statistical Abstract*, published annually by the California Department of Finance. While the aggregate values for GSP were not used in the TFP analysis, they were necessary to calculate Gross County Product (GCP). Using a methodology outlined in Boarnet (1996) and originally from the technique used by the Southern California Association of Governments (SCAG) to apportion statewide gross product to counties, we have the following relationship:

$$GP_{c,t} = \frac{Y_{c,t}}{Y_{s,t}} * GP_{s,t}$$

where GP = Gross Product
Y = Total Personal Income

For the above equation, the subscript "c" represents counties, "y" represents years, and "s" represents state values. Also from the above relationship, $GP_{c,t}$ represents GCP and $GP_{s,t}$ stands for GSP.

4.3 Input Variables

There are several more input variables than output variables. The needed input variables fall under the categories of public capital, private capital, labor and energy, and are listed below in Table 3.

Road miles are used as an quantity input into the TFP function for public capital. Road miles are divided into two categories, local road miles and state highway road miles. The data on road mileage was obtained from the *California Statistical Abstract*, and is used as an input quantity for public capital in the TFP analysis.

Table 3: TFP Input Variables		
Variable	**Quantity**	**Price**
Public Capital (local)	Local road miles	Local expenditures
Public Capital (state)	State highway road miles	State highway expenditures
Private Capital (proxy)	$ Value of stock	Producer price index
Labor	Number of workers	Income
Energy	Energy usage	Energy price

Corresponding to the input quantity for public capital is the input price. The input price that was used is capital expenditures for local roads and state highways. This data was obtained from two sources. The local level street and road expenditures data was gathered from the *Streets and Roads Annual Report*, which is published by the California Office of the Controller. For state highway capital expenditures, data was obtained from the California Department of Transportation Report *State Highway Program Financial Statements and Statistical Reports.* This report was published annually for the years from 1969 through 1992. For the missing years, statewide capital expenditure data was obtained from the *Assembly of Statistical Reports* published by the California Department of Transportation, and allocated to counties based on historical trends of capital expenditures.

Private Capital data was obtained from Boarnet (1996). This data extended only to 1988 and was unavailable for the years 1989 through 1997. We therefore used the private capital data extending from 1969 through 1988 to estimate private capital based on income and economic sector activity. This equation was subsequently used to forecast private capital for 1989 through 1997. Employment was used as a labor input quantity for the TFP analysis. Employment data was found from the REIS database on a county level for the needed years.

To assess the viability of the transportation highway network, a system usage measure was necessary. Perhaps the most significant measure of system usage is Vehicle Miles Traveled (VMT). The difficulty of VMT when performing a TFP analysis is its characterization. At first glance, it might easily viewed as an output of the highway network. As highways are constructed, labor and capital are clearly inputs, and it might follow that VMT is viewed as an output of the transportation system.

However, since we are focusing only on economic outputs of the highway network, it becomes clear that VMT does not fit as an output alongside other outputs such as personal income and GCP. Thus, it becomes necessary to include VMT elsewhere, namely as a TFP input. Using VMT as an input is acceptable since it is a contributor to the economic vitality of a county: it affects production output on a firm or industry level, so on the level of the highway network, it becomes a contributor to the overall system input. We can also use VMT over miles of roadway to obtain a measure of highway capital utilization.

VMT data for truck miles and automobile miles comes from the report *Truck Kilometers (Miles) of Travel on the California State Highway System*, published by the California Department of Transportation. Data for the years from 1974-97 was located, with earlier data being estimated from the reports *California Accident Data* and *Historical State Highway, County Road, and City Street Statistics, 1957-1972*, also both published by the California Department of Transportation.

4.4 Regression Variables

In addition to inputs and outputs, there are several variables that were included for regression purposes. Included in the regression variables are the ITS services that are the focus of this study. The cumulative number of ITS services per county then serves as an explanatory variable to regress with the output of the TFP analysis. By comparing the TFP output values with the level of ITS services, it is possible to assess the effect of ITS technologies on the transportation network's level of productivity.

The first ITS regression variable is the number of ramp meters installed per county for the 29 year time period. When the total number of ramp meters per county is summed for each year, we get the total number of ramp meters operating in the state (See Appendix A-12). This number is important in that it effectively shows the rate of ramp meter introduction for the years studied. Clearly, the rate has accelerated from its original pace, and continues to rise quicker each year. By the end of 1997, there were over 1700 ramp meters installed in 23 different California counties.[18]

Table 4: Regression Variables
Variable
ITS - Ramp Meters
ITS - Changeable Message Signs

Data was also collected for Changeable Message Signs (CMS's) in California (See Appendix A-13). Both ramp meters and CMS's were used because they represent two of the most widely implemented ITS strategies in California. Some form of ITS service, either ramp meters or CMS's, exists in over 30 California counties, and many of ramp meters and CMS's have been in operation for a substantial number of years. Thus, it is expected that any benefit to these services ought to be greater and more fully developed than newer ITS applications.[19]

[18] Data for ramp meters was provided by Laurie Guinness of Caltrans.
[19] Data for installed CMS's was also obtained from Laurie Guinness.

4.5 GRAPHS OF DATA

This section described briefly the graphs that are contained in Appendices A and B. The graphs in Appendix A are simple plots of some of the acquired data, and they serve to visually depict the growth over time of several of the data series and TFP variables. The graphs in Appendix B provide a closer look at the level of ITS technology in specific counties. Given below is a description of each graph in Appendices A and B.

4.5.1 GRAPHS IN APPENDIX A

A list of the graphs contained in Appendix A is given below. Appendices A-1 and A-2 provide a summary of the population and per-capita income in California as a whole and among counties. Given in Appendices A-3 and A-4 show how personal income and GSP in California have increased over the 1969-97 time period, when corrected for inflation. Appendix A-5 gives income growth as broken down by sector, over the studied time period. Appendices A-6 and A-7 show the aggregate increase in road miles for California for the given years, and Appendix A-8 shows total road miles in 1997 on a county basis. Appendix A-9 shoes how State Highway System VMT for autos and trucks has increased over the studied time period. A-10 graphs the VMT per road mile, showing the increase in capacity utilisation that has occurred on California state highways. The graphs in Appendices A-12 and A-13 give the aggregate level of ramp meters and CMS's operating in California for the time period from 1969-1997.

Appendix	*Graph Title*
A-1	California Population (By County, 1997)
A-2	California Population and Per-Capita Income (Statewide)
A-3	California Gross State Product
A-4	California Total Personal Income
A-5	California Total Personal Income by Sector
A-6	Total City and County Road Miles (Statewide)
A-7	Total State Highway Road Miles (Statewide)
A-8	California Road Miles (By County, 1997)
A-9	California Road Expenditures (Capital Outlay, Statewide)
A-10	State Highway VMT for Trucks and Autos (Statewide)
A-11	State Highway VMT per State Highway Road Mile
A-12	Total Ramp Meters (Statewide)
A-13	Total Changeable Message Signs (Statewide)

4.5.2 GRAPHS IN APPENDICES B AND C

The graphs in Appendix B plot the level of ITS implementation in each county with total county personal income. Both ramp meters and CMS's are graphed separately, though there are ten counties that had both forms of ITS technology present in 1997. Additionally, in 1997, twenty one counties had at least one CMS but no ramp meters, and one county had ramp meters but no CMS's.

Appendix *Graph Title*

Appendix	Graph Title
B	Ramp Meters and Gross County Product (By County, 1969-97) (For 11 California counties)
C	Changeable Message Signs and Gross County Product (By County, 1969-97) (For 31 California counties)

5.0 EMPIRICAL RESULTS

The two models described in section 3 were estimated on the data set outlined in the previous section. The first model, a production function is designed to answer the question does public capital and specifically new technology public capital contained in ITS applications have a significant impact on the output of small geographic areas.

The second model addresses the same issue but in a somewhat different way. It also can speak to the question of whether ITS capital provides areas with greater productivity. This is an important issue given the findings of Boarnet (1996). He found in his investigation of the impact of public investment that it did have a positive effect on gross output but that the impact was redistributive. This means public capital, like highways or ITS, will redistribute economic activity rather than add to it. Thus, such benefits resulting from public capital investment should not, he claims, be included in an assessment of the public capital investment.[20] However, the second model is exploring the question of whether TFP is affected by an ITS investment or any highway investment. If the productivity is greater with ITS it means the overall output of the region, county, state has increased relative to the non-ITS state of the world.

5.1 PRODUCTION FUNCTION

The results of the production function estimates are illustrated in Table 5. There were a number of models estimated including the translog model described in section 3. However, test of functional form led to the selection of a simpler log-linear model. The model estimated is illustrated below.

$$\ln GCP_{i,t} = \alpha_0 + \beta_L \ln L_{i,t} + \beta_2 \ln K_{i,t} + \beta_H \ln H_{i,t} + \sum_j \beta^j{}_{ITS} \ln ITS^j{}_{i,t} + \delta_H \ln(X * H_{i,t})$$
$$+ \delta_{ITS}(X * ITS_{i,t}) + \varepsilon_{i,t}$$

The variables are defined as in section 3; L is labour, K is private capital and H is highway capital measured in terms of miles of roadway.[21] The impact of ITS applications is measured in two ways. The direct affect of ITS is measured as the number of ITS

[20] In a project evaluation only user benefits should be counted and any economic benefits should be ignored since they are redistributive.

[21] In previous work the highway capital variable was measured by the dollar value of the capital stock whereas in this work the measure is a physical measure.

projects of a given type introduced in a given year. Two types of ITS applications were included, ramp meters and changeable message signs (CMS). These are captured by the β^j parameters in the equation.

There are also spatial effects considered in the model. As in Boarnet (1996) the impact of neighboring counties is captured in the δ_H parameter. This is designed to measure the distributional impact of public, specifically highway, capital. But there is also the idea that ITS can have the same impact. The same technique for the spillover effects of public capital was used to determine if ITS projects had spillover effects.
The results reported in Table 5 provide mixed evidence on the impact of ITS on economic growth. If the GCP variable is specified as including only private sector output, a positive coefficient on the highway and/or ITS variables is a sufficient condition to show a benefit for ITS and public capital. There is a positive externality that shifts the private output function demonstrating that public capital increases the productivity of private capital and labor.

However, if government services and expenditures are included in the dependent variable, a positive coefficient simply means that public capital has a positive influence on county output. Whether there is a net gain for the economy depends on the difference between the costs of public expenditure and the benefits.[22] This will depend on whether public capital has a complementary or substitute relationship with private capital and labor.

The coefficient on labor is positive indicating labor adds to county output. This result is consistent with the existing literature. Private capital as well as highway capital is also positive indicating private capital adds to output. Highway capital is measured by the physical amount of highway capacity. The coefficient can be interpreted as an elasticity.[23] A 1 percent increase in the amount of highway miles would lead to a .2 percent increase in highway miles. However, this is not the complete story. If there are redistributional affects, so investments in one county leads to growth but at the expense of adjacent counties. Thus, the test is that highway infrastructure is productive is based on moving economic activity from one county to another. As highways create move accessibility and mobility one county is provided with a competitive advantage.

The test of a first order spatial lag of highway mileage is captured in the δ_H variable. The coefficient on highway capital is positive indicating a positive influence on economic output. However, the variable X*H is a test of the spillover effect. If the coefficient is positive, counties reinforce one another so a neighboring county investing in more highways can make you better off. However, if the coefficient is negative, it means economic activity is shifted to adjacent counties as they invest in highway capital. In Table 5 δ_H is –0.139. The value is les than the value on the highway variable, 0.1597. The net positive difference means despite redistributing economic activity, adding highway

[22] Evidence from the literature on CGE (computable general equilibrium) models is each $1 of public capital costs approximately $1.40. Therefore, the productivity benefits must exceed 40 percent of the expenditures.
[23] The elasticity is a measure of the degree of responsiveness of one variable with changes in another.

capital has a net positive impact on the county. If the coefficients had been of the same magnitude it would mean all positive economic benefits obtained within a county are offset by losses in neighboring counties.

Similar issues arise with ITS applications since they represent new technology applied to the transportation (generally highway) system. Our attempt to distinguish the impact of different types of ITS applications was not successful. ITS represents new technology and this would be expected to affect the other factor inputs differently. One would therefore expect the coefficients to differ between ramp meters and CMS applications. The data set is not rich enough to distinguish separate effects, so the ITS applications were aggregated into a single ITS variable.

Table 5

Results of Production Function Model

Dependent Variable: Log of gross county product

Variable	Coefficient	Std Error	t statistic
constant	8.9112	1.394	6.39
Ln (Labor)	0.5764	0.125	4.61
Ln (Private Capital	0.1882	0.093	2.02
Ln (Highway Capital)	0.1597	0.042	3.80
Ln (ITS - ramp meters)	*NS*		
Ln(ITS - CMS)	*NS*		
Ln(ITS - Aggregate)	0.0183	0.0097	1.89
Ln(X*ITS)	0.0003	0.0042	0.00
Ln(X*H)	-0.139	0.05	-2.78
time effects	year dummies		
county effects	fixed		
R-square	0.98		
No. observations	1687		

The coefficient on the ITS variable is positive, 0.0183, which shows that ITS investments will have a small but positive affect on economic growth.[24] However, the same phenomena as occurs with highway capital may occur with ITS applications, there are spillovers, so economic benefits may be transferred from adjacent counties or regions. The variable X*ITS is a first order spatial lag measuring the number of ITS applications in adjacent counties. If the coefficient on this variable is positive it means adjacent counties reinforce one another; that is, the economic benefits from the investment in ITS applications will be enhanced if an adjacent county also invests in ITS projects. If the coefficient is negative it means the gains in one county from an ITS application come at

[24] As the data set is refined and expanded, we can explore ITS interactions.

the expense of reductions in economic activity in adjacent counties. The coefficient is positive but it is not statistically significant. It would appear the impact of ITS is not spatially distributed but this result requires further study.

5.1.1 Summary

The results of the analysis provide some new results for the public capital literature and for policymakers debating the issue of whether and how much to invest in public capital and particularly ITS. This model is the first attempt to empirically measure the impact of ITS. Previous work has looked at ITS on a project basis or drawn conclusions from simulation results. The results show that highway capital provides local areas (measured by counties) with a competitive advantage creating output gains. Previous research found that the gains were offset by losses in adjacent counties. The net impact was to redistribute economic activity. Our results differ since not all of the gains are obtained from adjacent areas. There is a net positive benefit. This is important for any highway project evaluation since there are benefits that should be included in any benefit cost evaluation.

The impact of ITS applications has not been assessed in an economic model before. This research provides the first results to show ITS applications have a positive impact on economic growth by providing local areas with a competitive advantage. ITS creates economic gains. These gains do not appear to result from shifting economic activity from other jurisdictions. This result, however, needs further investigation.

What does this mean for the question of including benefits in benefit-cost assessments of highway investments and ITS projects? Our results show that highway capital has a net economic benefit on a local area. Some of the economic gains are the result of shifts from adjacent areas but not all. Whether they are included depends on the geographic scope of the project funding. If a highway project is funded at the state level it may be some counties, which contribute to highway projects through their tax levies are made worse off since they have some economic activity transferred away from them. On the other hand some counties experience a net economic benefit. If the net gains are sufficiently large to offset losses such net benefits net to be considered since a net welfare gain, at the state level, results.

ITS projects, on the other hand, provide net economic benefits without apparently cannibalizing the net economic benefit is a welfare gain. The spillover effects did not show any statistical significance but the positive sign on the spatial spillover variable is intriguing. A significant positive sign would suggest Caltrans would generate added benefits to adjacent counties by investing in ITS projects. Such benefits need to be considered in any evaluation.

Further research needs to explore three issues. First, is there a positive or negative spillover effect between ITS projects in different t jurisdictions? Second, how do ITS projects interact? Are there synergies that lead to greater benefits? If so, it means investments in ITS should take place as clusters. Finally, what is the mechanism by which ITS applications provide economic benefits? In other words, how does transportation and ITS applications specifically fit into consumers and producers utility and profit functions?

5.2 TFP Analysis

The TFP analysis is the second approach used in assessing the contribution of ITS to the productivity and economic growth of the California economy. The production function models the economic growth results of ITS. The TFP analysis addresses a different issue, how does ITS affect economic growth; particularly is productivity influenced in any way?

The TFP analysis used the output of each county as the aggregate output.[25] The inputs used were labour, highway capital and private capital.[26] The mean value of the sample was used as the reference point for the analysis.

The TFP calculation is a gross measure in the sense it measures the growth in outputs relative to the growth in inputs. However, the physical, economic and regulatory environments can differ markedly. These factors must be taken account of before any legitimate TFP comparisons between counties could be made. The method of creating a ‘net’ TFP value is to regress structural and other characteristics data on the gross TFP measure. By including measures of ITS, we can identify the separate contribution of ITS applications (ramp meters and CMS) while accounting for other influence as well.

Table 6 contains the estimates of the TFP regression. A number of different functional forms were examined and combinations of variables. The results of intended to provide orders of magnitude. The counties were entered as dummy variables and are not reported. There was a mixture of signs and levels of significance.

The GCP variable was entered as an indicator of size. There is significant size variation across the counties in California as well as over time. The coefficient is positive and significant. Larger counties tend to have higher levels of productivity growth but their advantage is not overwhelming. The time variable is intended to capture trend effects of growth in TFP over time. Generally there has been an upward trend in productivity growth. Certainly the last few years have been exceedingly high in a number of areas driven by the high technology industries and tourism.

The two variables of interest for our purposes are the investment in highway miles and the impact of ITS applications. The parameter estimate on Highway miles is positive and significant (at the 10 percent level). The result is that added miles add to county productivity. However, the effect is small with an elasticity of 0.01; a 1 percent increase in highway miles leads to a .01 percent increase in productivity. This result should not be unsurprising. As we have seen in the data section, the majority of California’s investment

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[25] In the next year we will be using revenue aggregates of the several sectors to create the output variable.

[26] Measures of energy use are still being developed. It may not be possible to include this since some of the data are proprietary.

in highways took place in the sixties, since that time *relatively* little stock has been added. These results are consistent with the general literature in this area.

The variable of most interest is the ITS applications. In the earlier model, we found economic growth (GCP) was positively related to the level of ITS projects in the county. In this model we find that productivity is one mechanism that drives this economic growth. ITS has a positive, albeit small, impact on TFP. The elasticity of county TFP with respect to the number of ITS applications is .002; a 10 percent increase in ITS applications leads to a .02 percent increase in TFP.

Table 6

TFP Regression Results for ITS Applications

Dependent Variable: Log of TFP

Variable	Coefficient	Std Error	t statistic
constant	0.09872	0.0632	1.56
Ln (GCP)	0.03911	0.0149	2.62
Ln (Highway Capital)	0.01179	0.0062	1.90
Ln (time)	2.43711	0.6291	3.87
Ln(ITS - Aggregate)	0.00265	0.002	1.33
county effects	year dummies		
R-square	0.84		
No. observations	1687		

6.0 SUMMARY AND CONCLUSIONS

An objective of ITS within the California Transportation Plan was to improve productivity of the transportation system. This research has explored two research questions. First, do ITS applications have an impact on the economy of California? And second, if they do have an impact, what is the mechanism that yields the benefits? If there are economic benefits to be experienced from ITS applications, those benefits ought to be included in any benefit-cost assessment of an ITS project.

The paper began with a motivation for undertaking this work. ITS development has reached a stage that further refinements can be pursued only if it is clear they yield real economic benefits. Deployment is therefore essential to show first that ITS can provide the potential gains that were claimed by ITS proponents. Second, it is necessary in order to understand how the ITS applications will fit into the system, not in a technical sense but in an economic and social sense. How are they to be used by travelers and shippers to improve economic well-being? How should the ITS applications be refined to enhance their acceptance and use in the marketplace?

This research represents a first attempt to address these questions. There has been an extensive literature on the impact of public capital on economic growth. There has been mixed evidence on the role and importance of public capital. Studies based on aggregate national or state data have found little evidence to support the impact of public capital as being any larger than private capital. However, it may be because highway development has a more local effect. We therefore developed our data sets to reflect economic activity at the county level.

ITS is public capital but a particular type of public capital. Some ITS applications are designed to meet user needs. In particular, we focus on those applications that both stimulate demand as well as facilitate trade. In the former case, as the system provides greater accessibility, the transactions cost of engaging in trade (purchasing goods and services) are lower. This should be reflected in more economic activity and economic growth. For firms, ITS can lower the costs of doing business both in terms of providing inputs in a timely fashion using newer management technologies such as Just-in-Time delivery as well as in the distribution of products. A transportation system that ensures firms can deliver products to customers in a timely manner will also stimulate economic growth. The issue in all of the ITS technologies is how they meet user needs and how they integrate into firm strategies.

Our modeling took two distinct but related approaches. In the first case we used a production function model that represented the way a county assembled and delivered a range of goods and services to the marketplace. Included in the production function were private capital, labor resources, highway capital and measures of the development and integration of ITS projects in to the highway system. Two ITS technologies were considered, ramp meters and changeable message signs. The empirical results show that ITS projects have a positive impact on gross county output. The results show that highway capital provides local areas (measured by counties) with a competitive advantage creating output gains. Previous research found that the gains were offset by losses in adjacent counties. The net impact was to redistribute economic activity. Our results differ since not all of the gains are obtained from adjacent areas. There is a net positive benefit. This is important for any highway project evaluation since there are benefits that should be included in any benefit cost evaluation.

The second modeling effort was to develop measures of TFP. This productivity measure takes account of the aggregate growth in outputs as well as inputs. New technology affects the economy in several different ways. It can allow us to do old things in new ways and to do new things. Technology is an enabler and it must be combined with personal and industrial strategies to yield new experiences, new products and services to add to the economic and social welfare of California. This research has really focused on the doing old things in new ways, lower costs and improved productivity. To this end our estimates show ITS adds benefits that should be counted in any project evaluation. The benefits are in the form of improvements in productivity. This leads to cost reductions in the delivery of gross county product. This answers a question which arose from our estimates of the production function, if ITS increases output, how does this happen? What we do not yet know is where, in what industries the impacts occur.

This research provides the first evidence of whether and how ITS contributes to economic growth and productivity – an objective established by the California Transportation Plan and ITS in particular. The next set of questions includes, what industries are most affected by ITS applications? Does it matter how many ITS applications are present, in other words, are there diminishing returns to similar ITS projects?[27] Finally, does it matter how ITS projects are combined? This latter question also arose out of our research on production functions as well, and will be a central part of the subsequent research agenda.

[27] Our investigation of ramp meters in the TOPS Report found that adding more pre-set ramp meters yielded few returns and could in fact make you worse off. However, if the technology were added to ramp meters in the form of synchronization the benefits yielded were significant.

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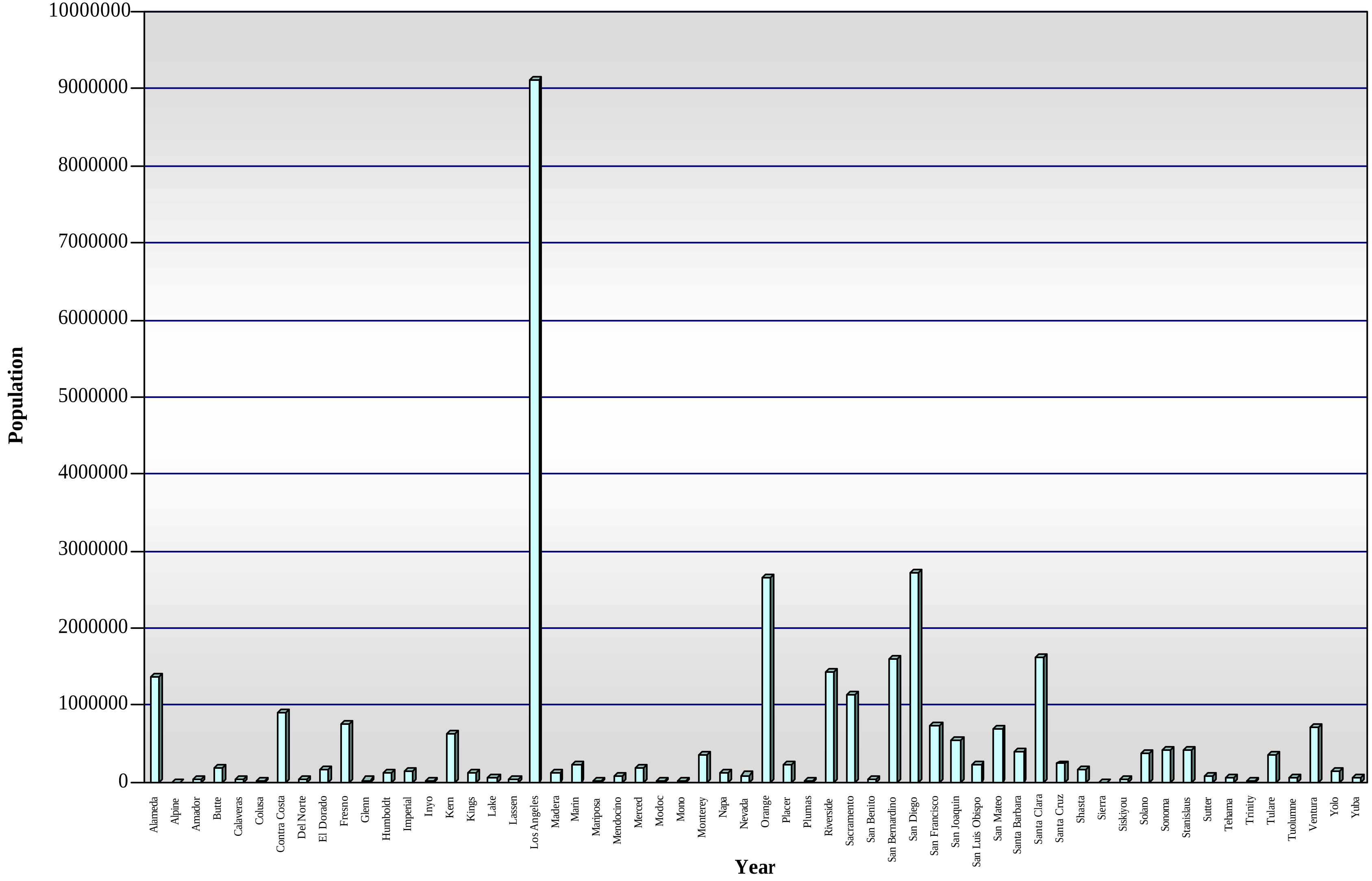
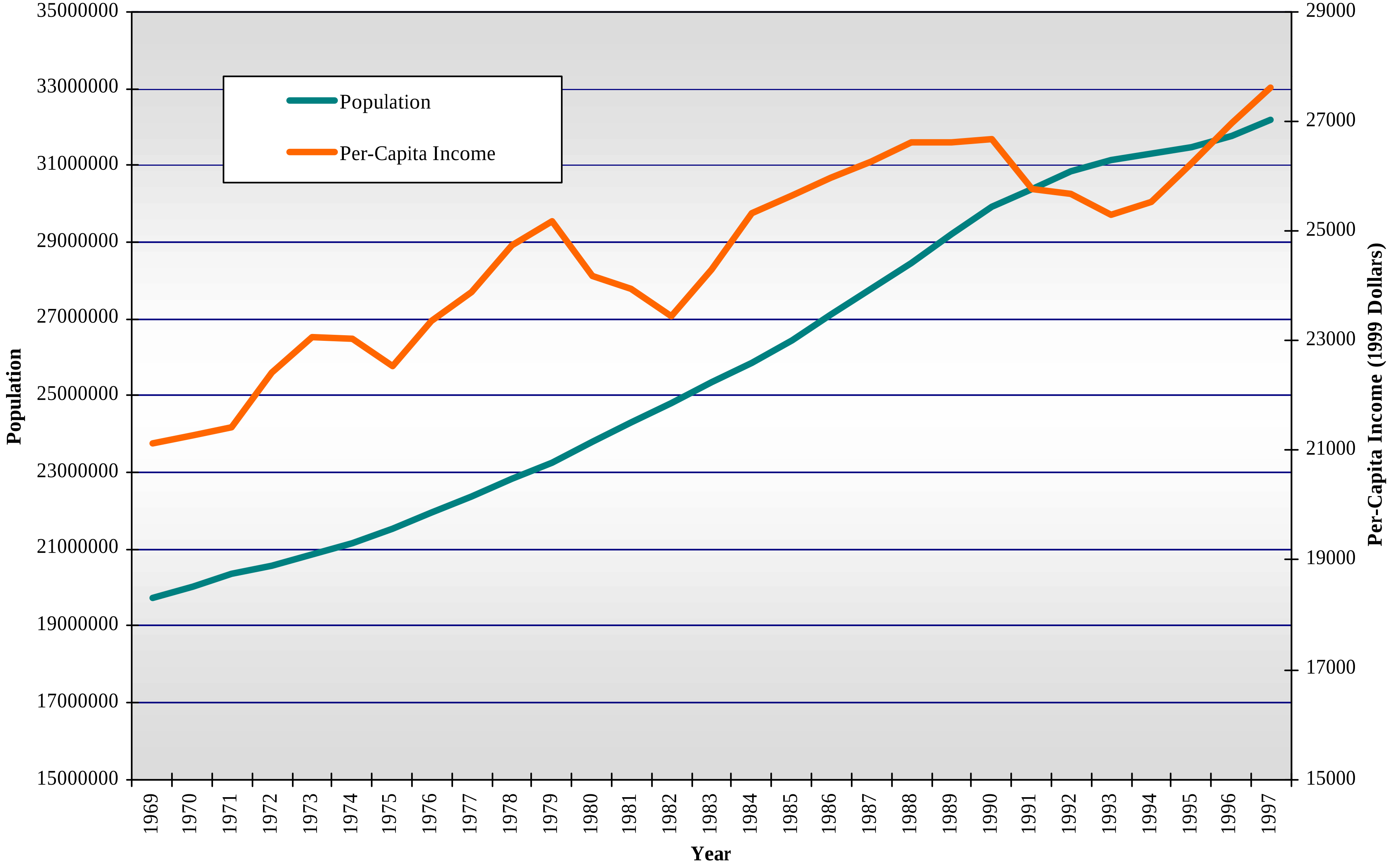
APPENDIX B RAMP METERS AND GROSS COUNTY PRODUCT (BY COUNTY, 1969-97)

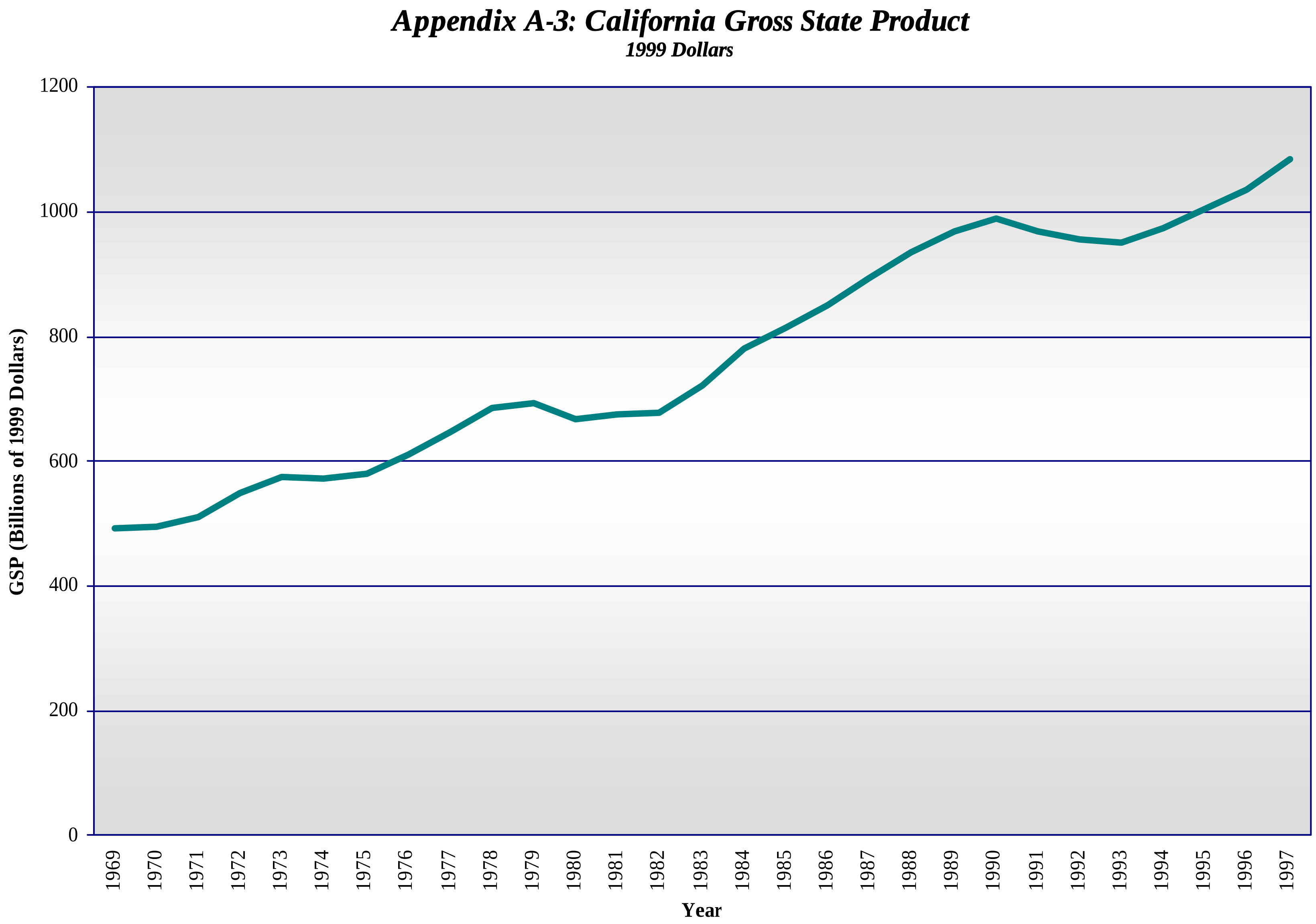
APPENDIX C CHANGEABLE MESSAGE SIGNS AND GROSS COUNTY PRODUCT (BY COUNTY, 1969-97)

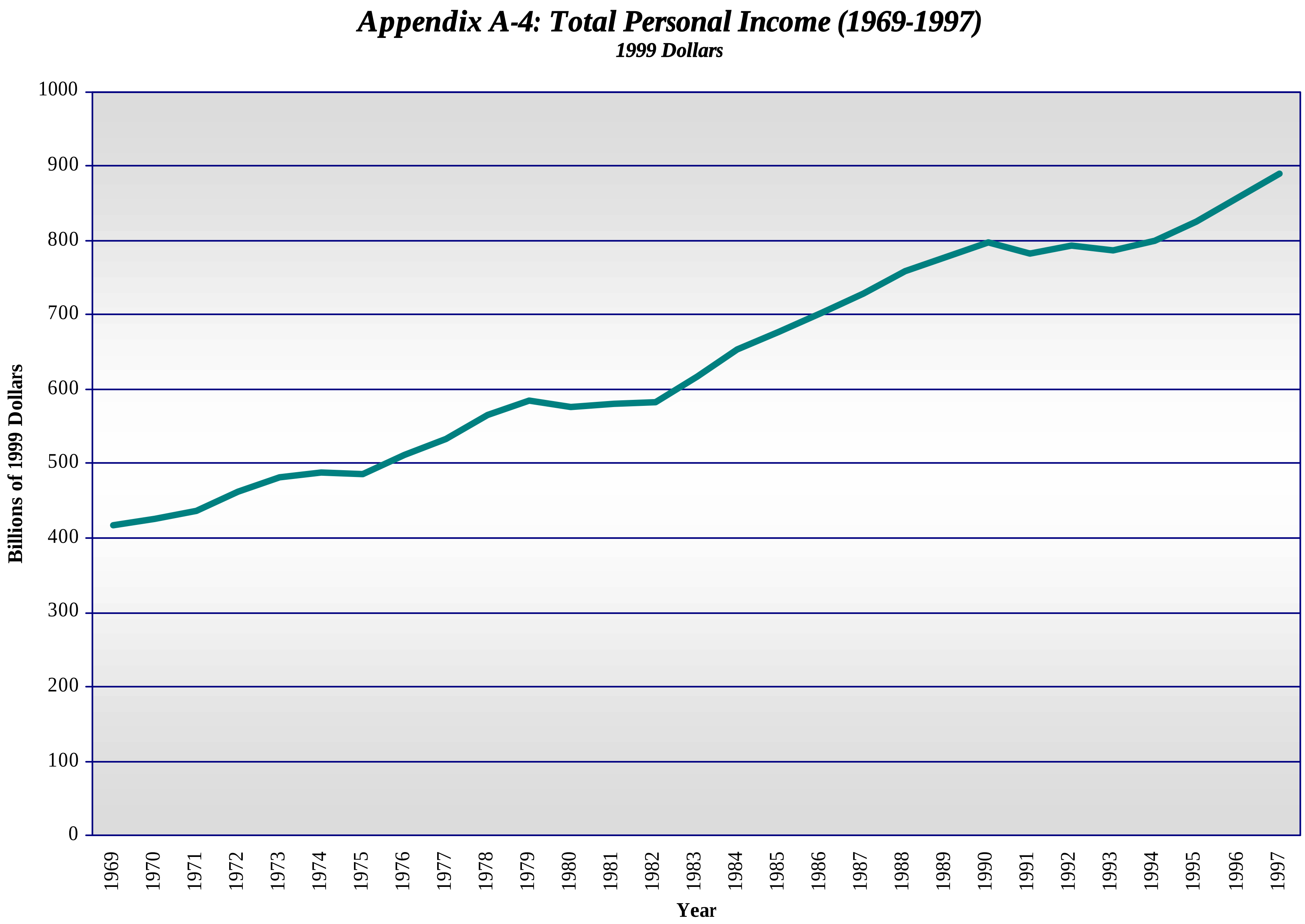
Appendix A-1: California Population (1997)



Appendix A-2: California Population and Per Capita Income



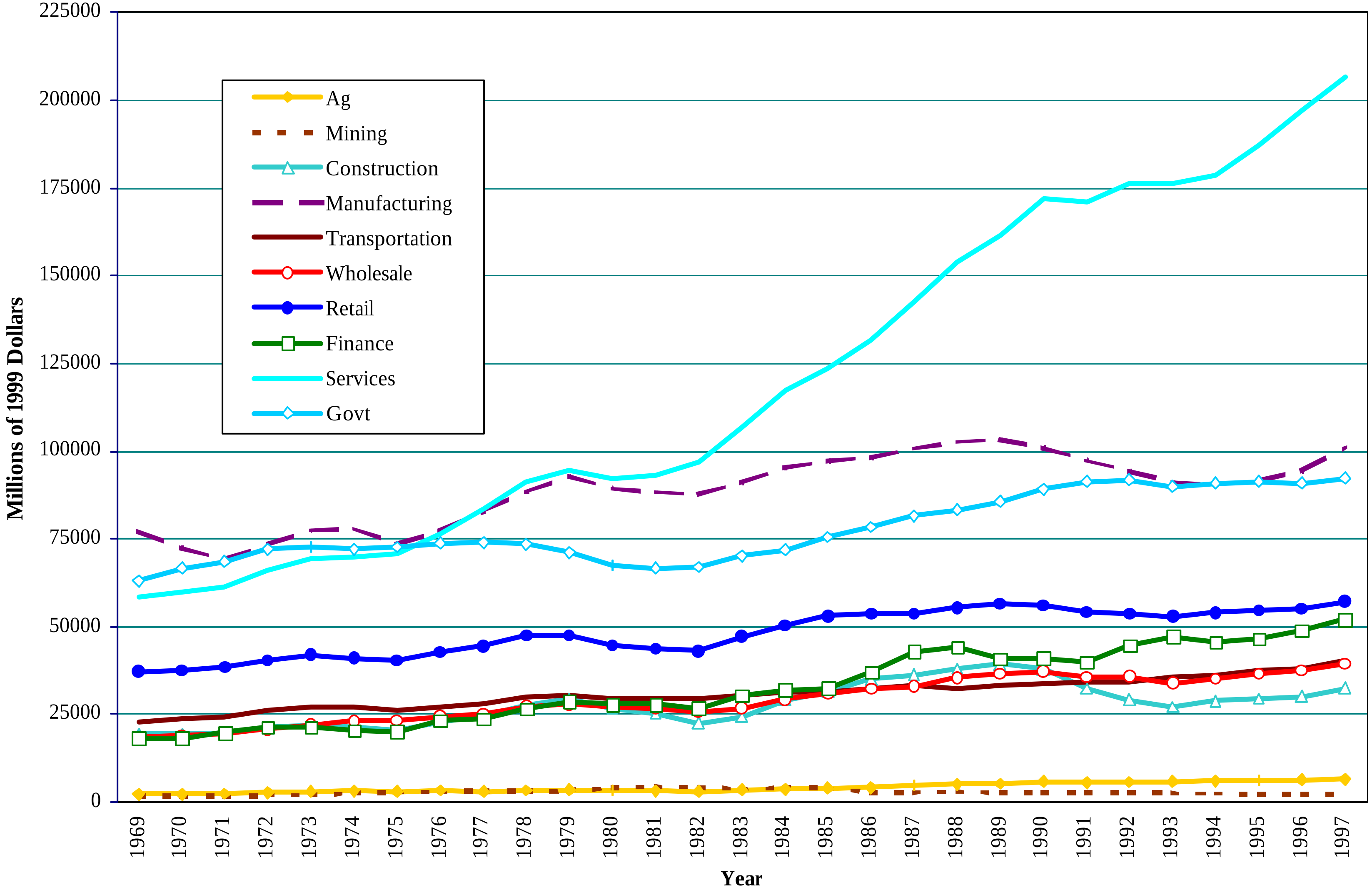

Appendix A-3: California Gross State Product
1999 Dollars
GSP (Billions of 1999 Dollars)
0
200
400
600
800
1000
1200
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
Year



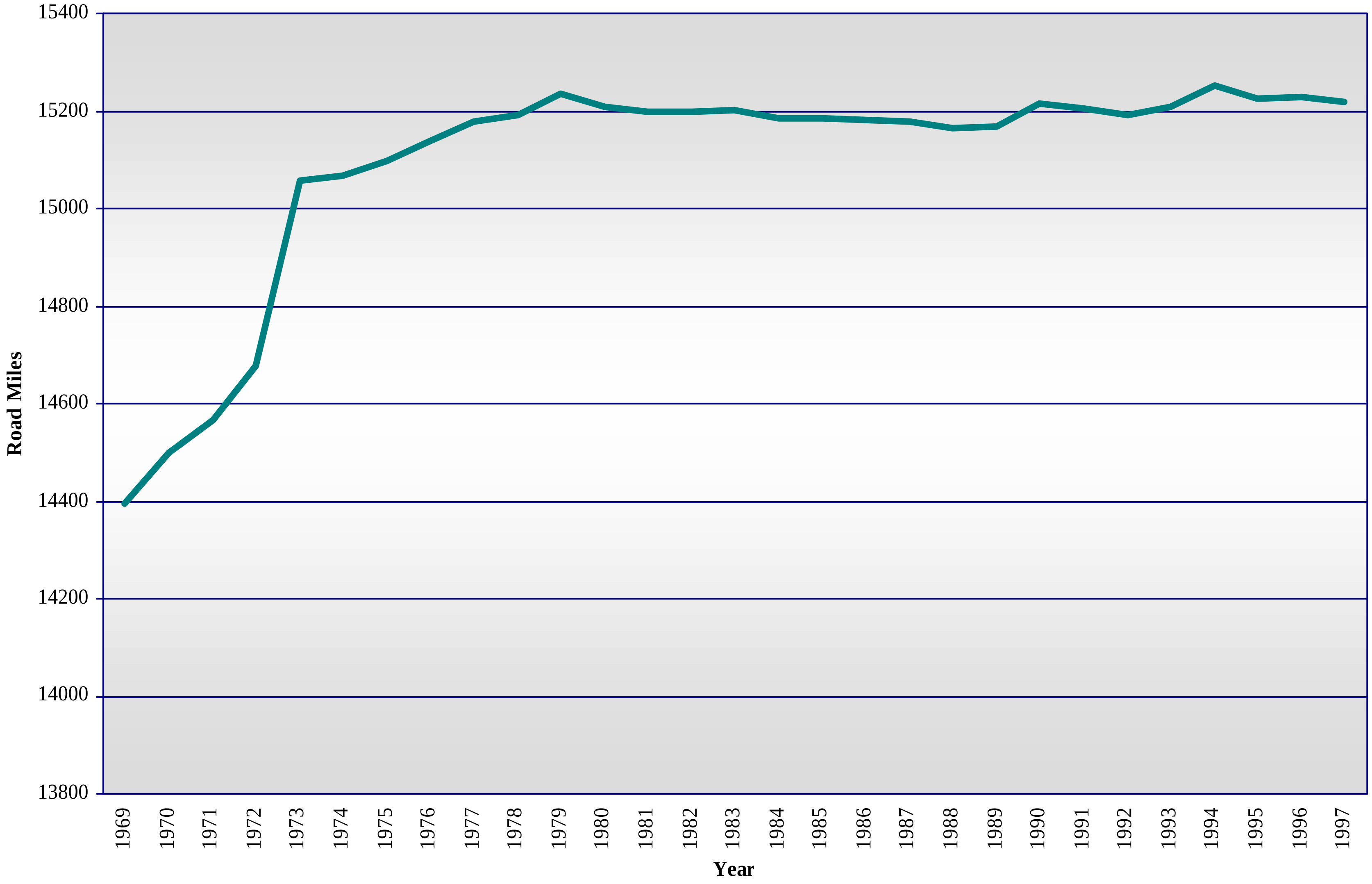
Appendix A-4: Total Personal Income (1969-1997)
1999 Dollars
Billions of 1999 Dollars
1000
900
800
700
600
500
400
300
200
100
0
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
Year

Appendix A-5 California Total Personal Income by Sector (1969-1997)

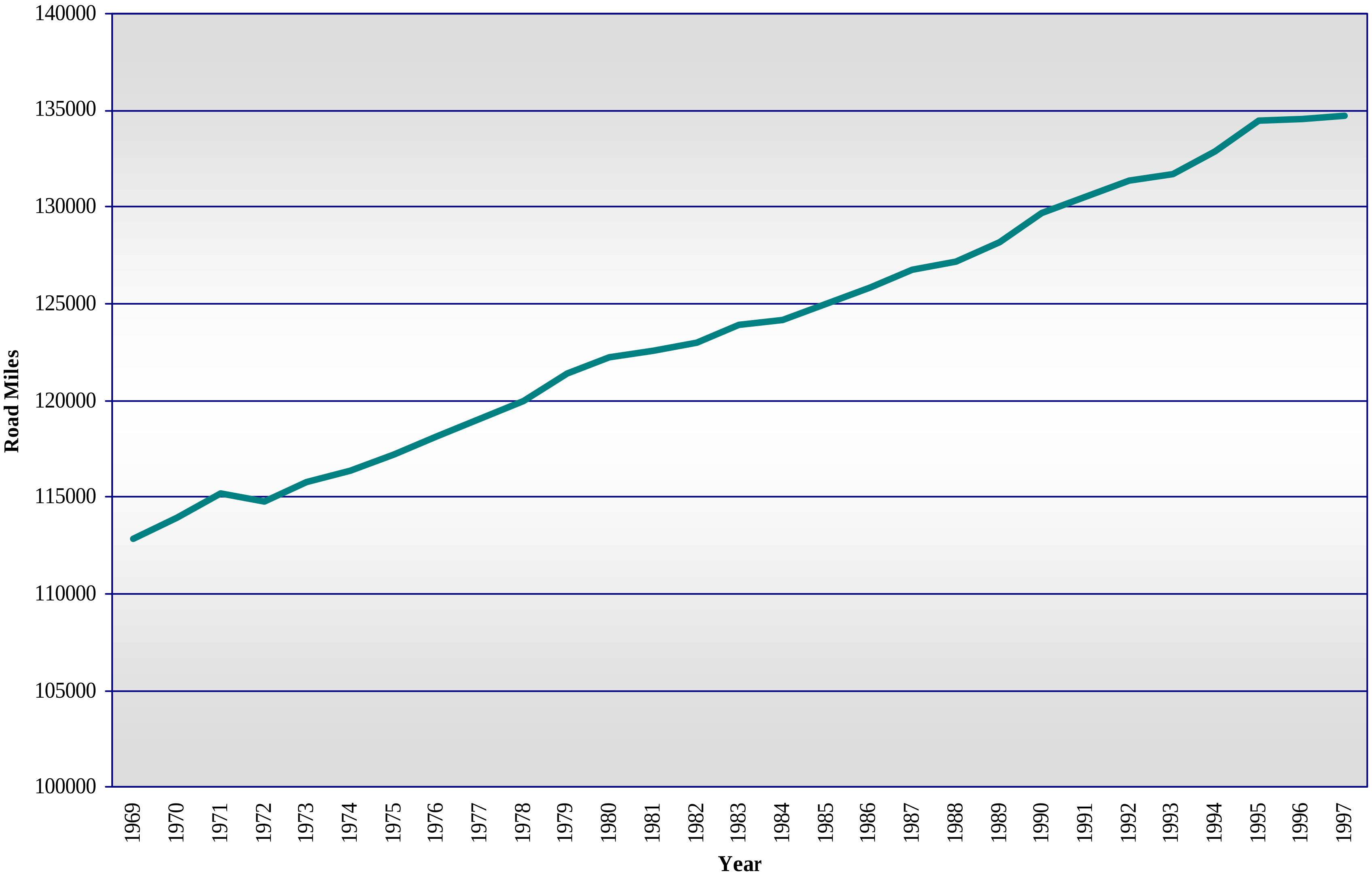
1999 Dollars



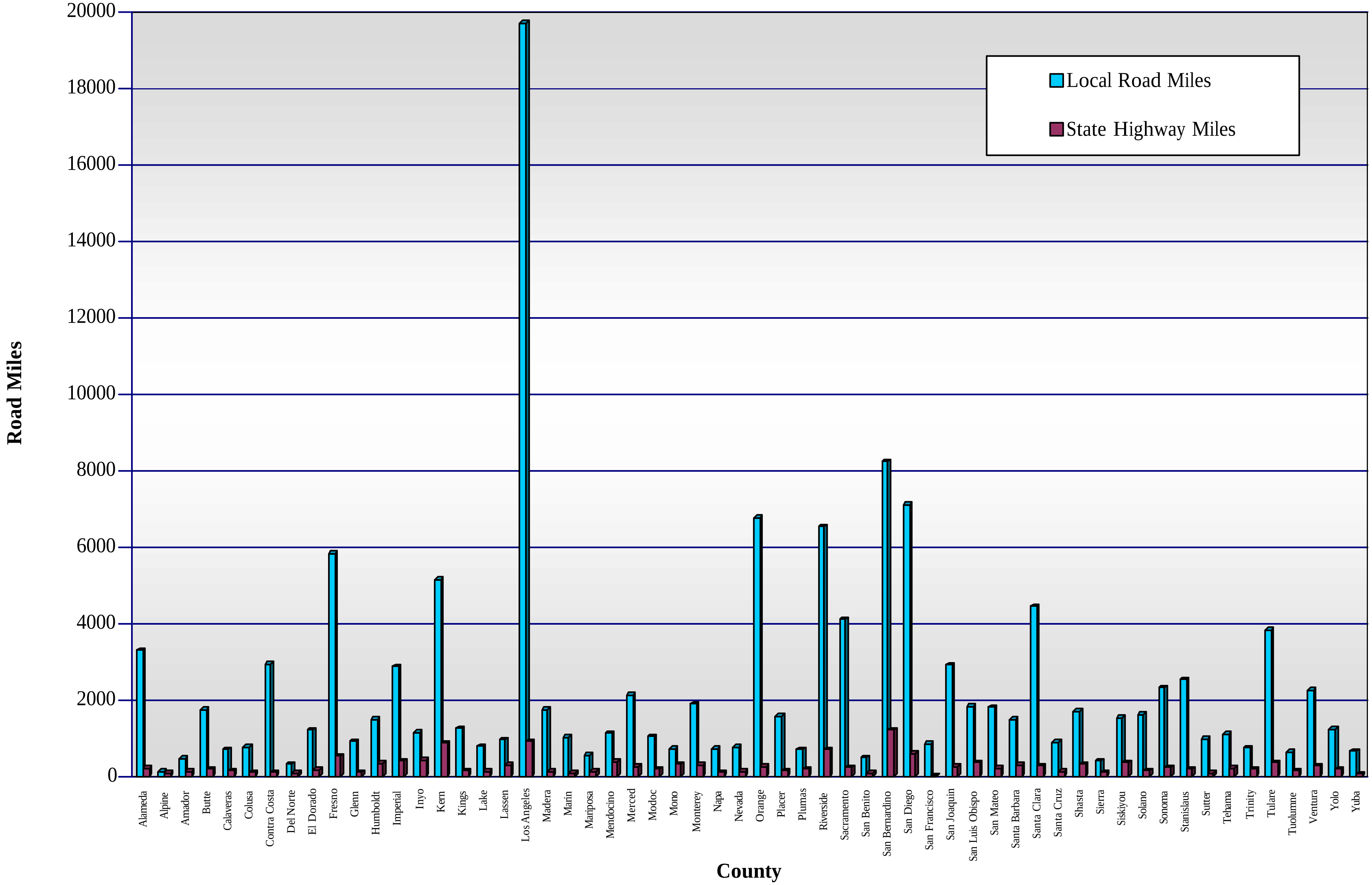
Appendix A-6: California State Highway Road Miles (1969-1997)



Appendix A-7: California City and County Road Miles (1969-1997)

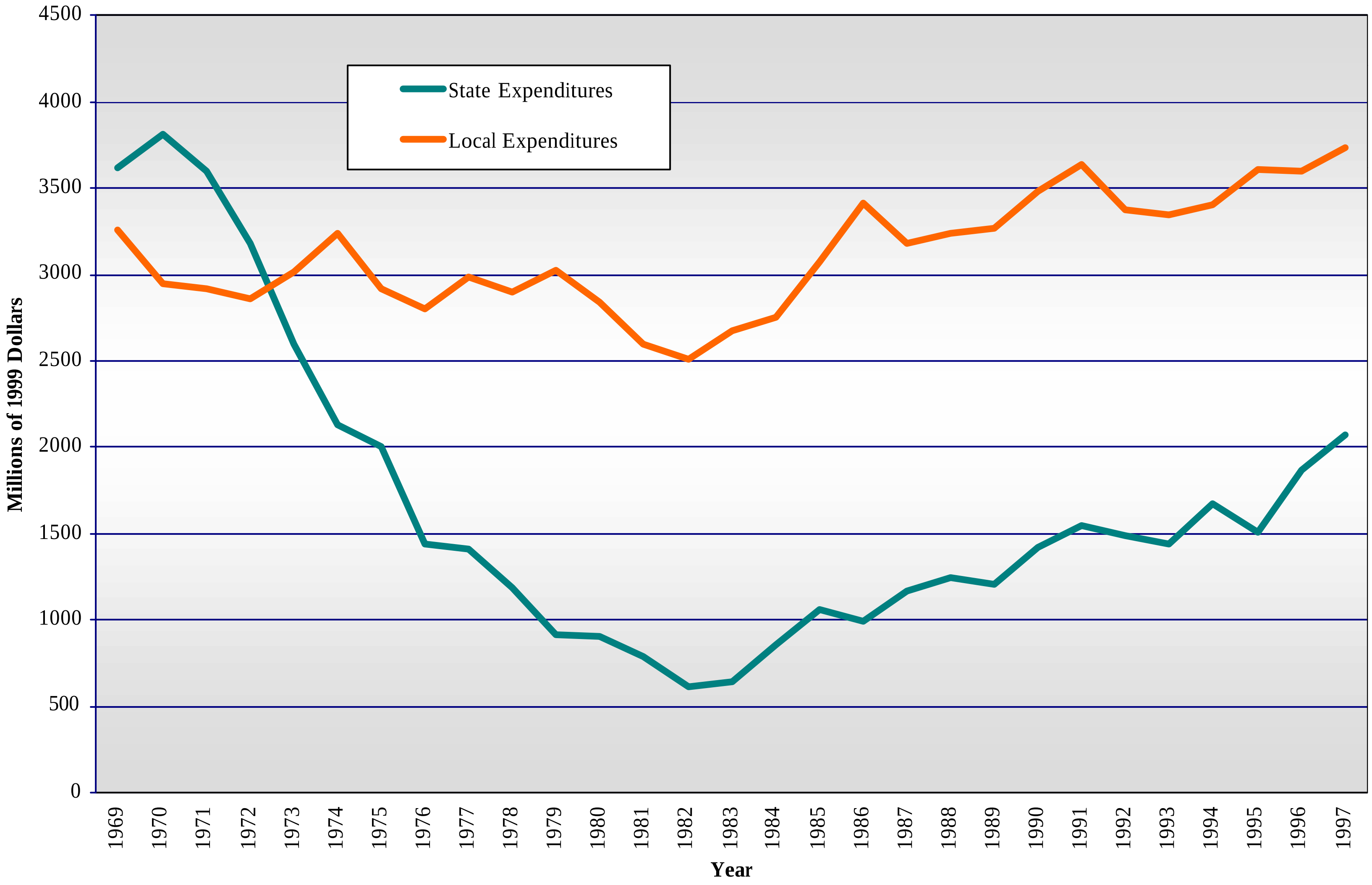


Appendix A-8: California Road Miles by County - 1997

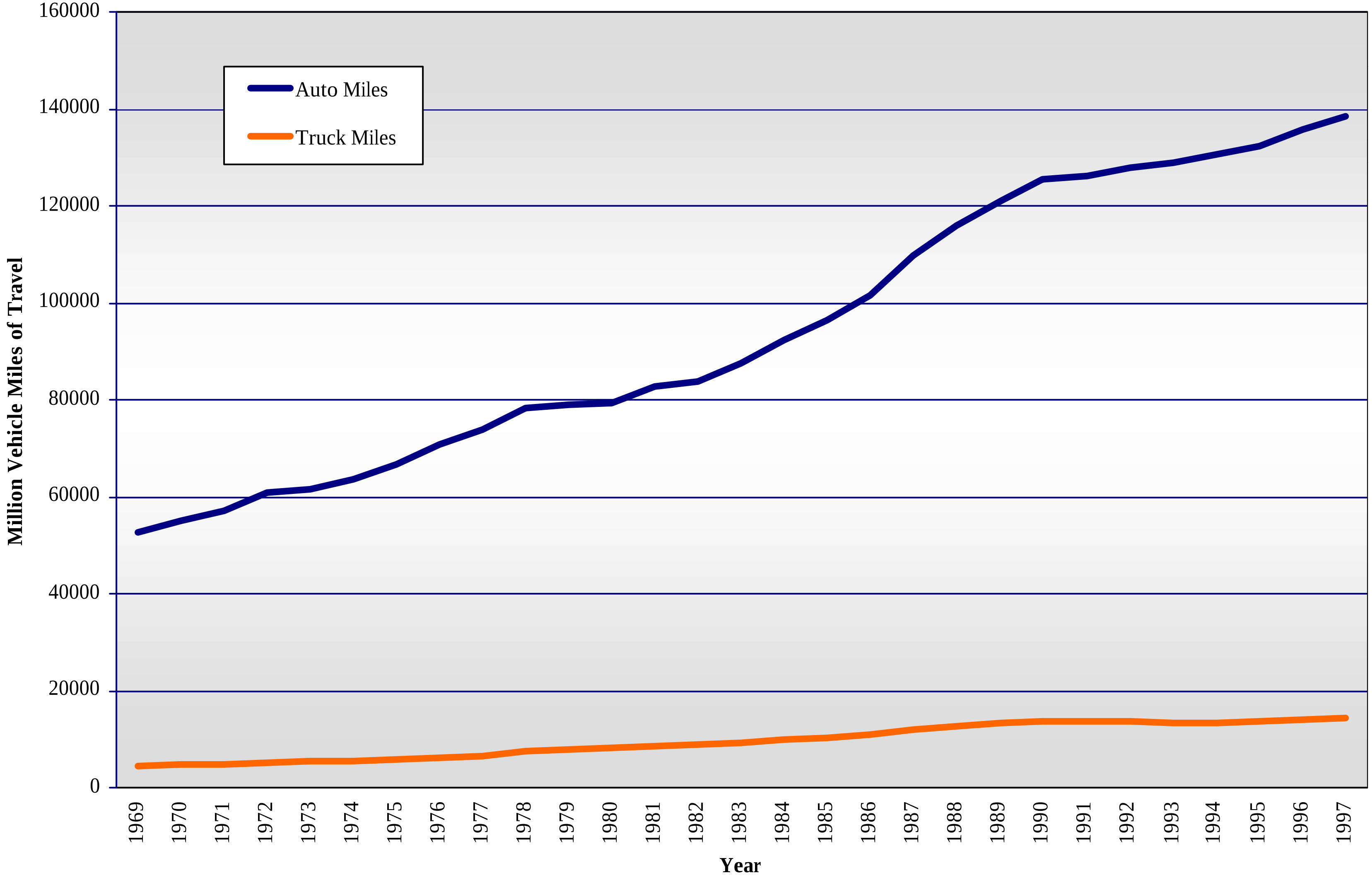


Appendix A-9: California Road Expenditures (1969-1997)

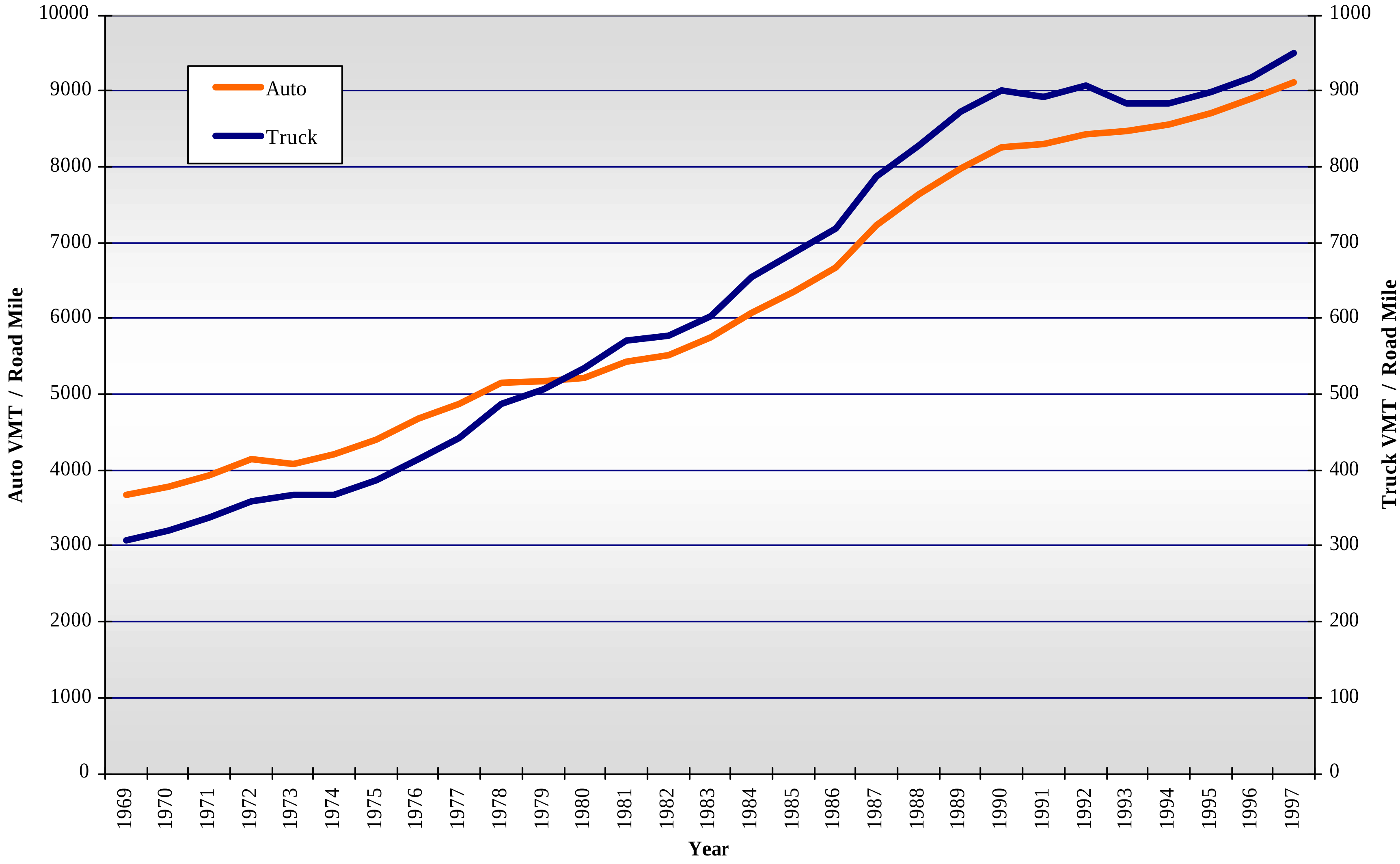
1999 Dollars, Capital Outlay Expenditures



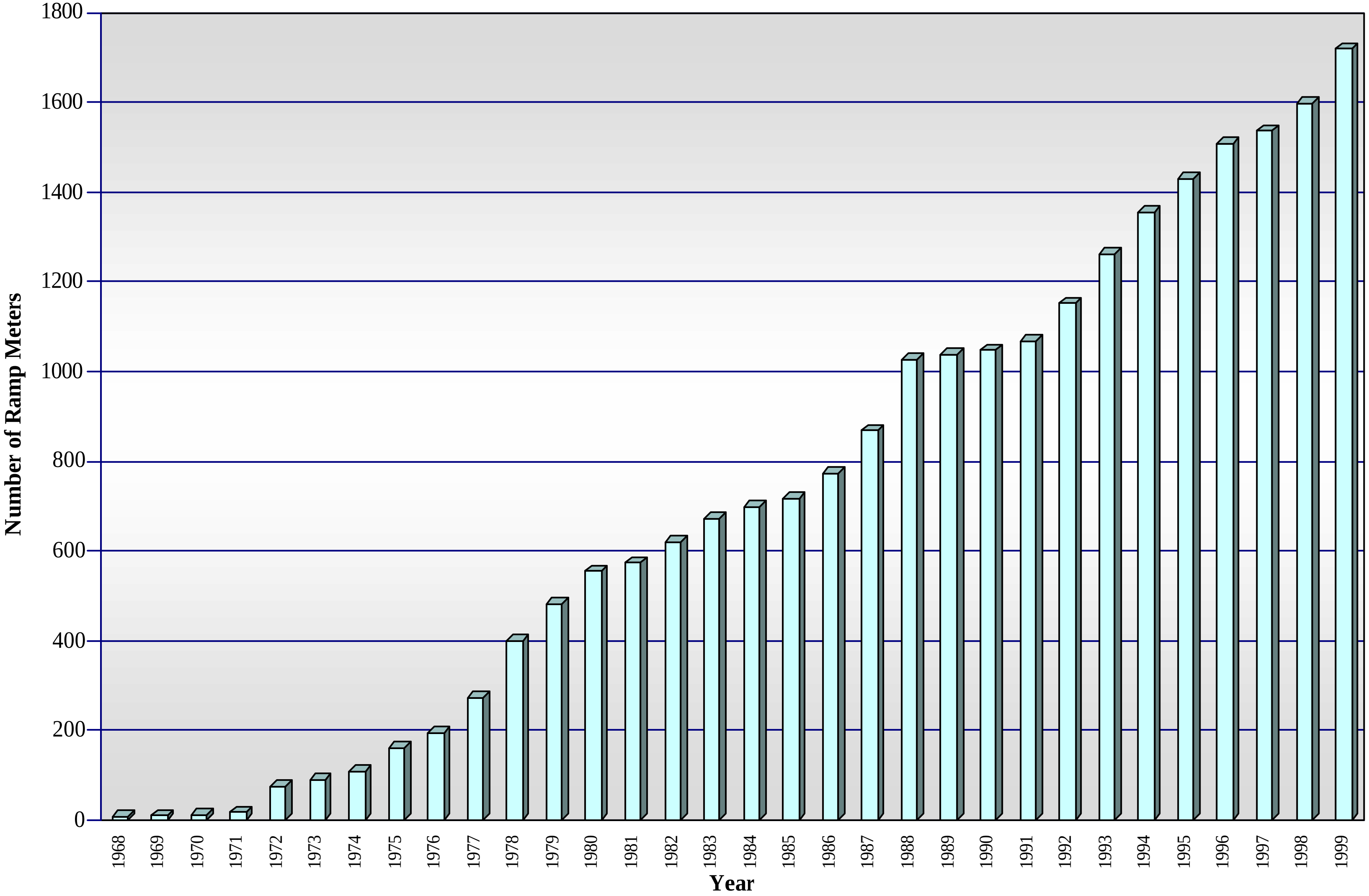
Appendix A-10: California State Highway VMT (1969-1997)



Appendix A-11: VMT per Road Mile on State Highway System

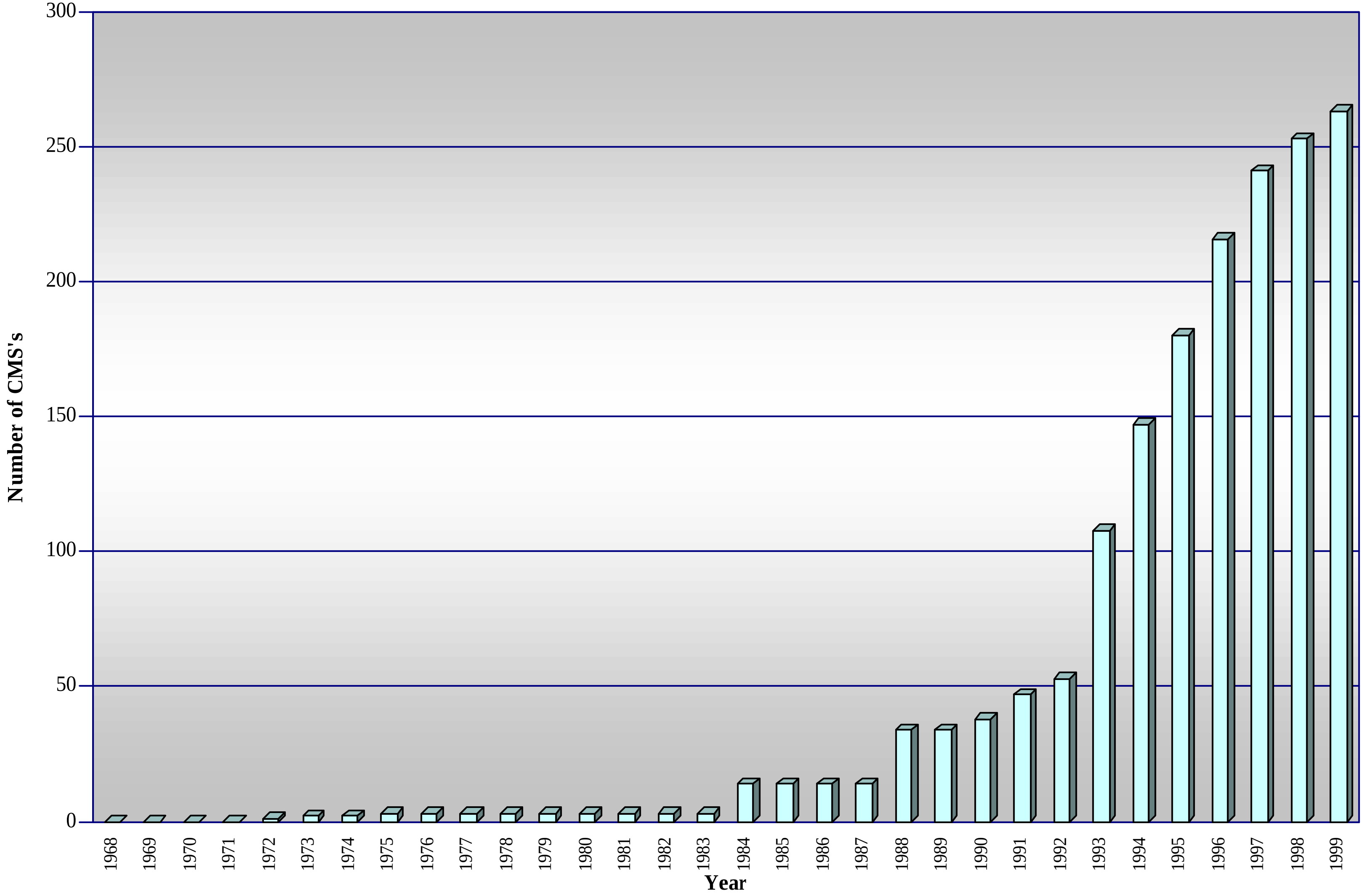


Appendix A-12: Total California Ramp Meters

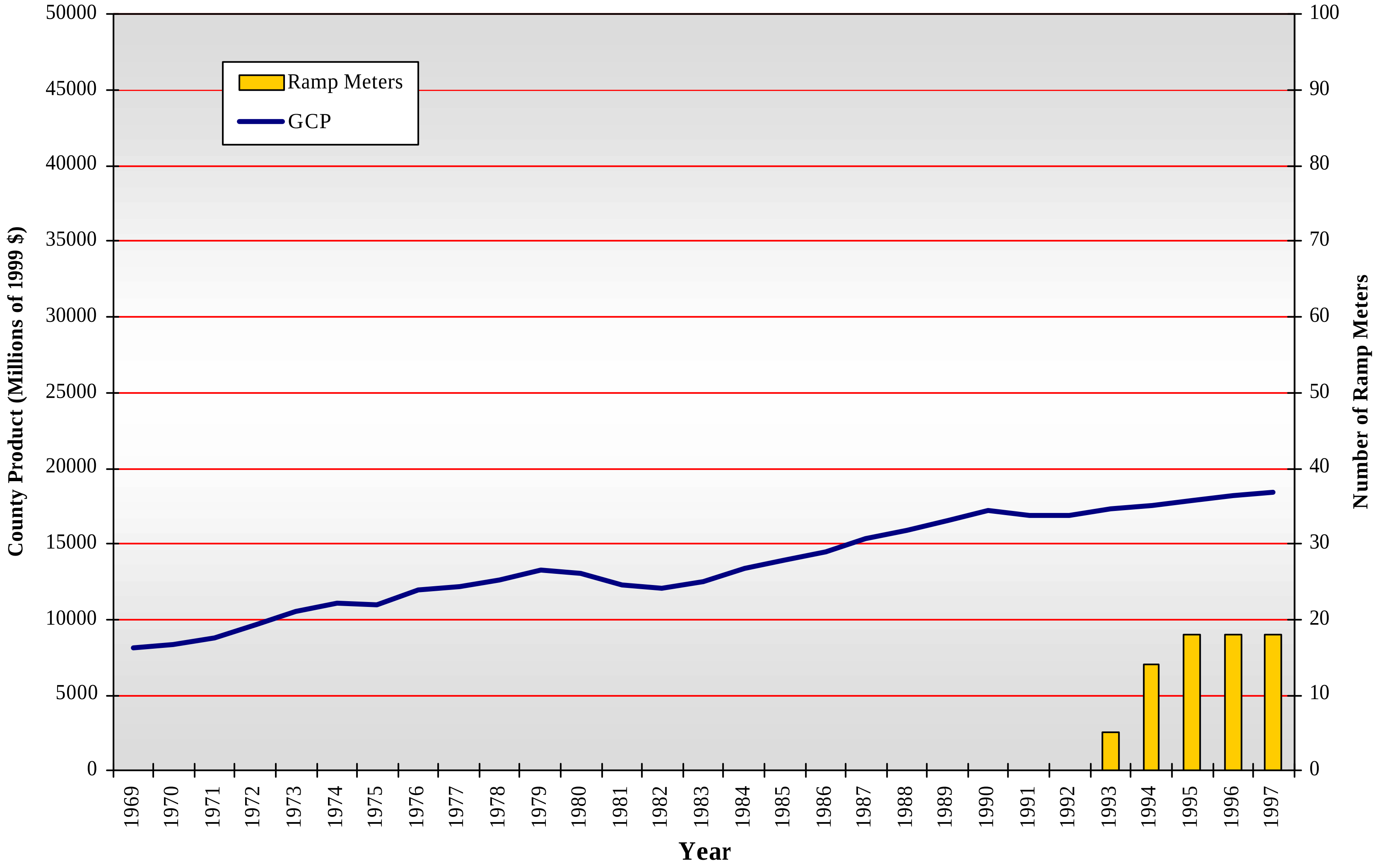


Appendix A-13: California Changeable Message Signs

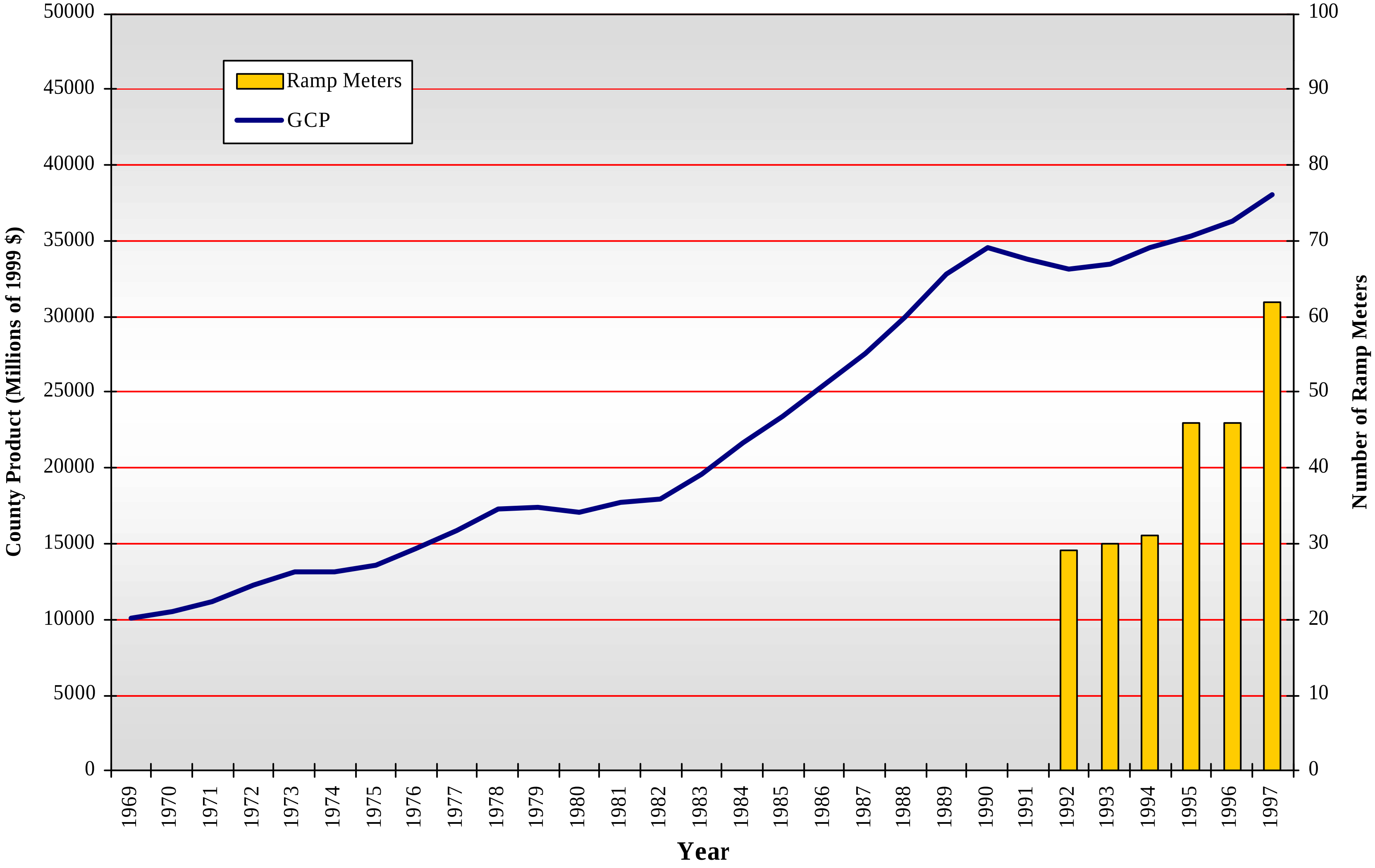
(Does not include 87 signs where no date of installation was known)



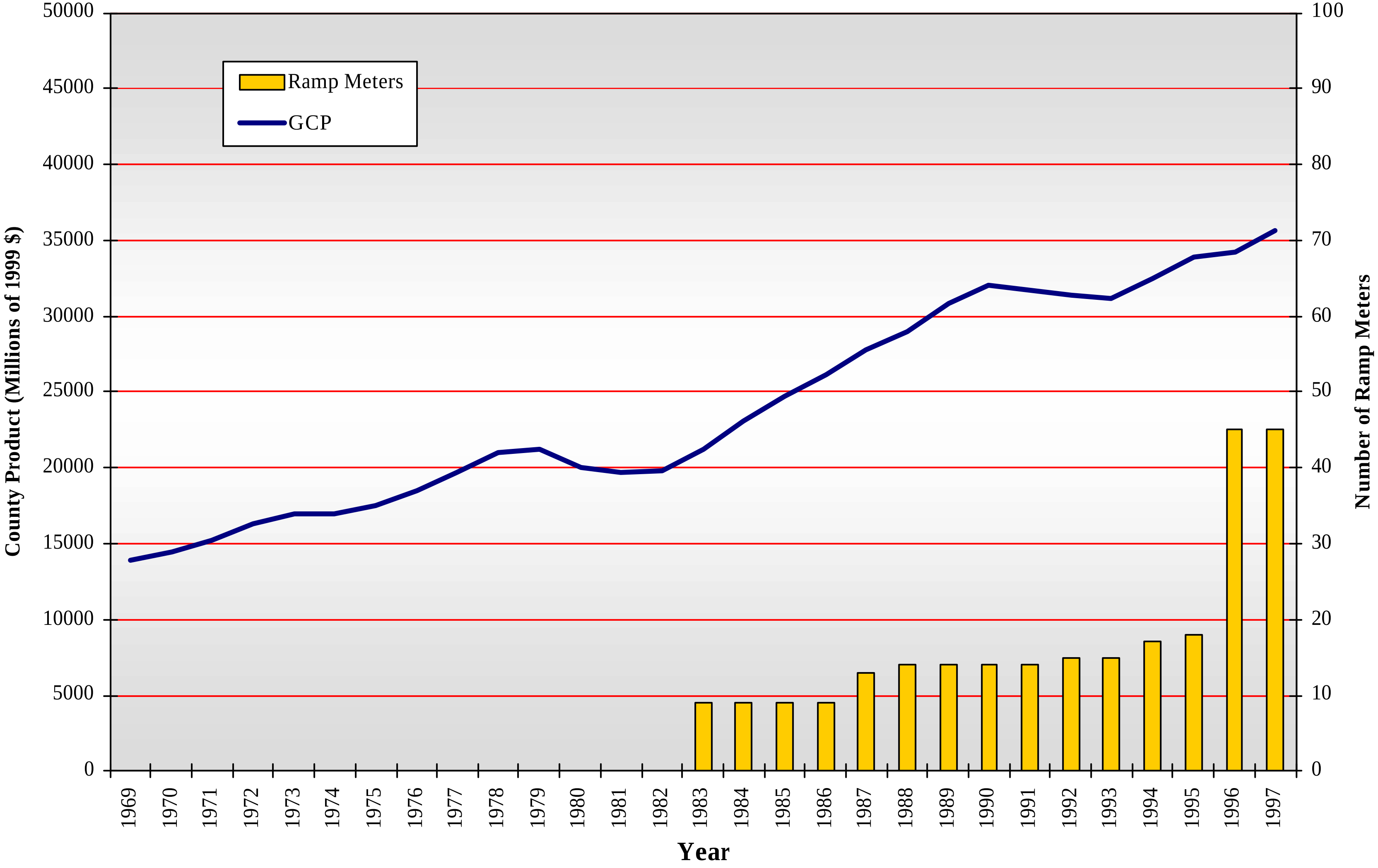
Fresno County - Gross County Product and Ramp Meters



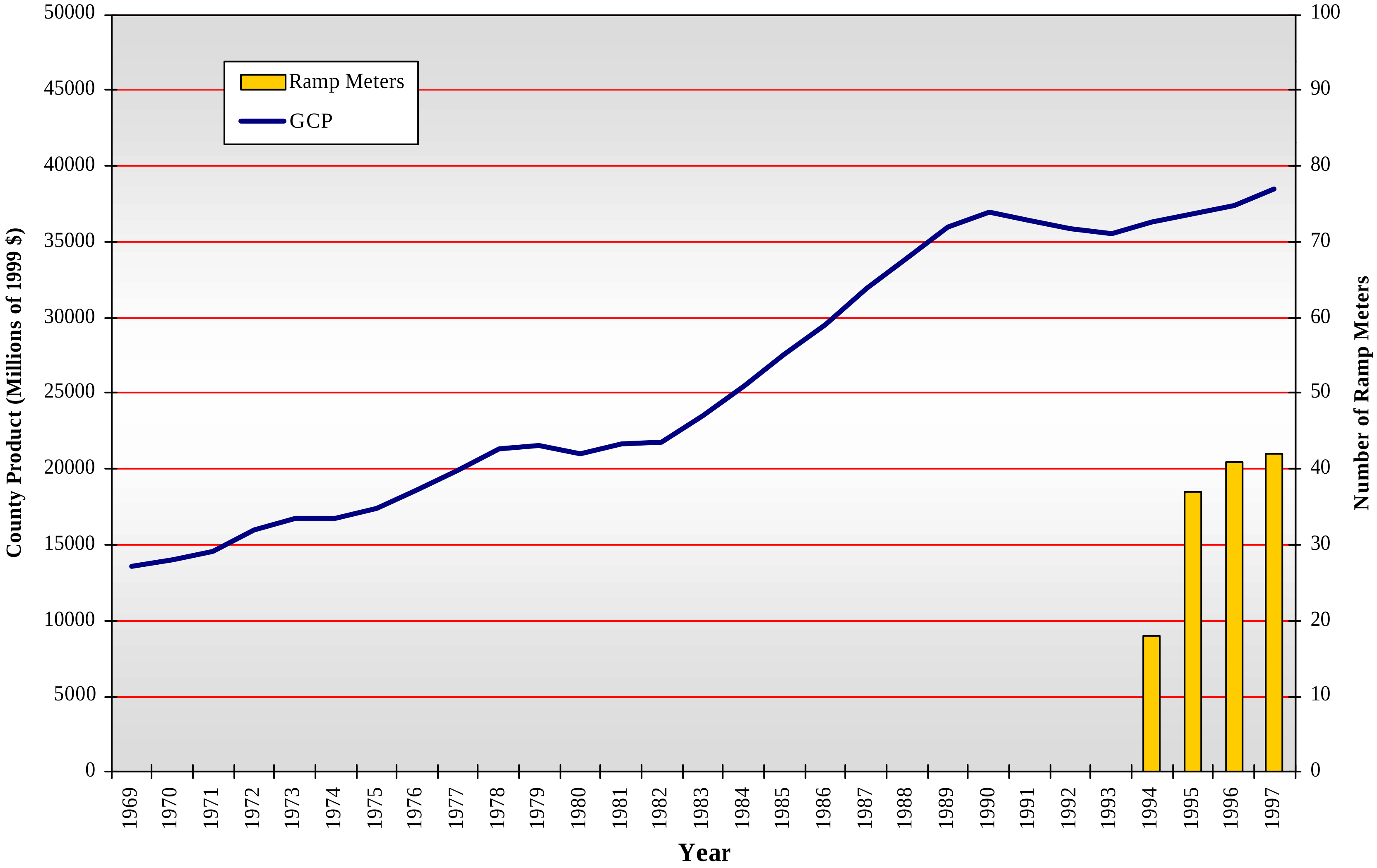
Riverside County - Gross County Product and Ramp Meters



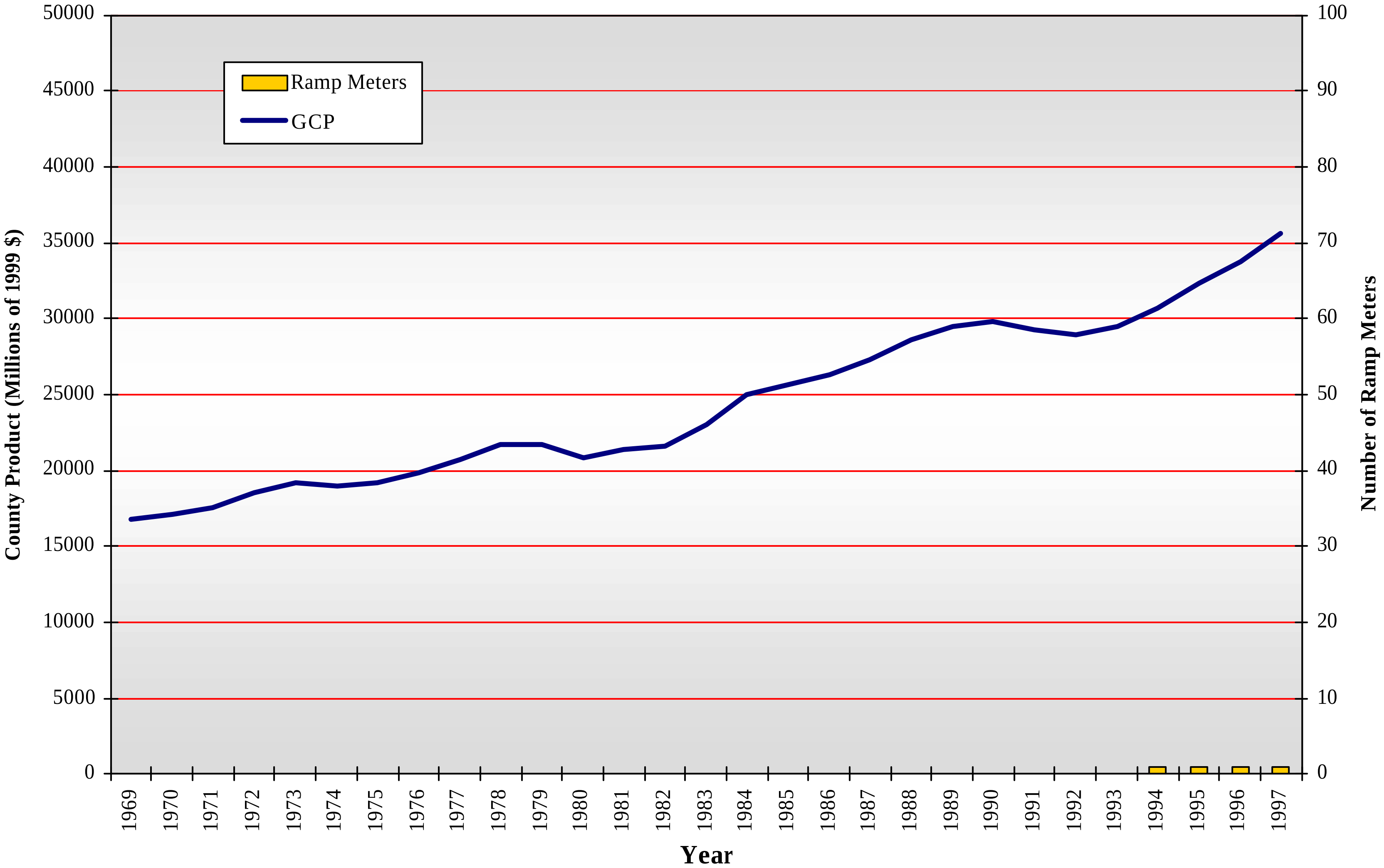
Sacramento County - Gross County Product and Ramp Meters

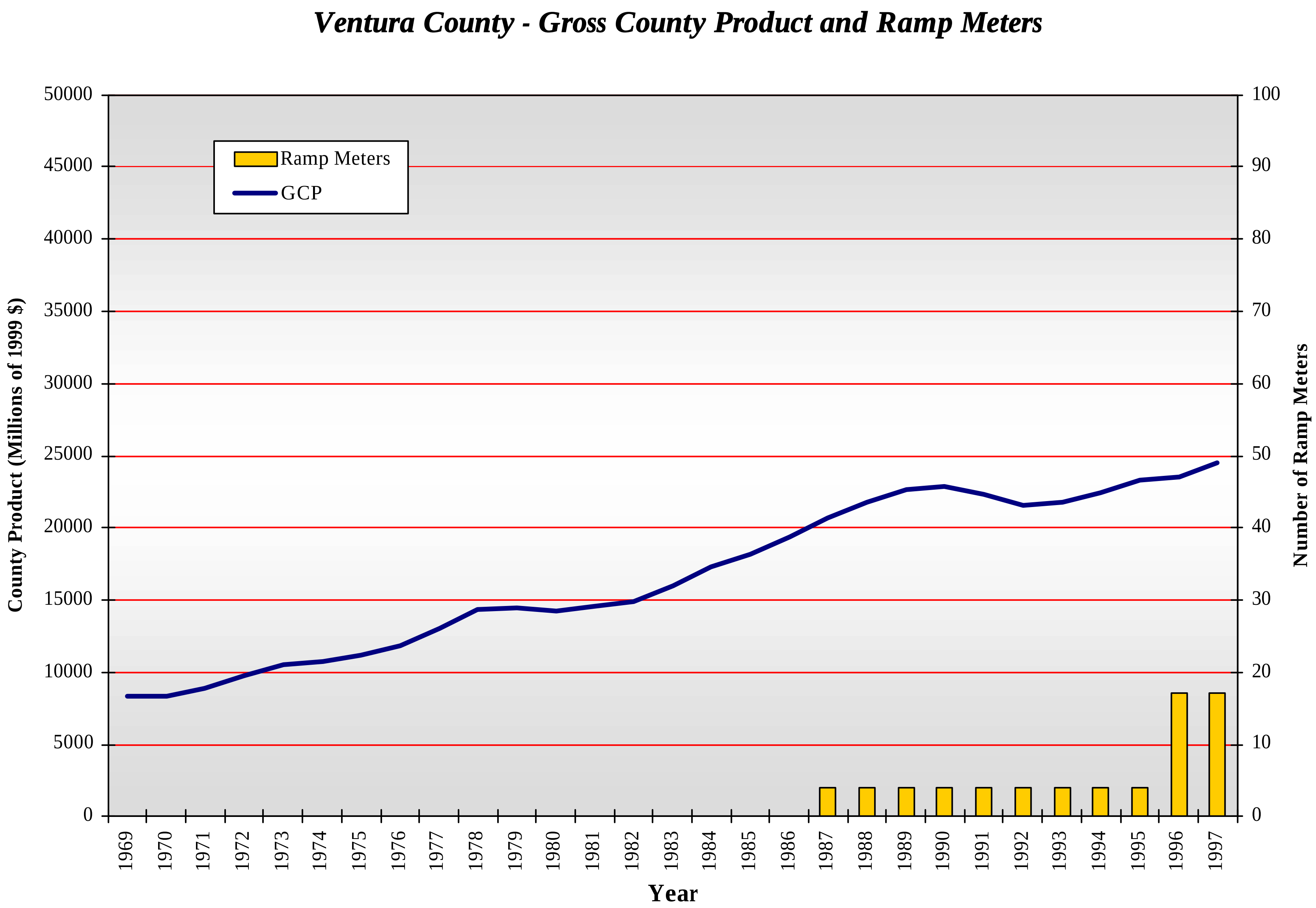


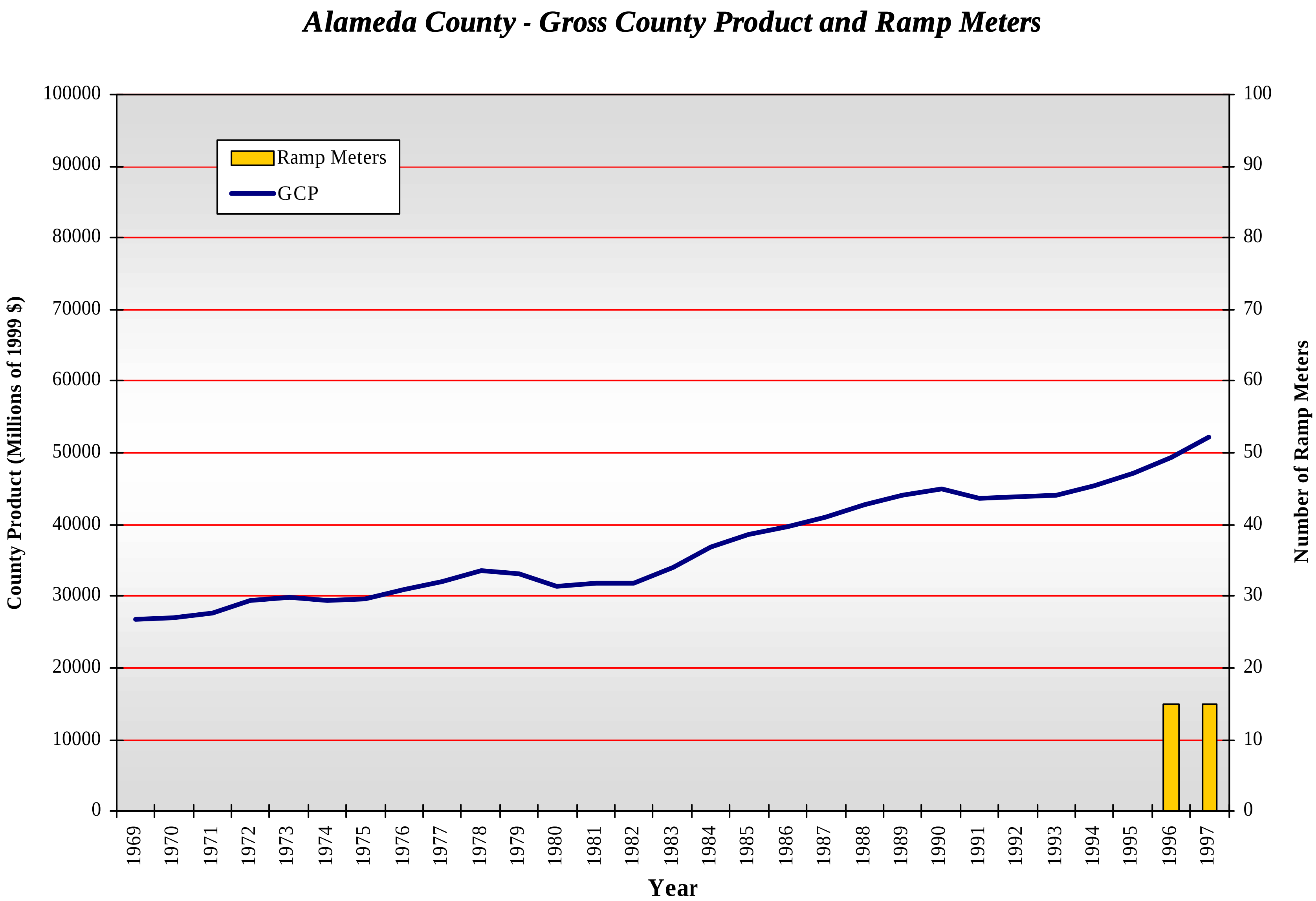
San Bernardino County - Gross County Product and Ramp Meters



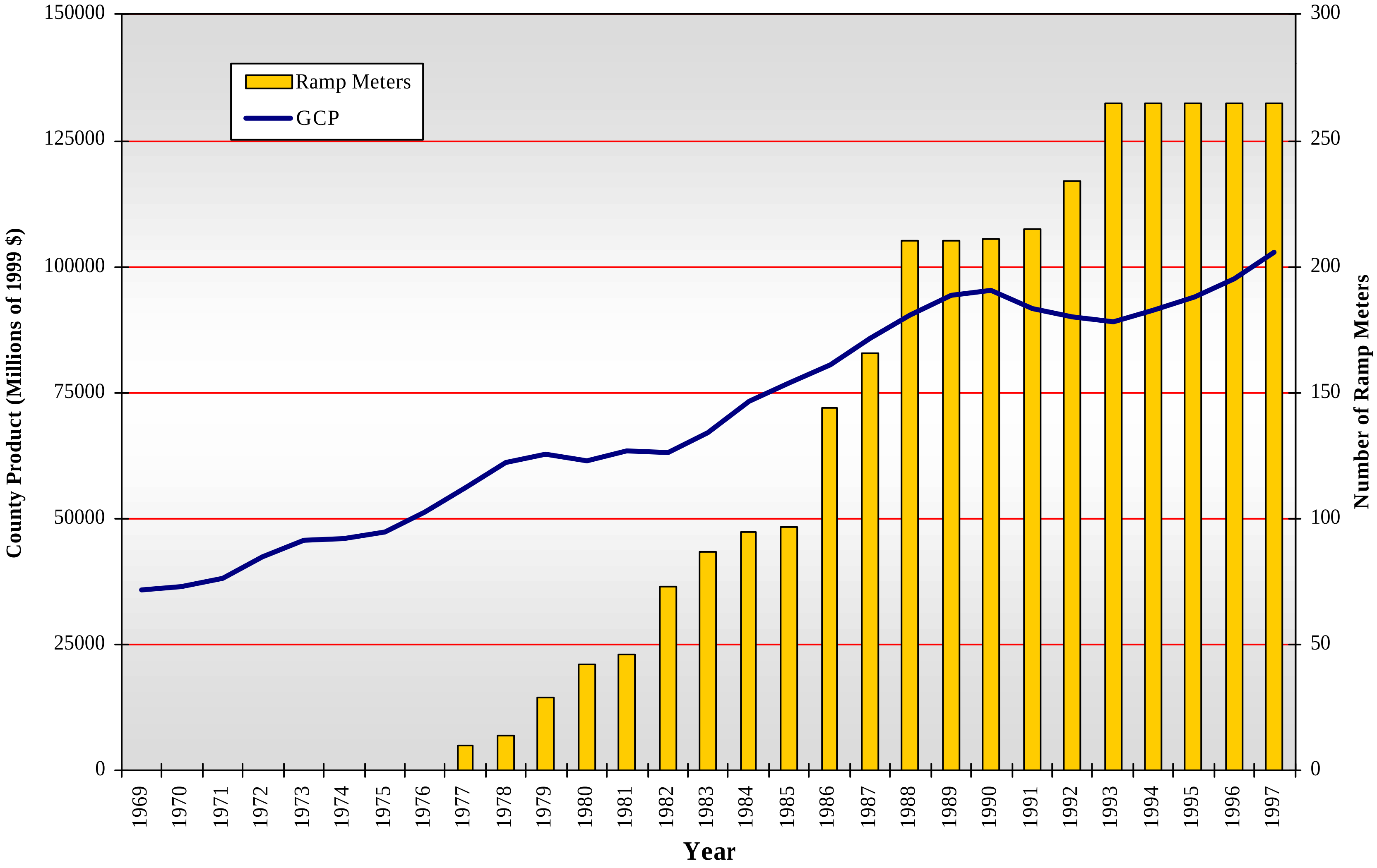
San Mateo County - Gross County Product and Ramp Meters

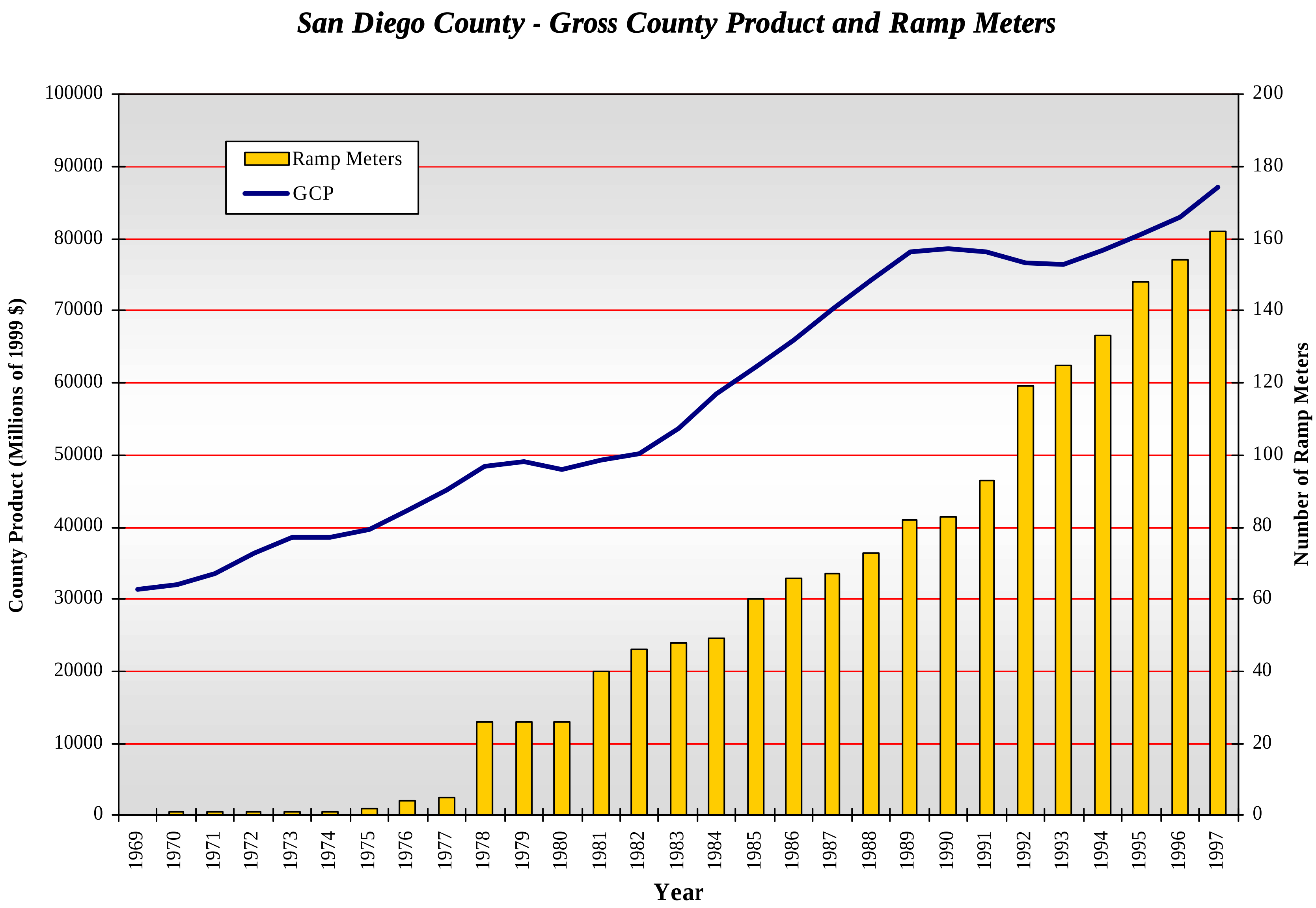



Ventura County - Gross County Product and Ramp Meters
Ramp Meters
GCP
County Product (Millions of 1999 $)
Number of Ramp Meters
Year
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
0
10
20
30
40
50
60
70
80
90
100
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997

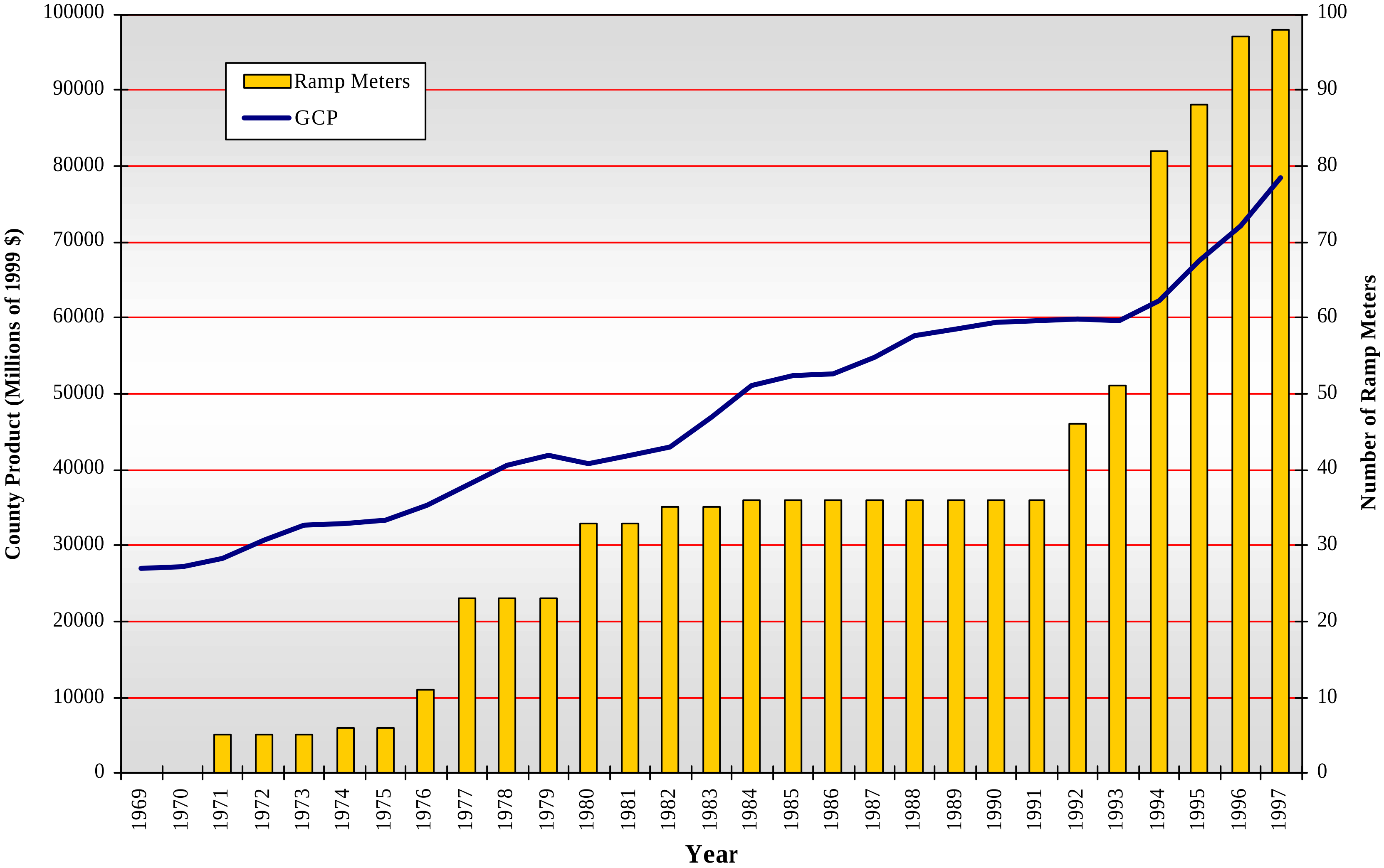

Alameda County - Gross County Product and Ramp Meters
Ramp Meters
GCP
County Product (Millions of 1999 $)
Number of Ramp Meters
Year
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
0
10
20
30
40
50
60
70
80
90
100
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997

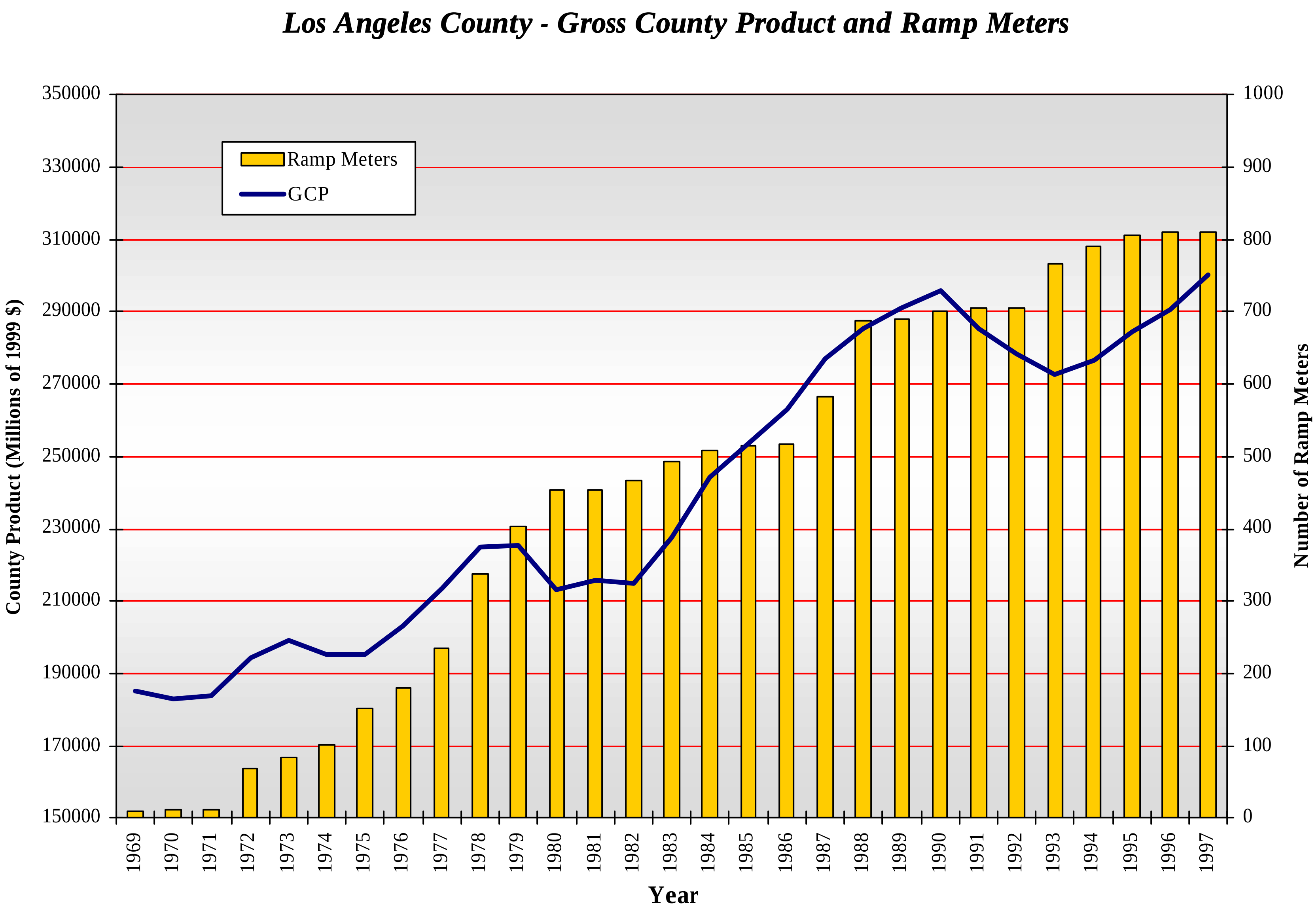
Orange County - Gross County Product and Ramp Meters




San Diego County - Gross County Product and Ramp Meters
Ramp Meters
GCP
County Product (Millions of 1999 $)
Number of Ramp Meters
Year
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
200
180
160
140
120
100
80
60
40
20
0
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997

Santa Clara County - Gross County Product and Ramp Meters




Los Angeles County - Gross County Product and Ramp Meters
Ramp Meters
GCP
County Product (Millions of 1999 $)
Number of Ramp Meters
Year
350000
330000
310000
290000
270000
250000
230000
210000
190000
170000
150000
1000
900
800
700
600
500
400
300
200
100
0
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
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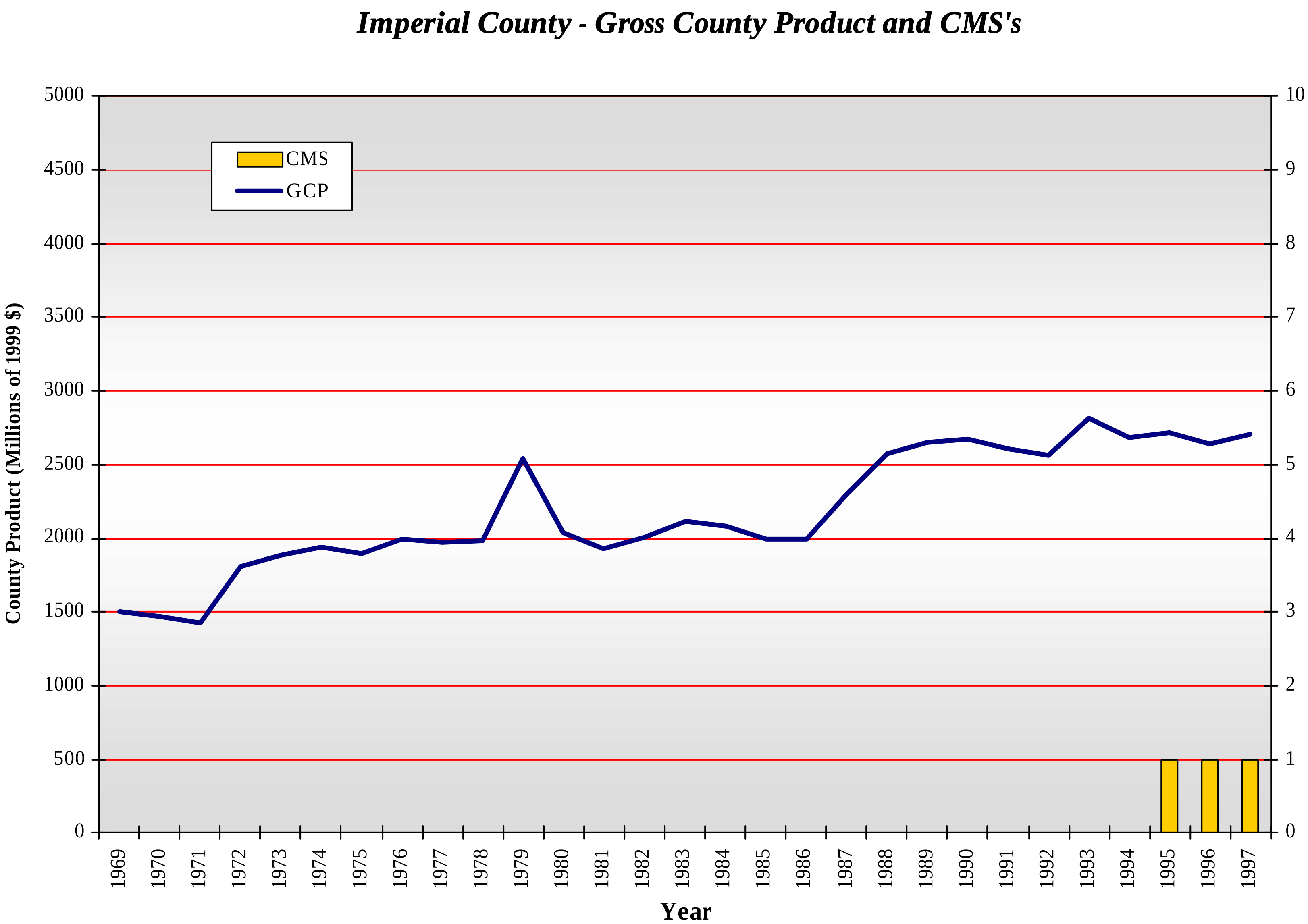
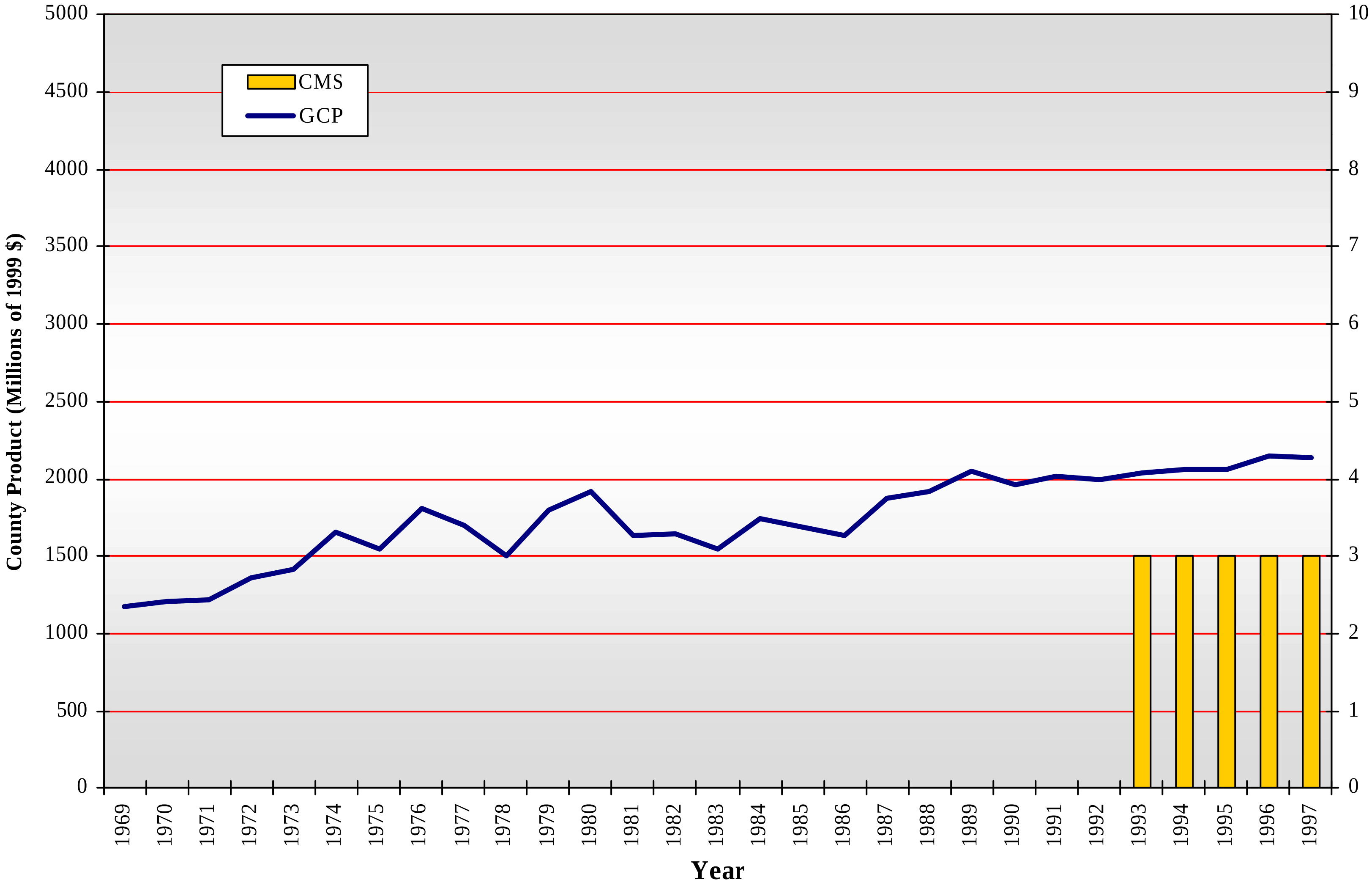
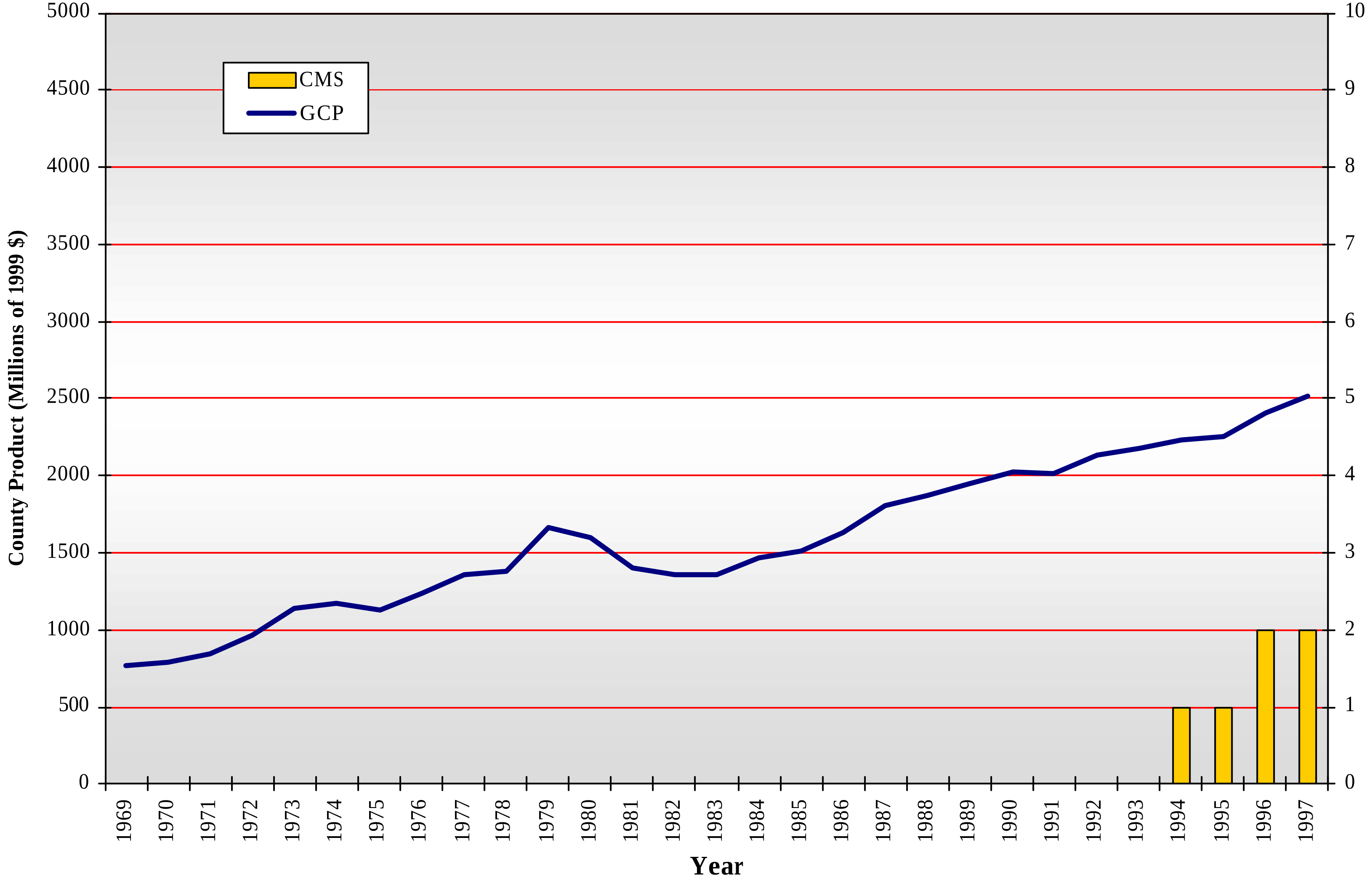
1992
1993
1994
1995
1996
1997

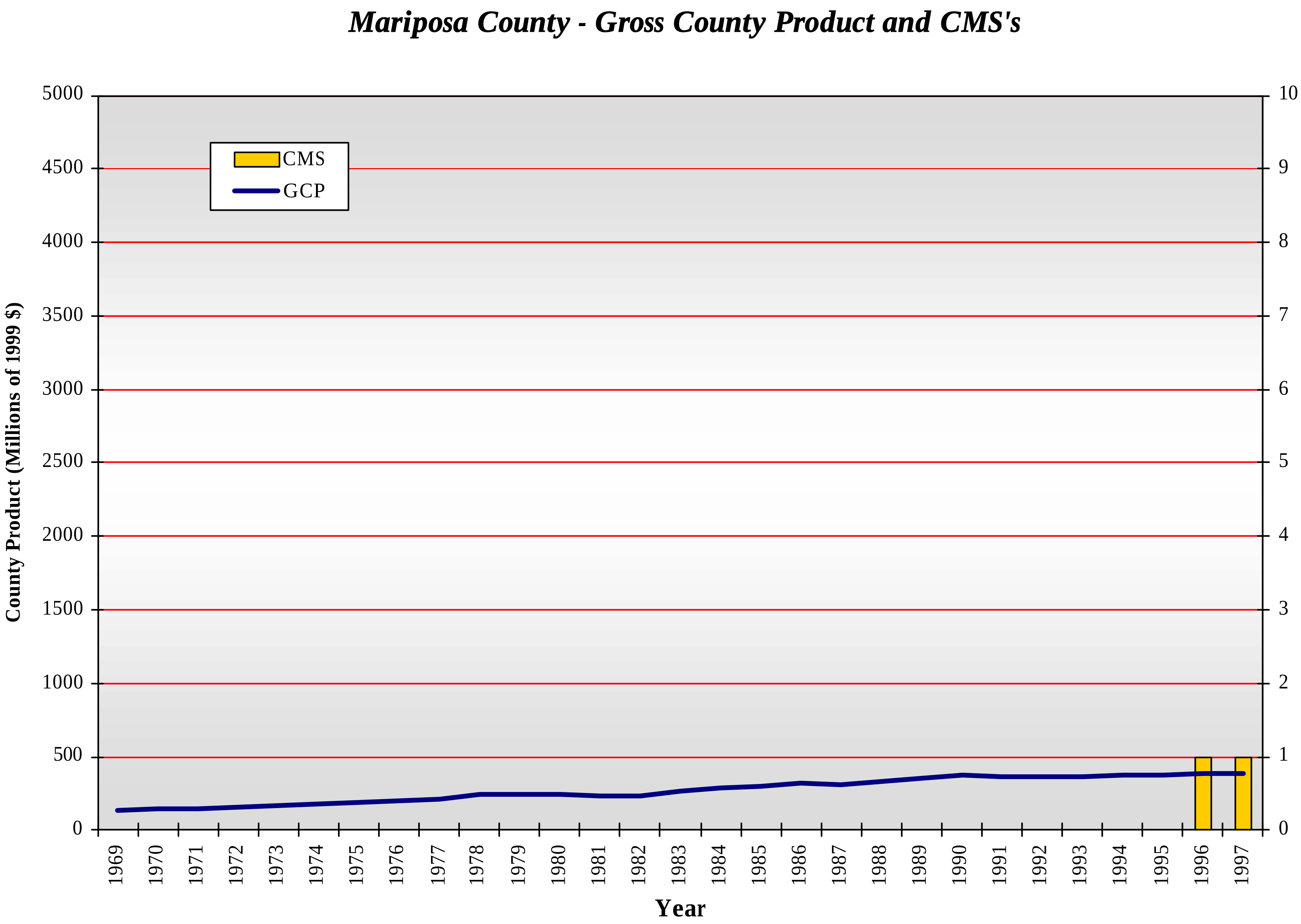

Imperial County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
Year
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
10
9
8
7
6
5
4
3
2
1
0
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997

Kings County - Gross County Product and CMS's



Madera County - Gross County Product and CMS's




Mariposa County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
10
9
8
7
6
5
4
3
2
1
0
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
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1982
1983
1984
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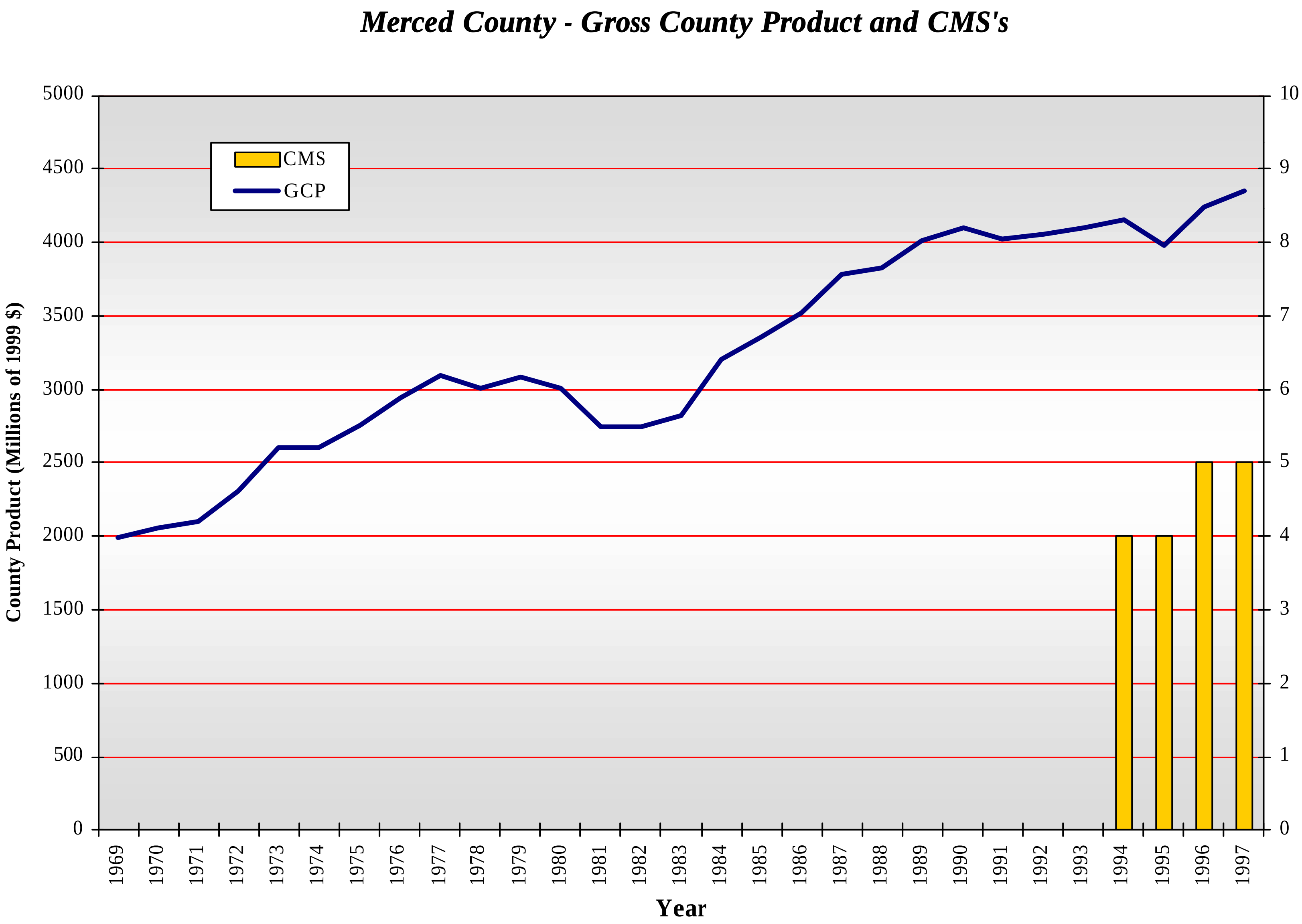
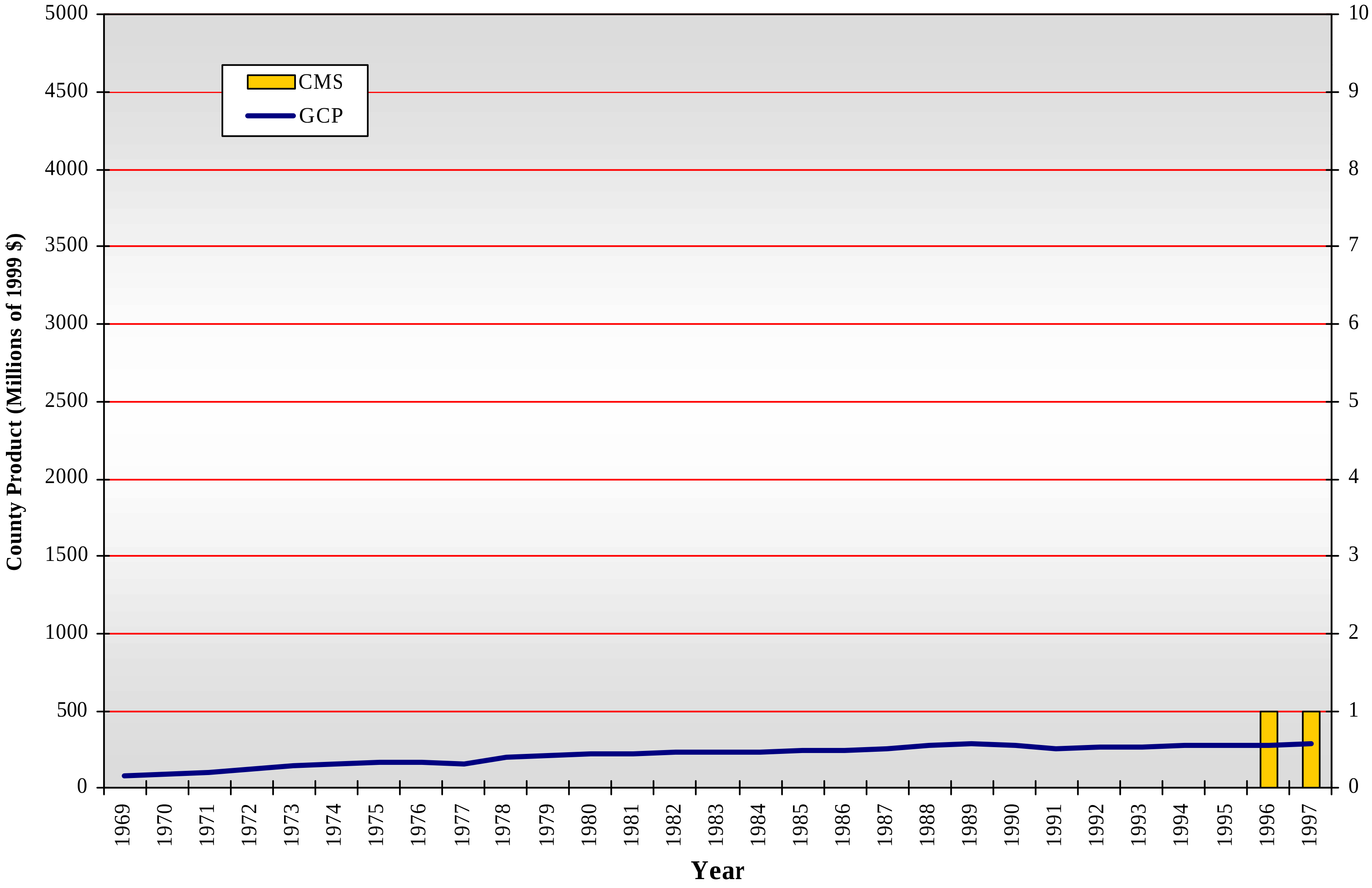
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
Year

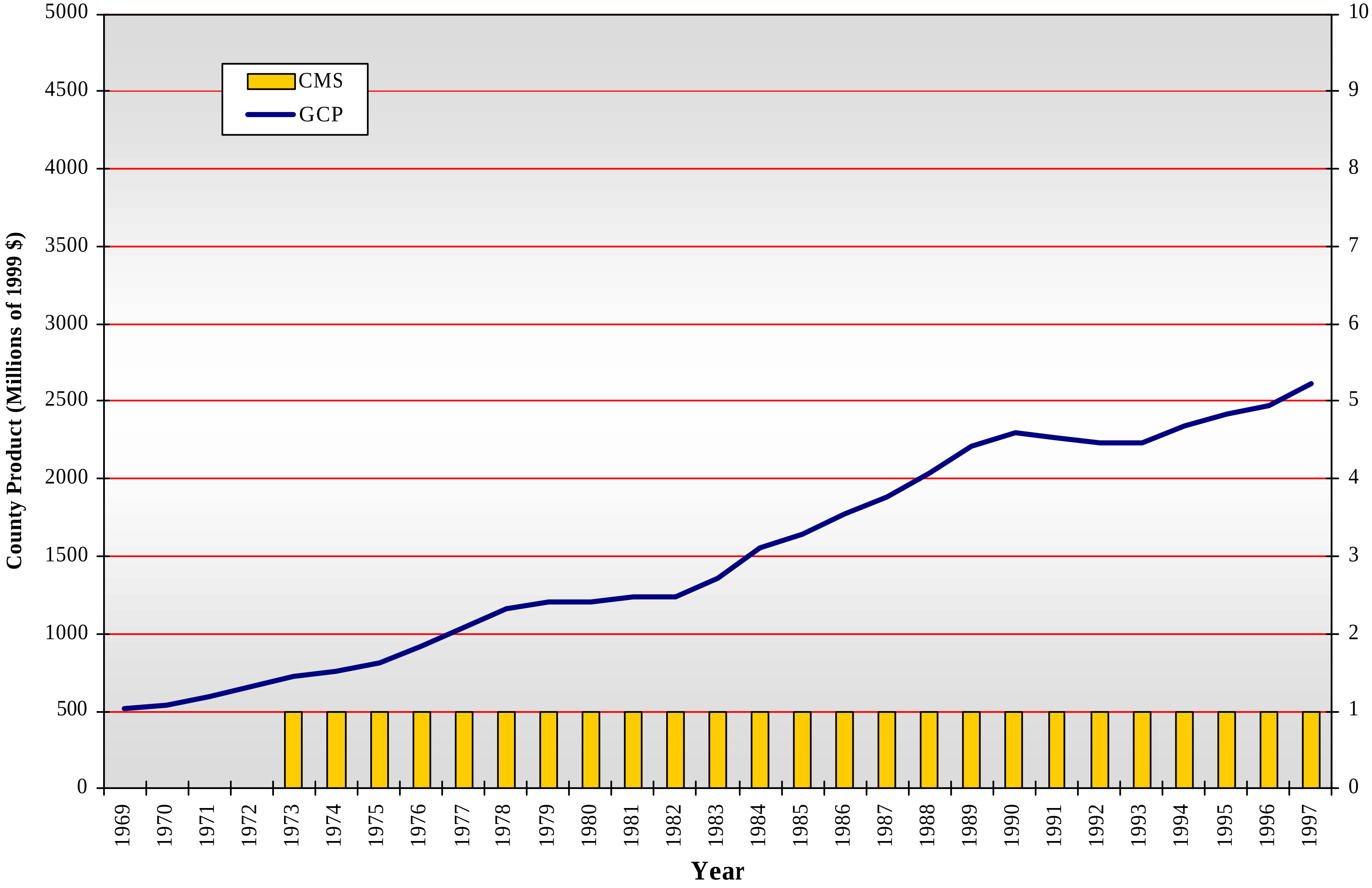


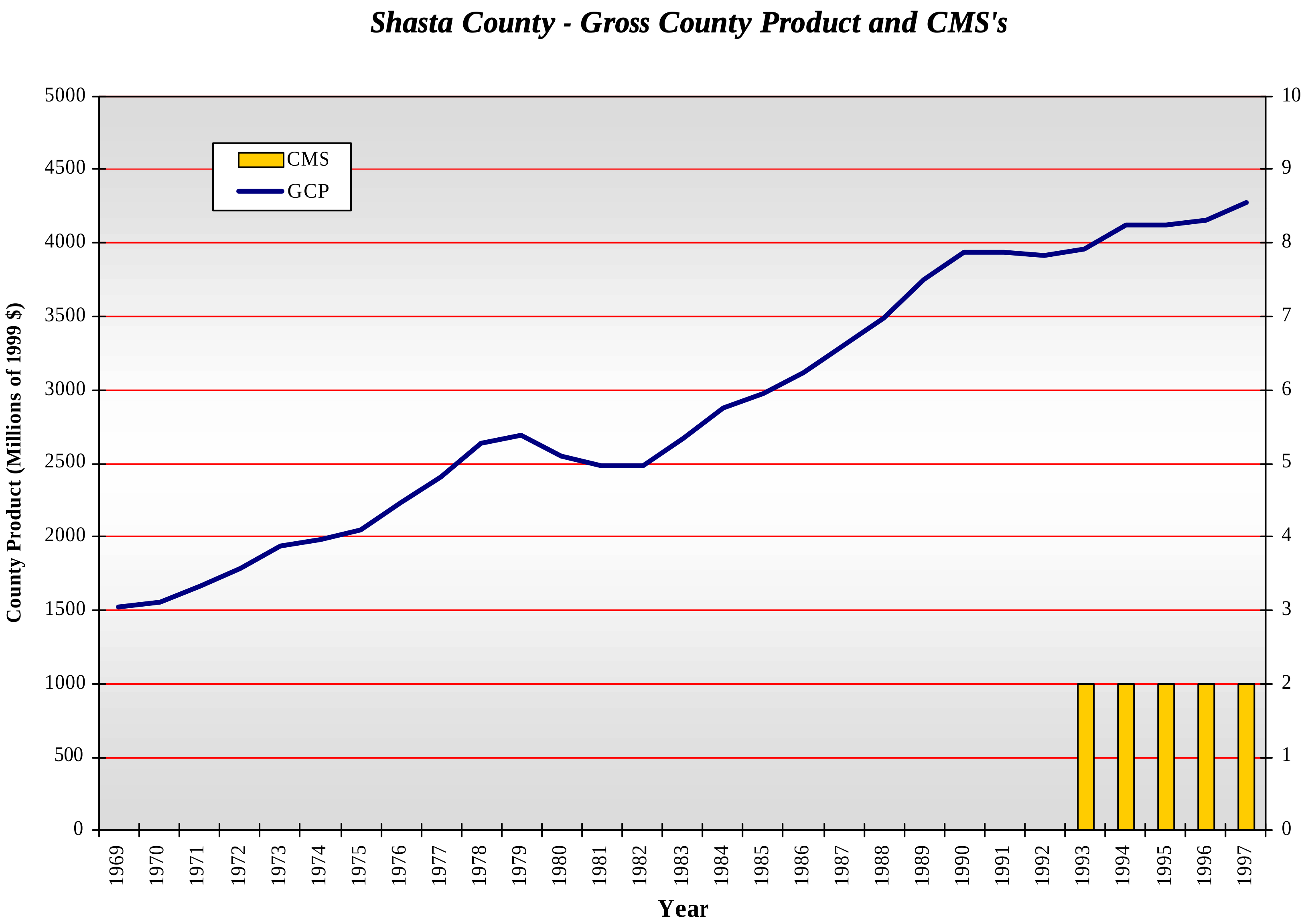
Merced County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
Year
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
1
2
3
4
5
6
7
8
9
10
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997

Mono County - Gross County Product and CMS's



Nevada County - Gross County Product and CMS's




Shasta County - Gross County Product and CMS's
County Product (Millions of 1999 $)
Year
CMS
GCP
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
1
2
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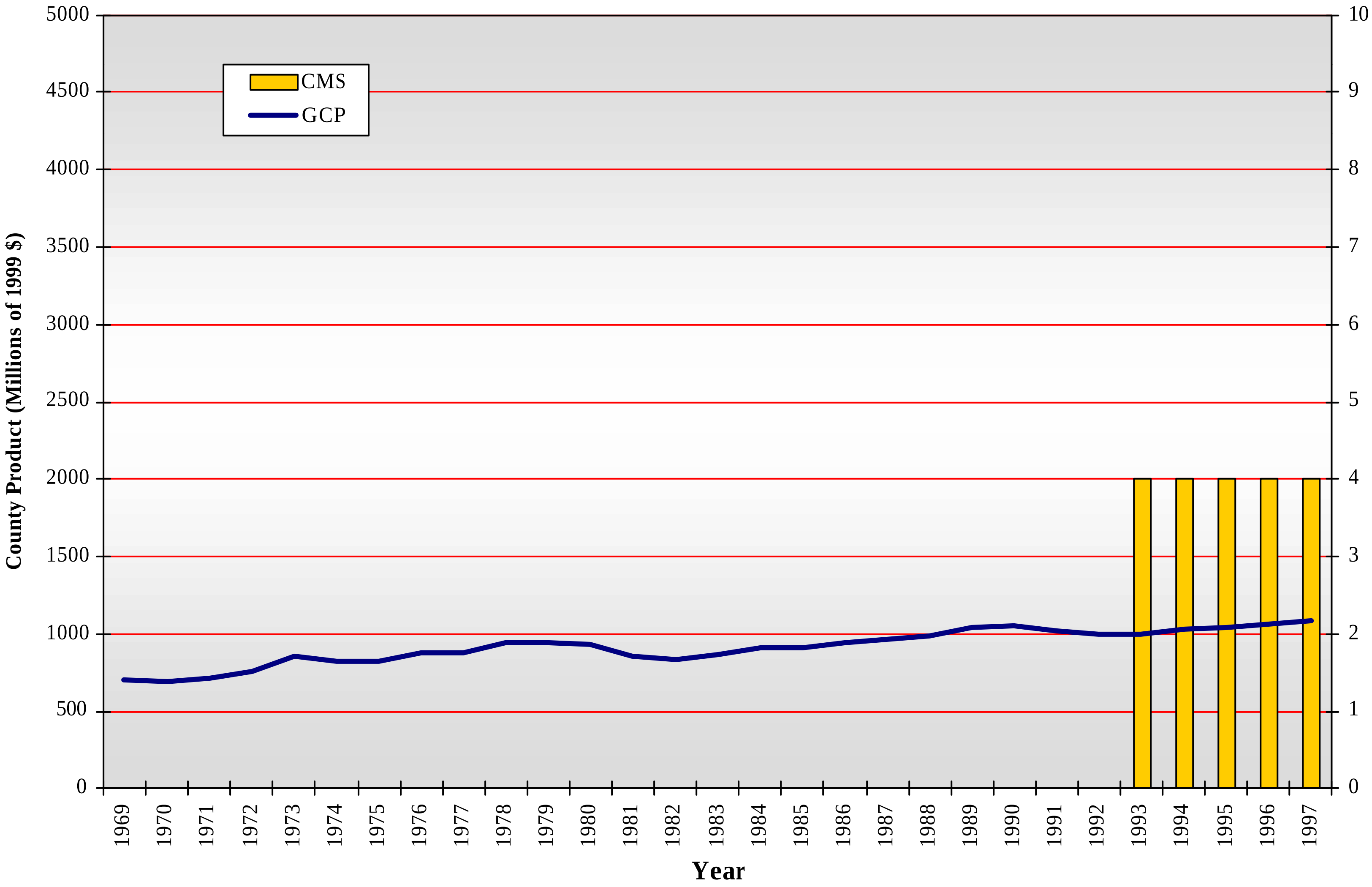
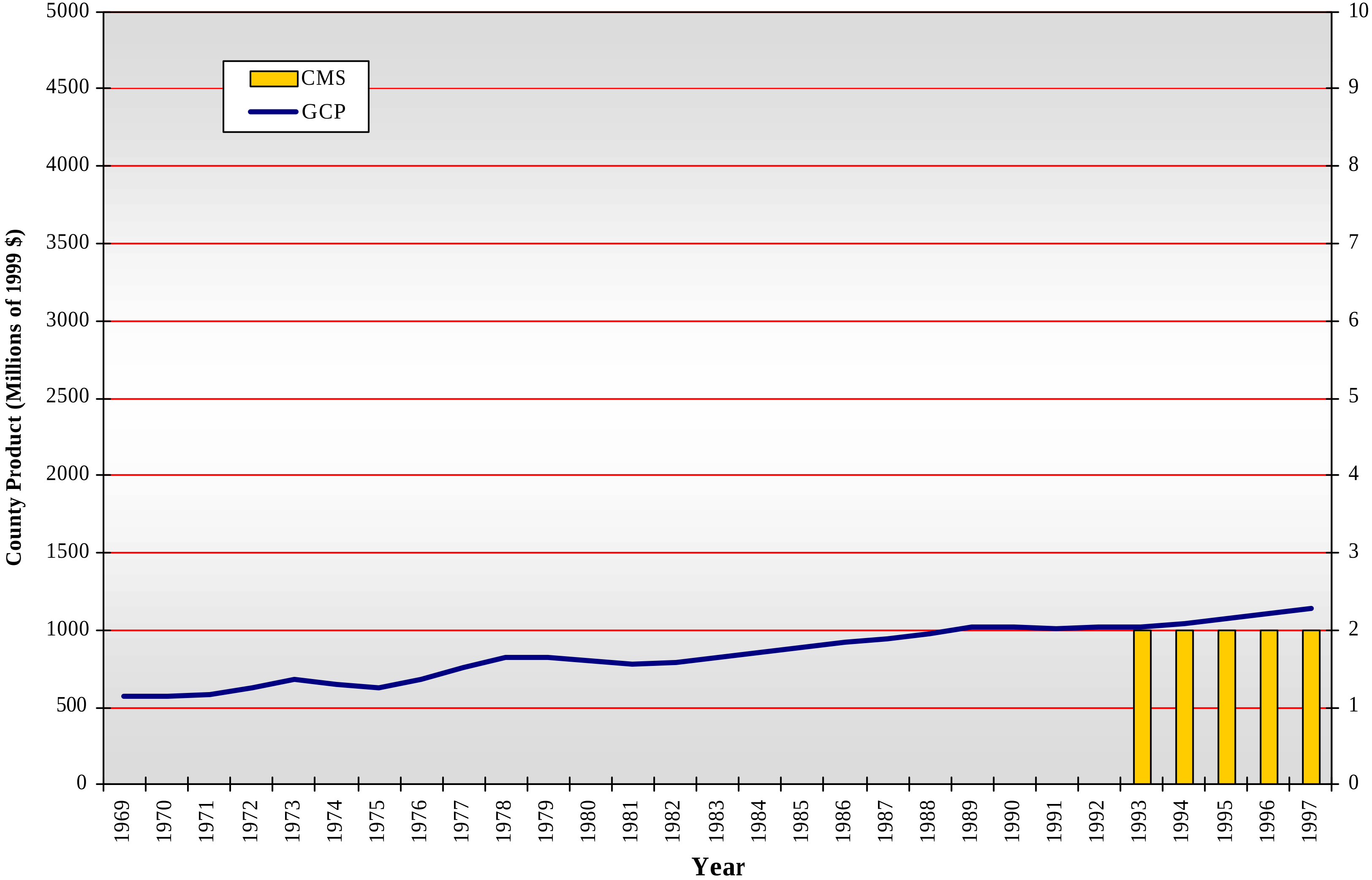
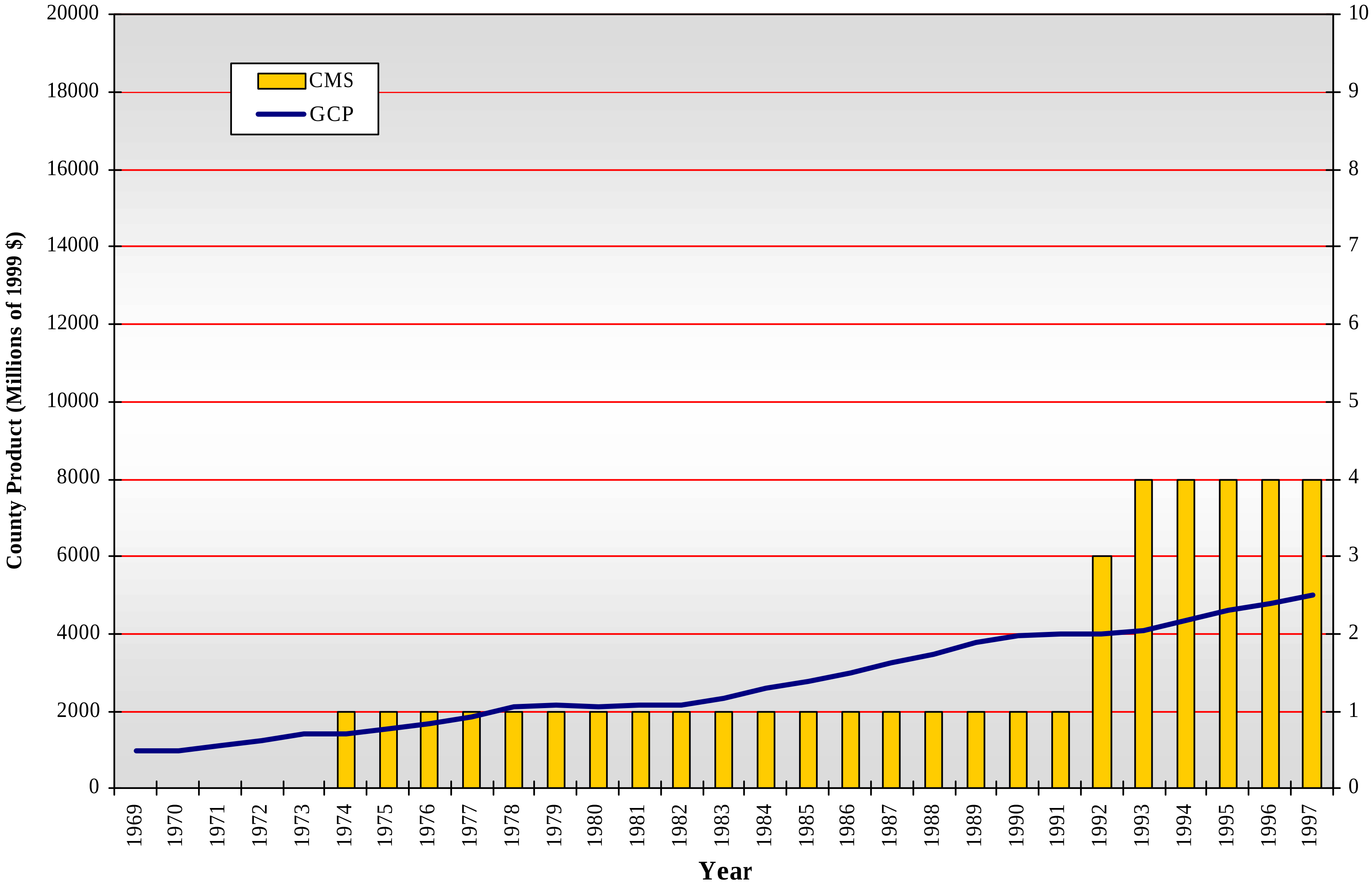
Siskiyou County - Gross County Product and CMS's

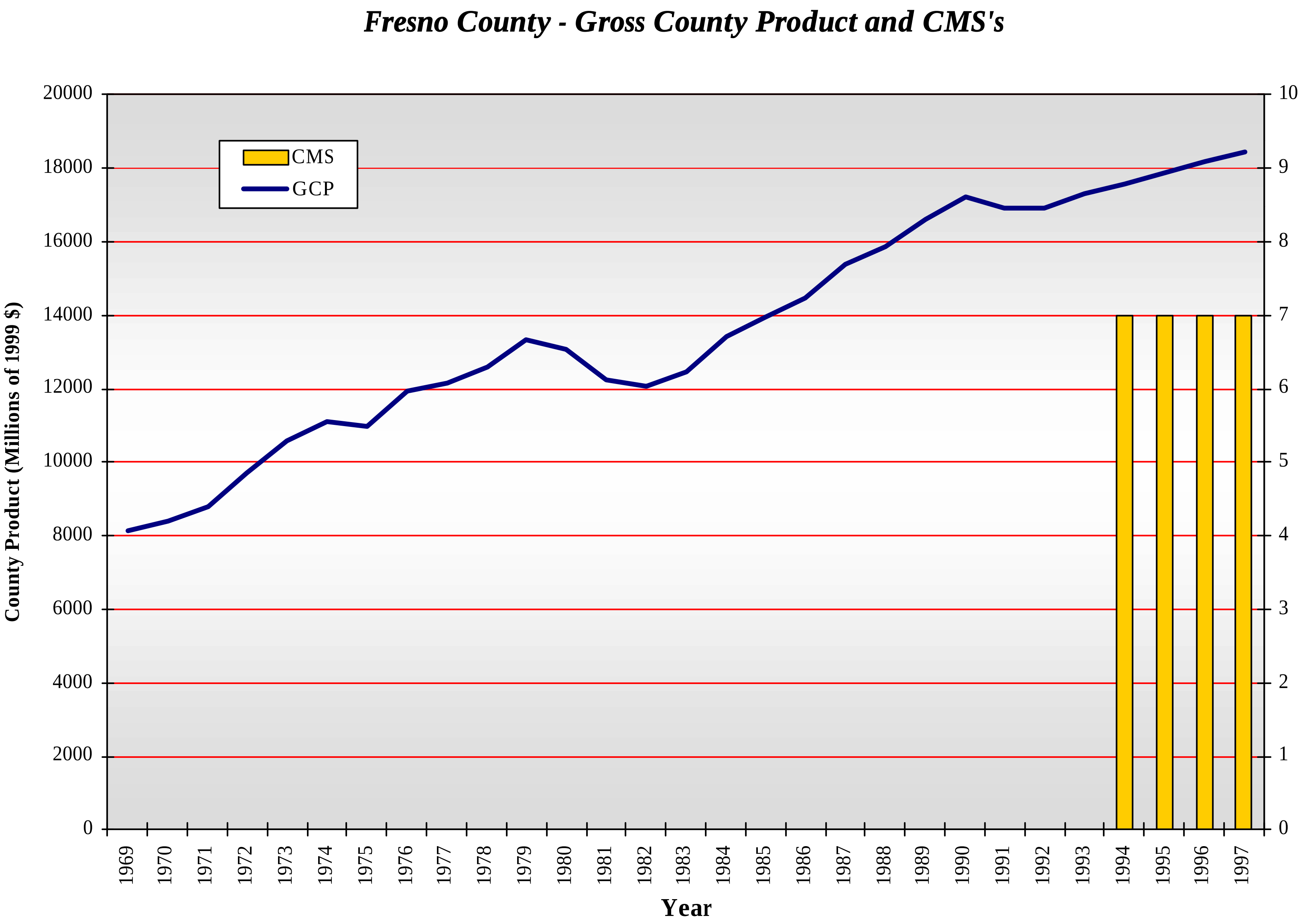


Tehama County - Gross County Product and CMS's



El Dorado County - Gross County Product and CMS's





Fresno County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
10
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8
7
6
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4
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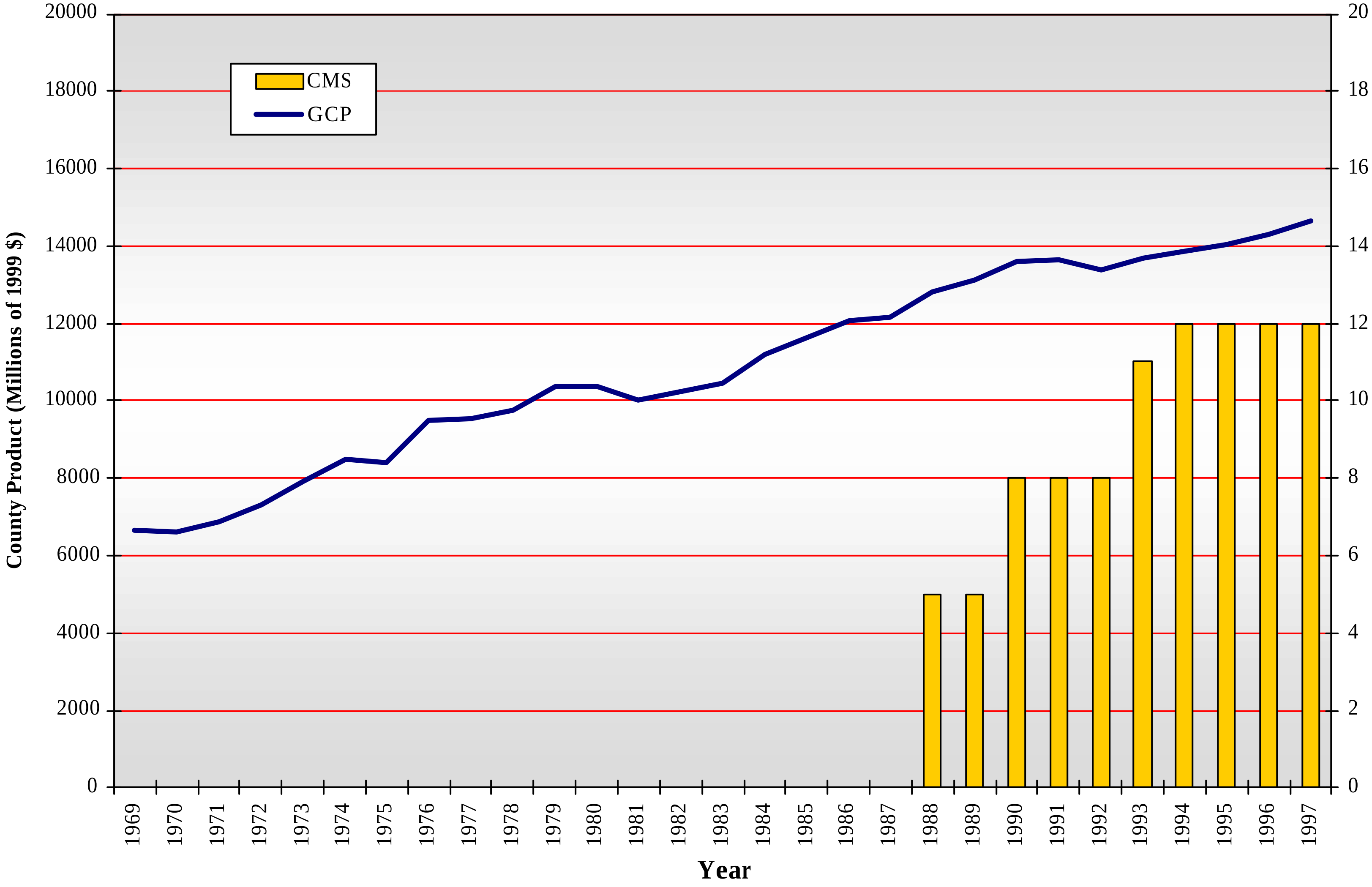
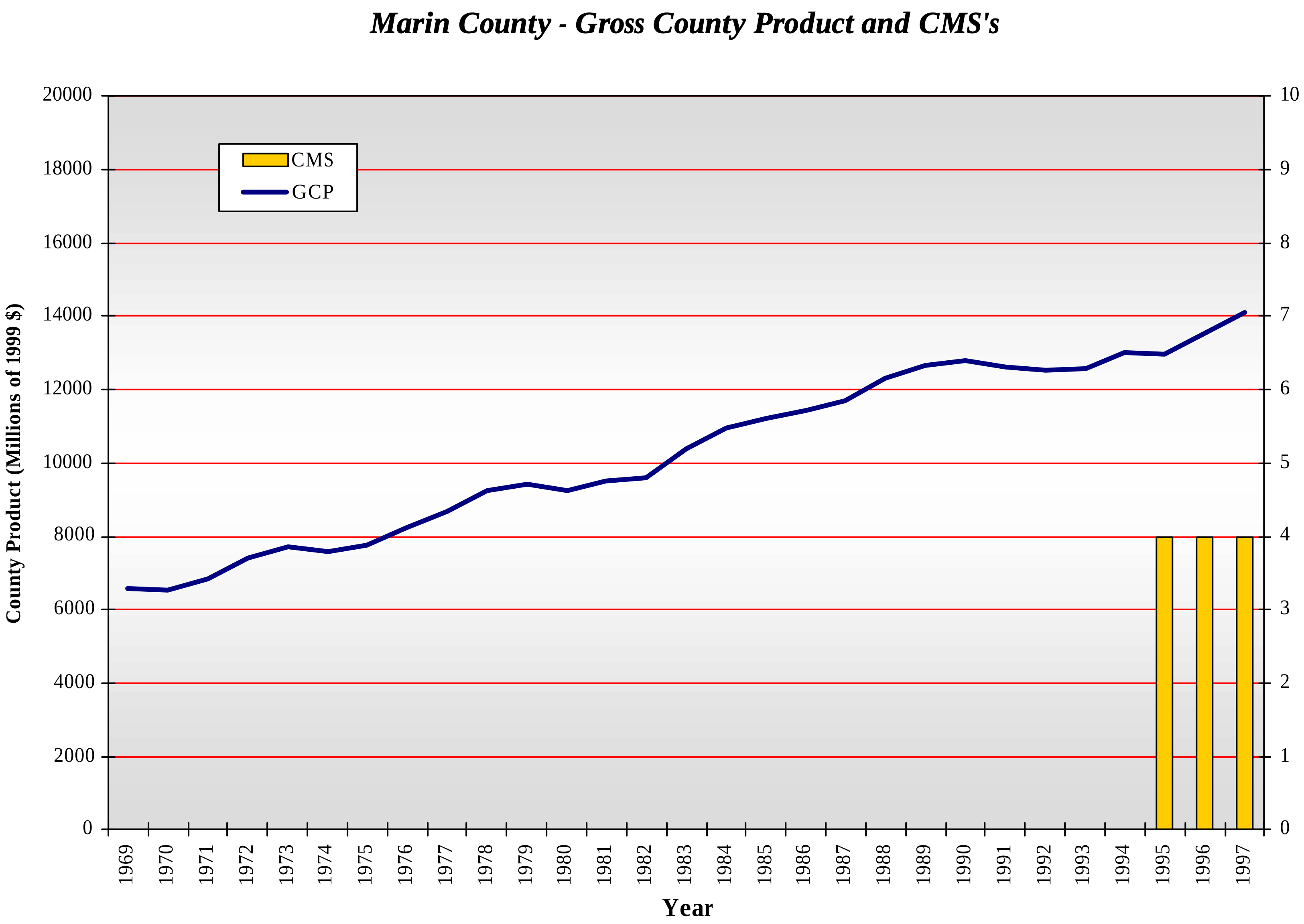
1993
1994
1995
1996
1997
Year

Kern County - Gross County Product and CMS's




Marin County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
Year
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
0
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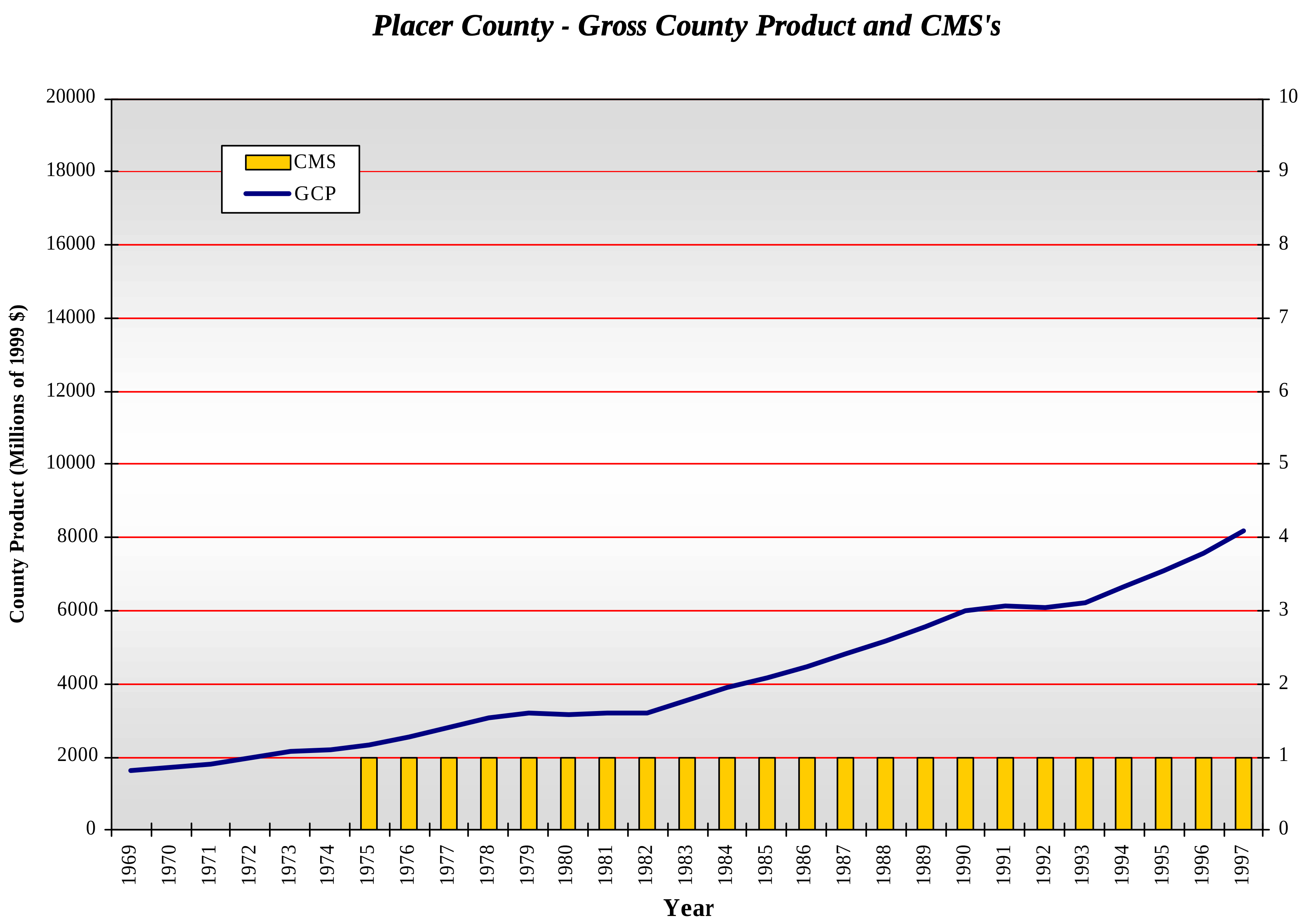
Placer County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
0
1
2
3
4
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1969
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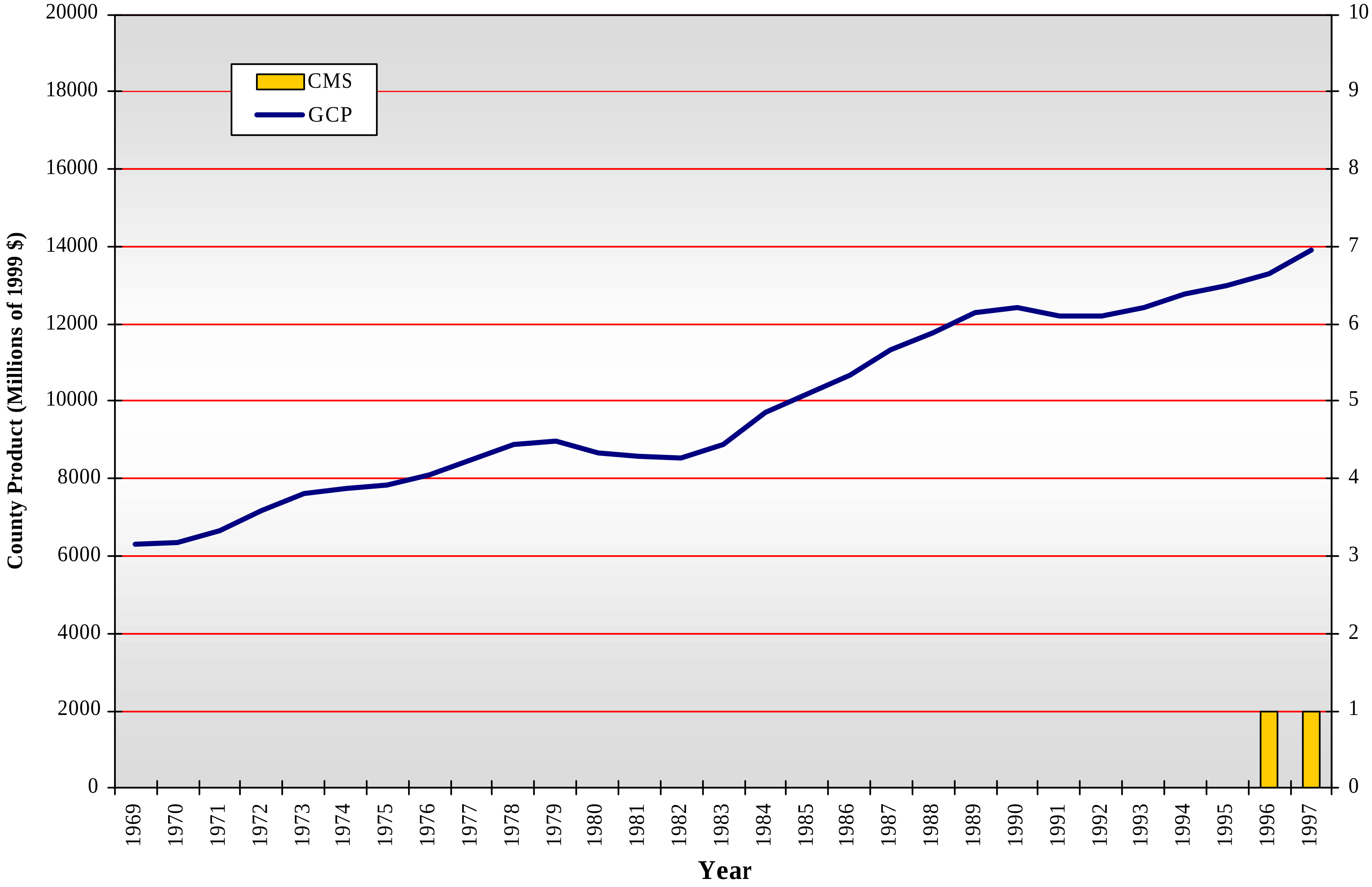
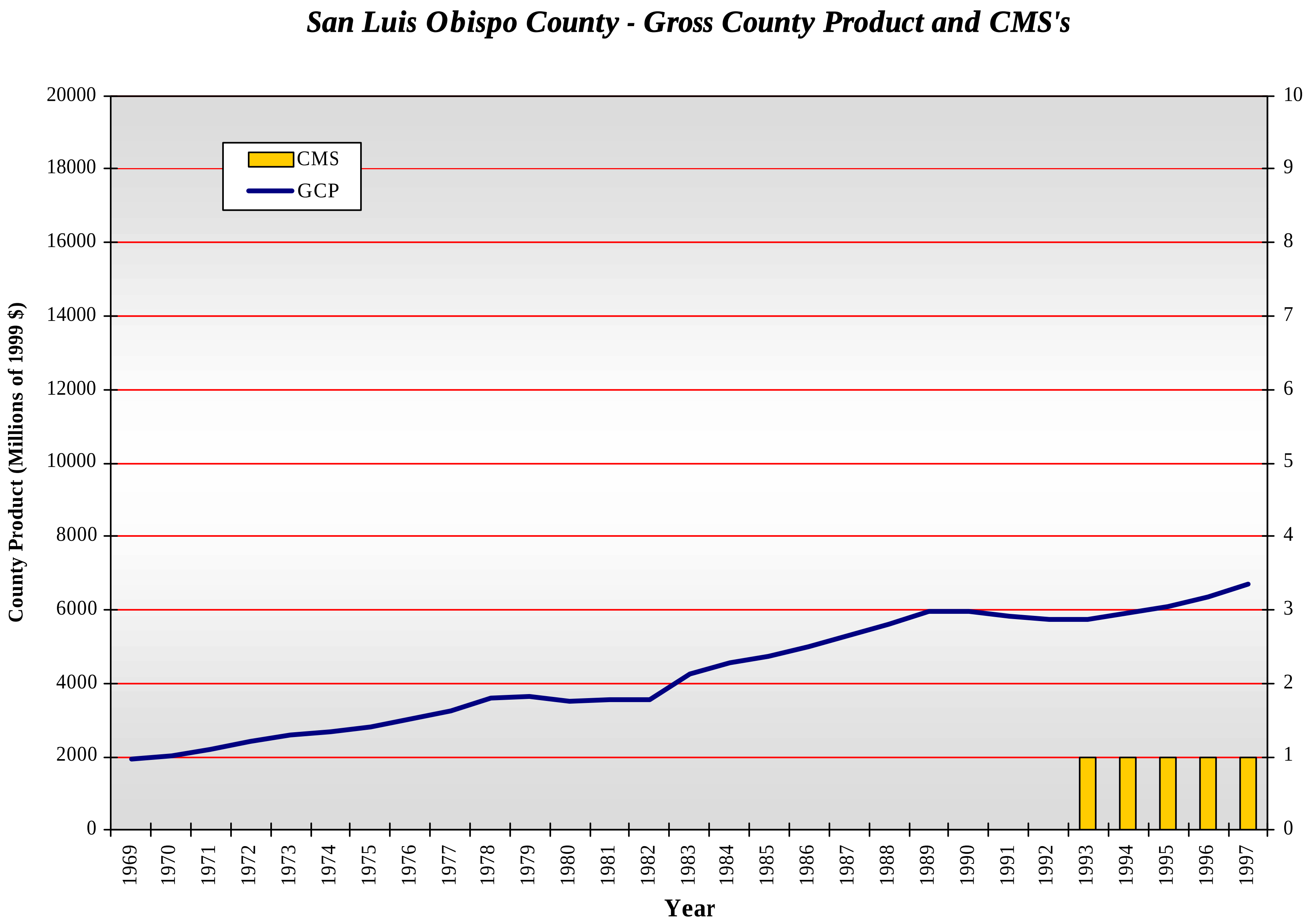
1993
1994
1995
1996
1997
Year

San Joaquin County - Gross County Product and CMS's




San Luis Obispo County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
Year
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
10
9
8
7
6
5
4
3
2
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0
1969
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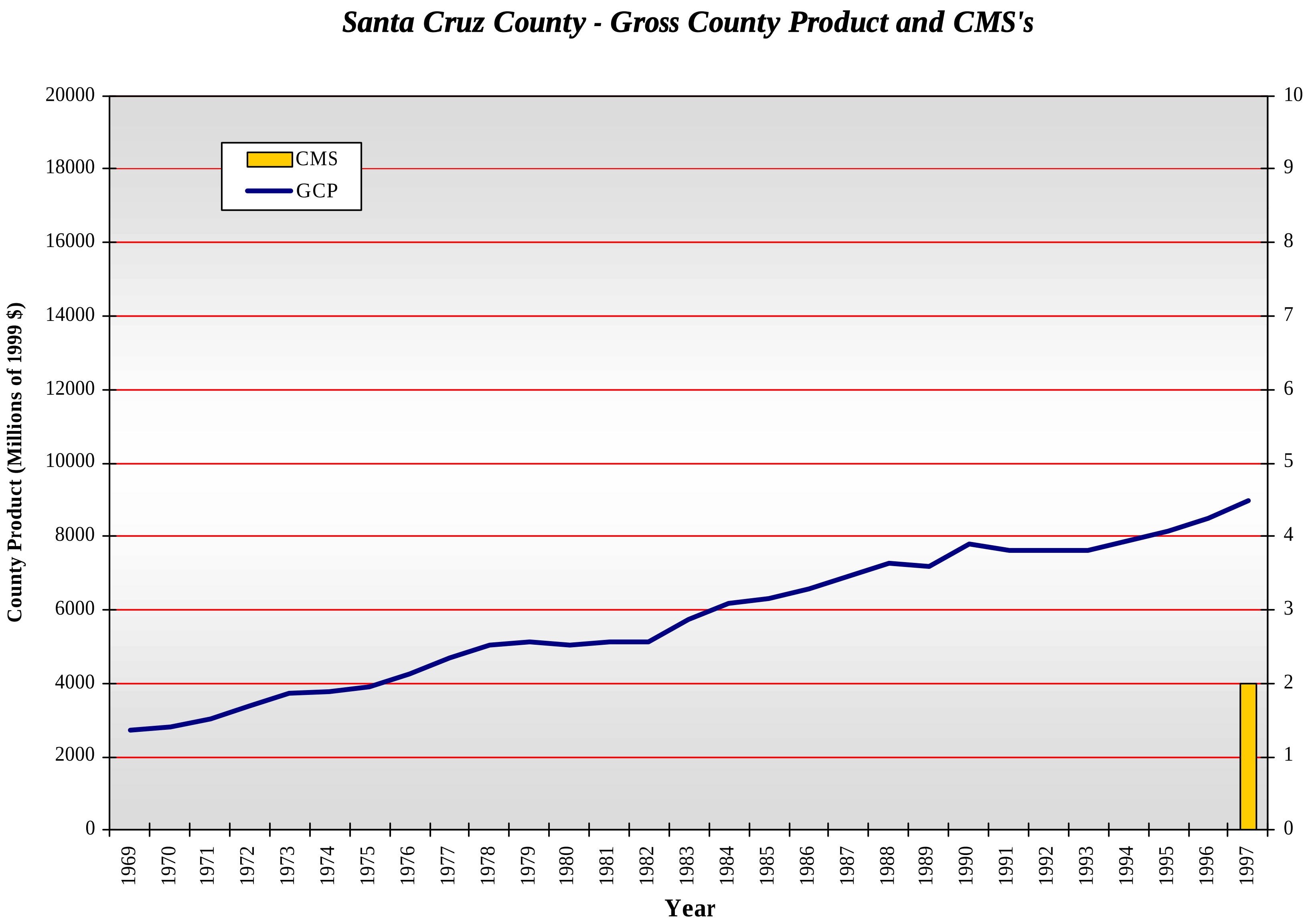
Santa Cruz County - Gross County Product and CMS's
County Product (Millions of 1999 $)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
0
1
2
3
4
5
6
7
8
9
10
CMS
GCP
1969
1970
1971
1972
1973
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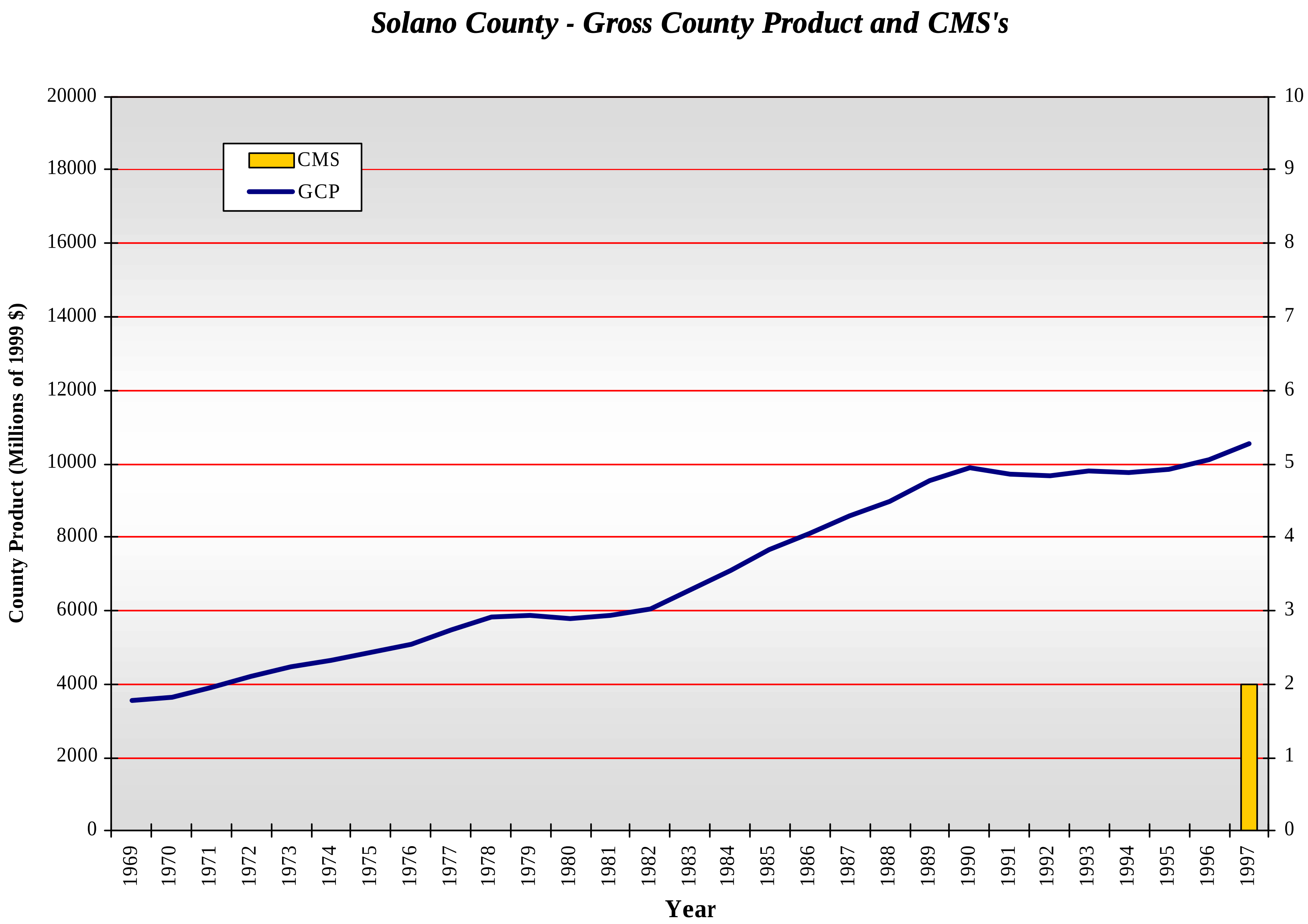
1995
1996
1997
Year



Solano County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
10
9
8
7
6
5
4
3
2
1
0
1969
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1971
1972
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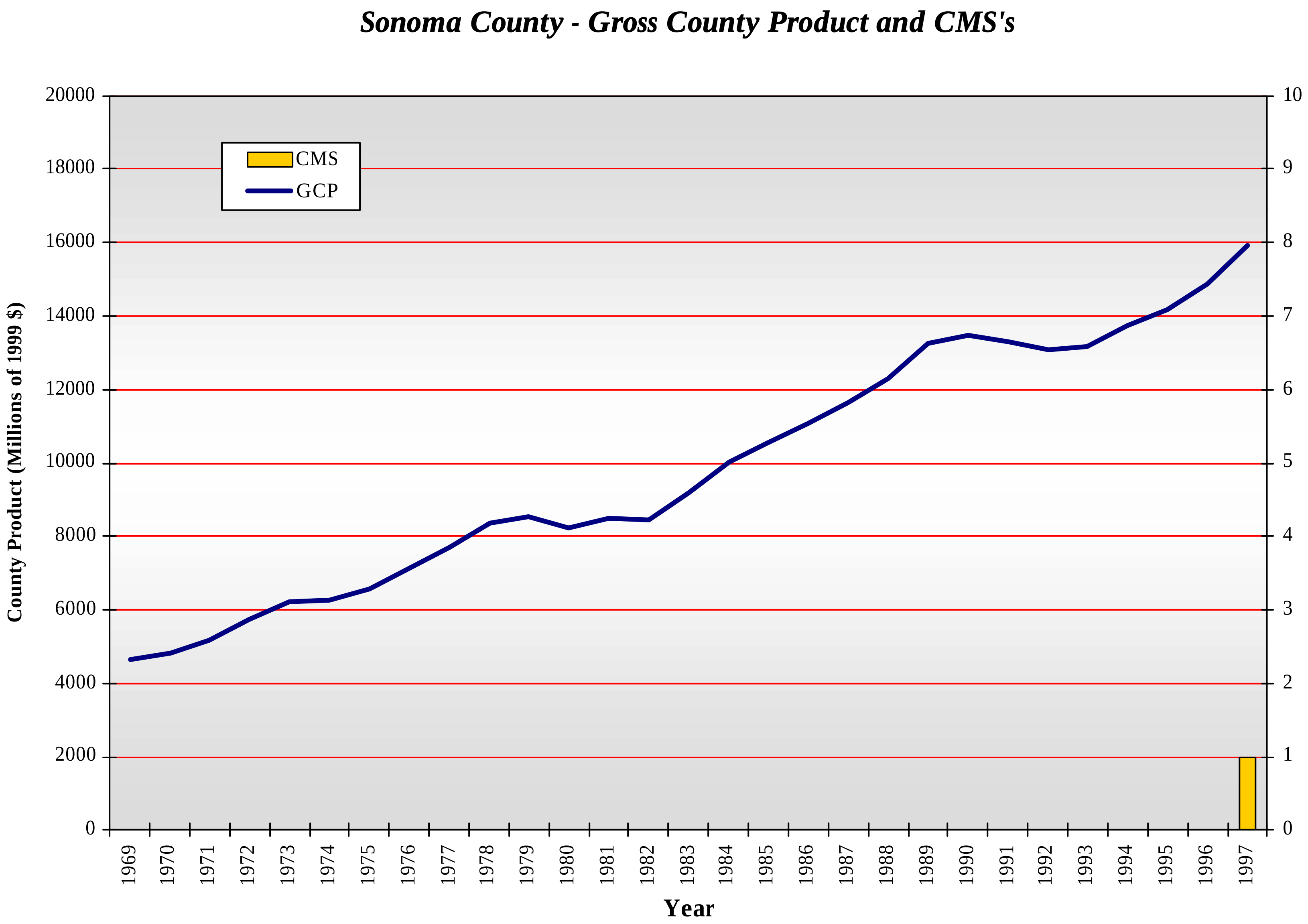
1996
1997
Year



Sonoma County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
10
9
8
7
6
5
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1969
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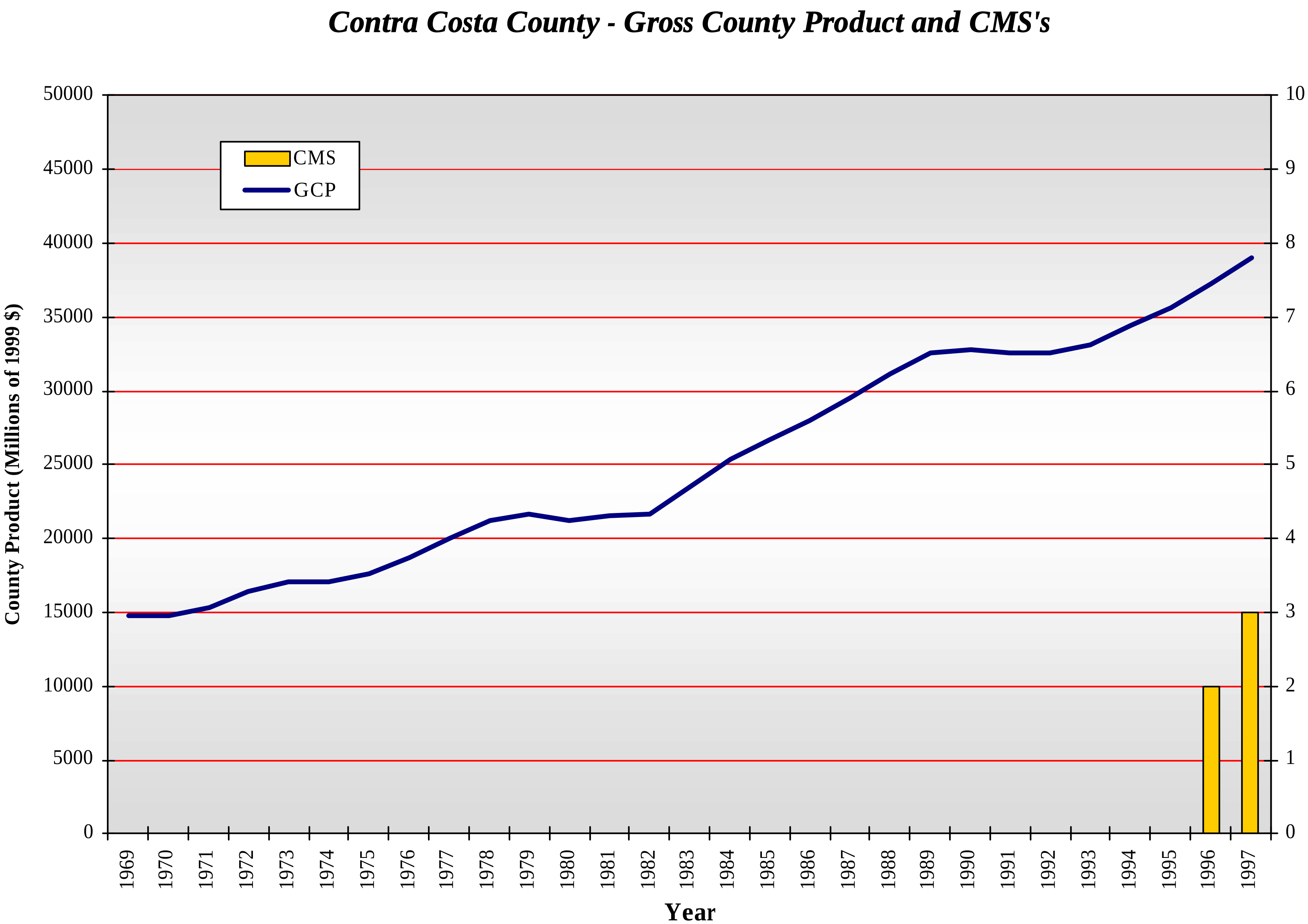
1995
1996
1997
Year



Contra Costa County - Gross County Product and CMS's
County Product (Millions of 1999 $)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
10
9
8
7
6
5
4
3
2
1
0
CMS
GCP
1969
1970
1971
1972
1973
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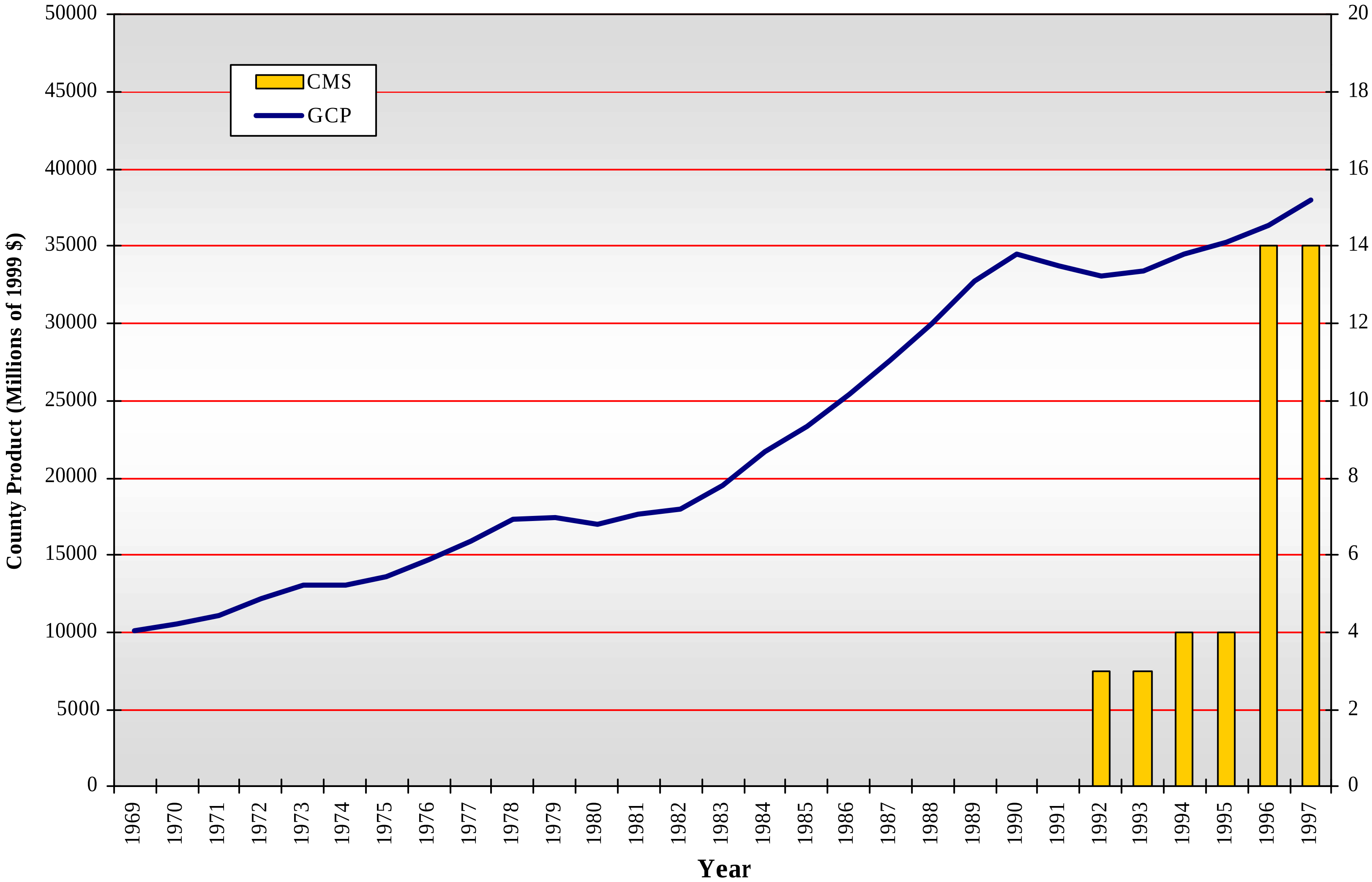
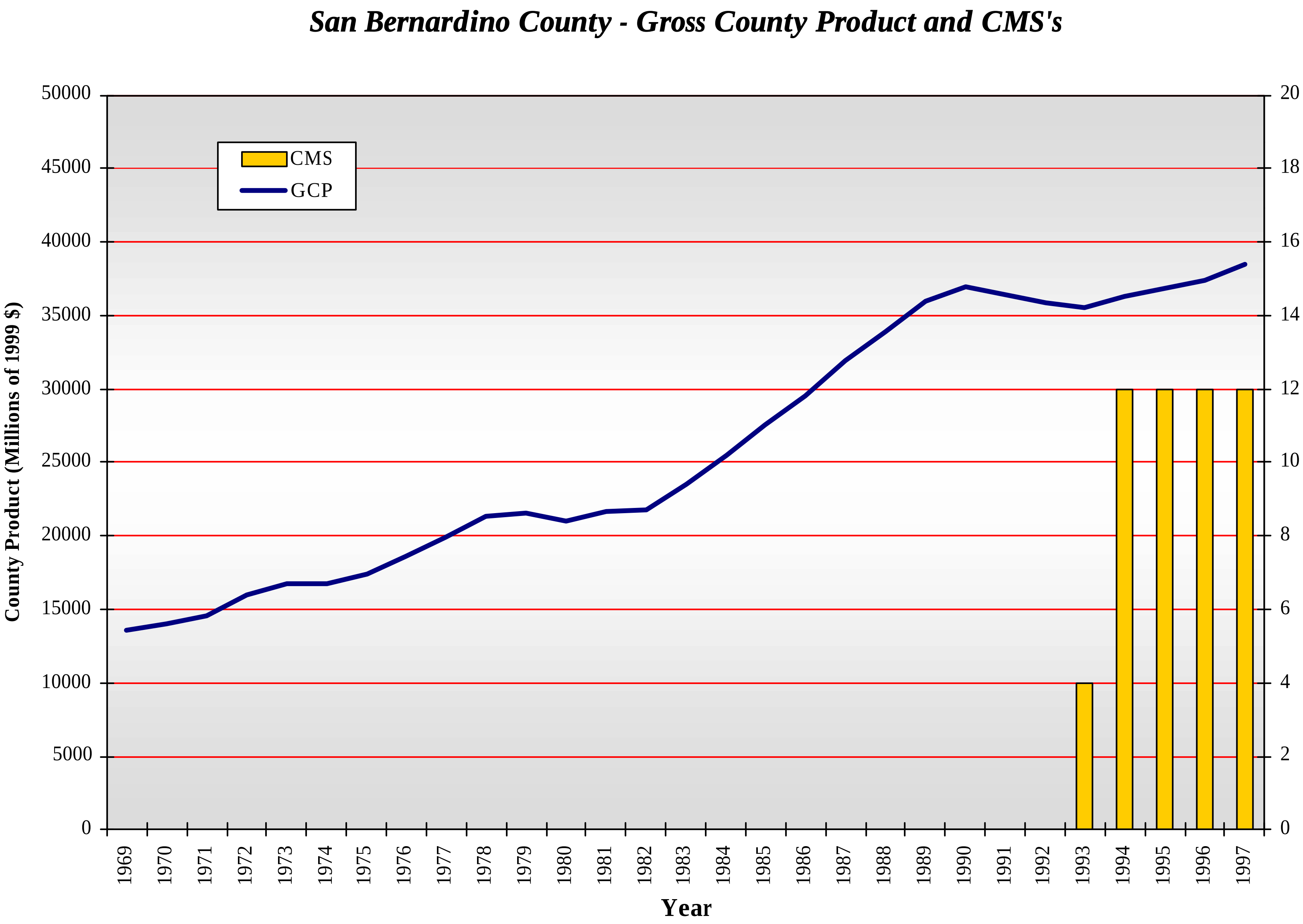
1995
1996
1997
Year

Riverside County - Gross County Product and CMS's




San Bernardino County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
Year
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
20
18
16
14
12
10
8
6
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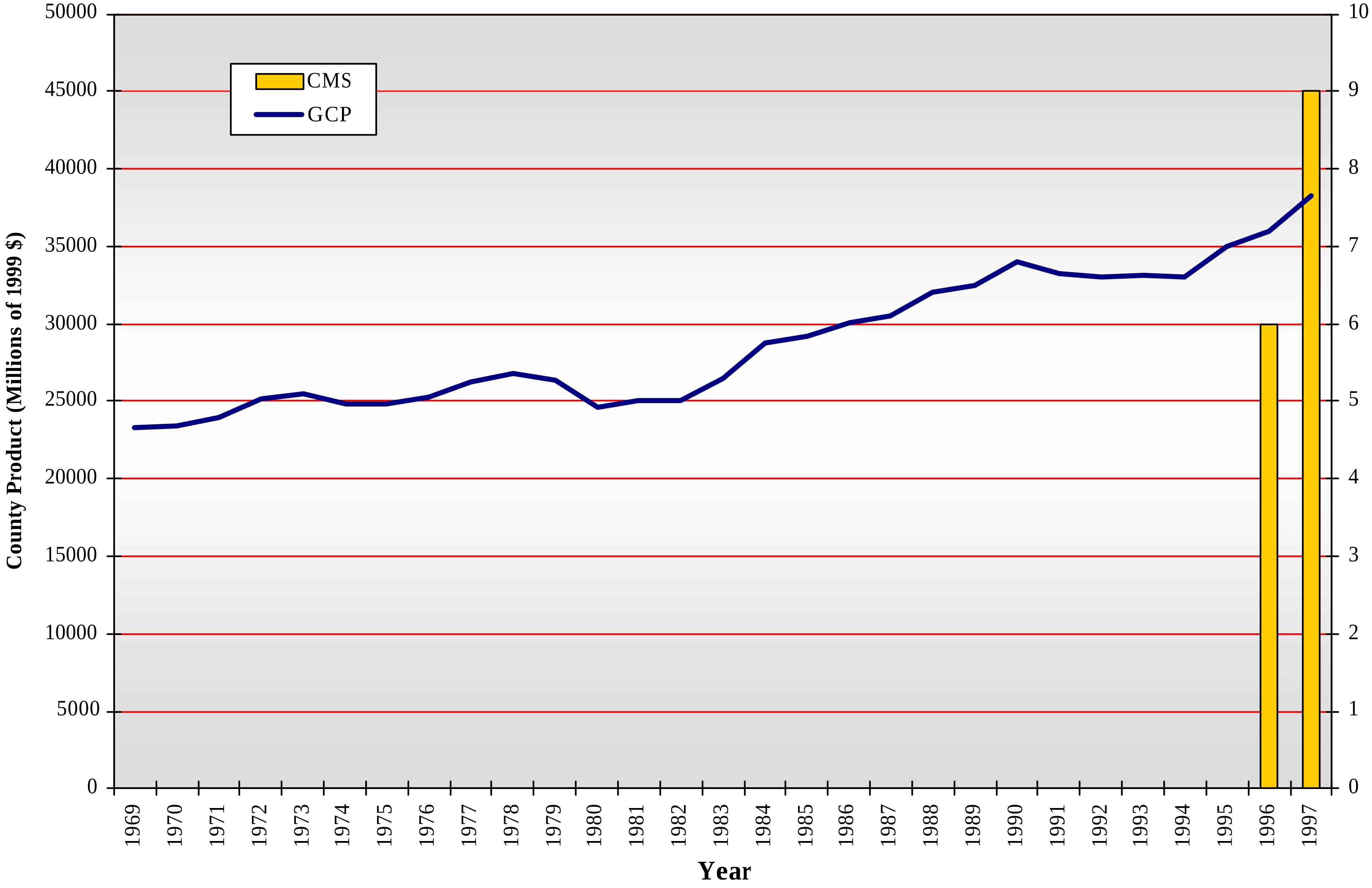
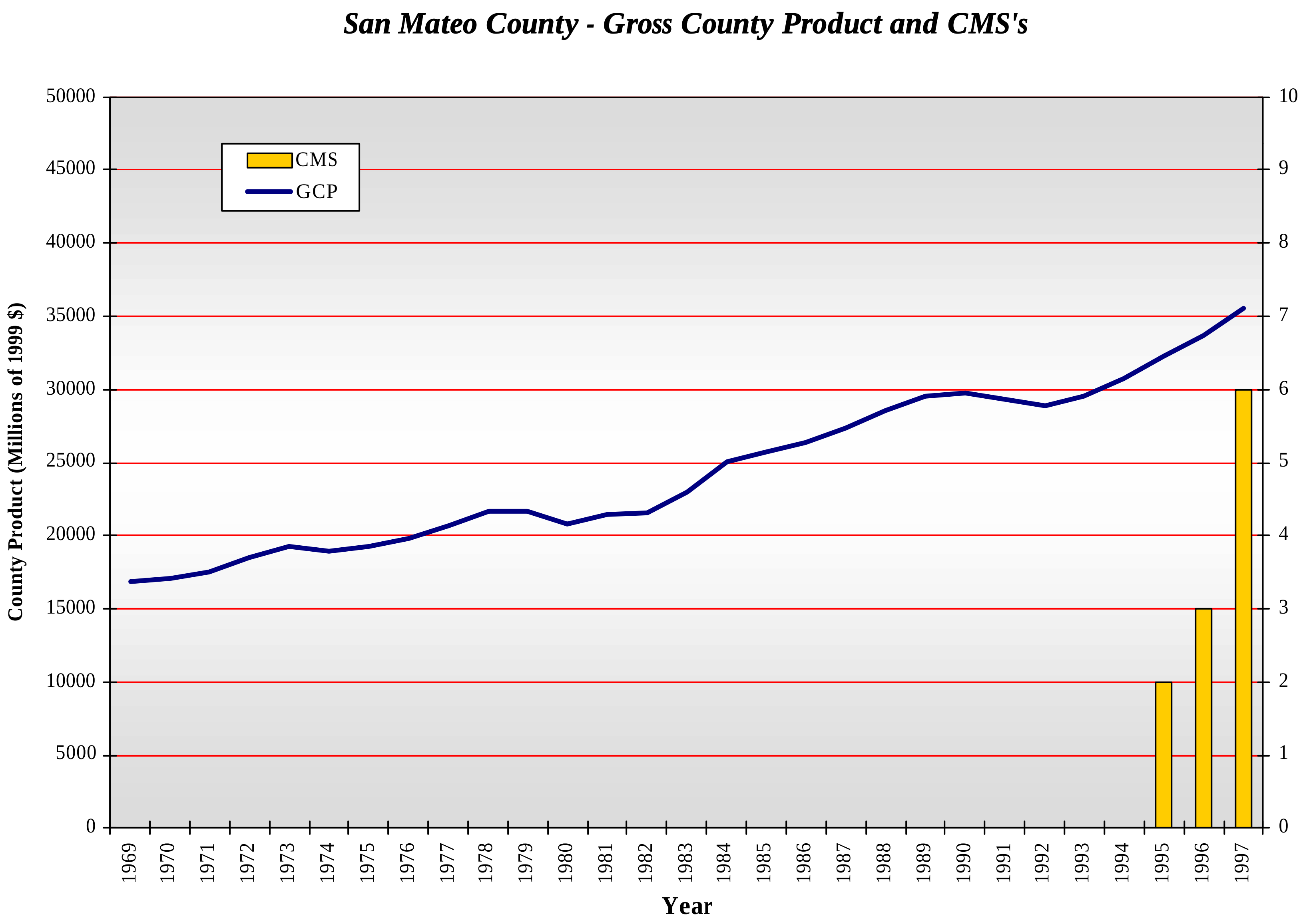
San Francisco County - Gross County Product and CMS's




San Mateo County - Gross County Product and CMS's
CMS
GCP
County Product (Millions of 1999 $)
Year
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
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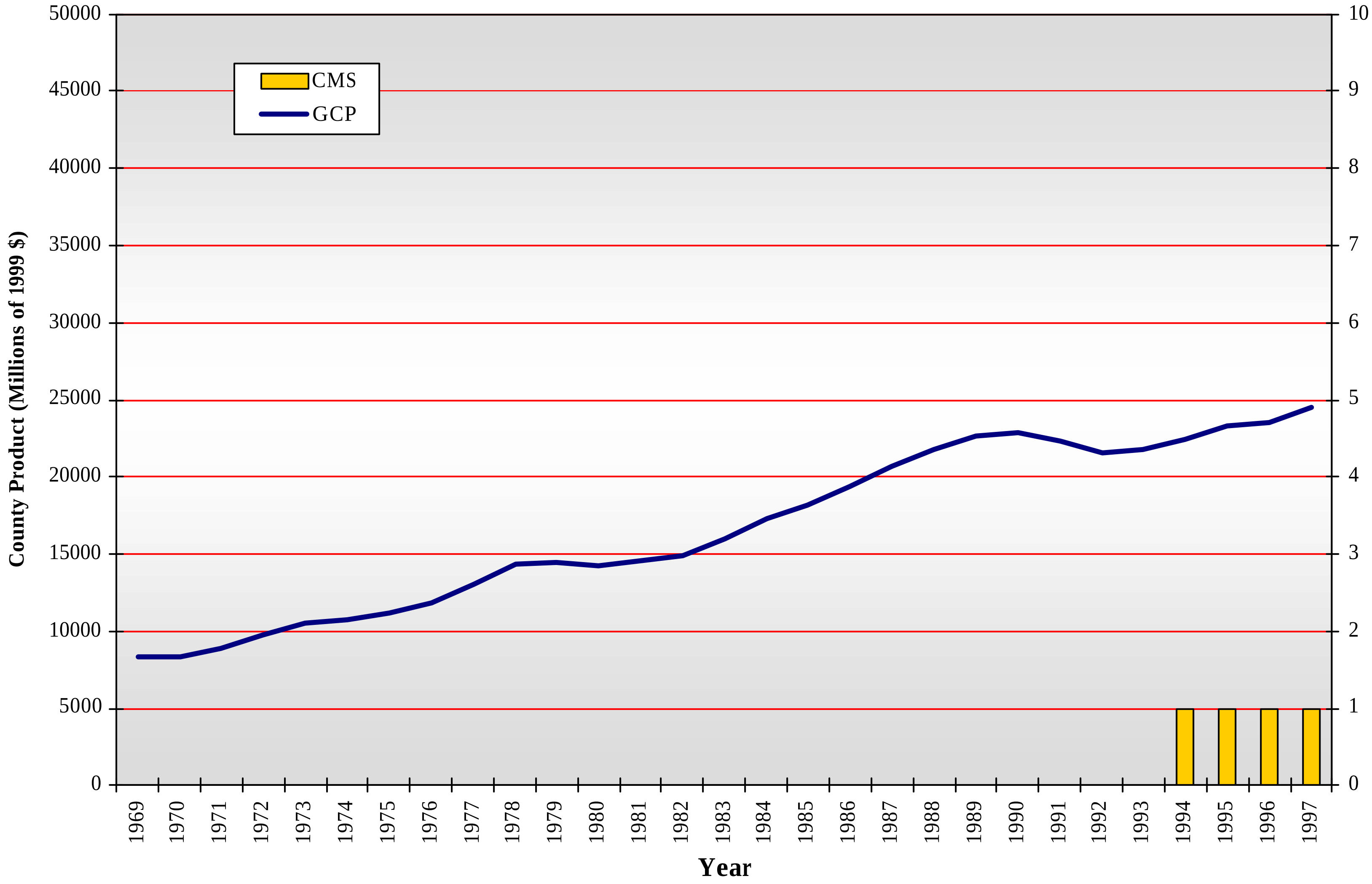
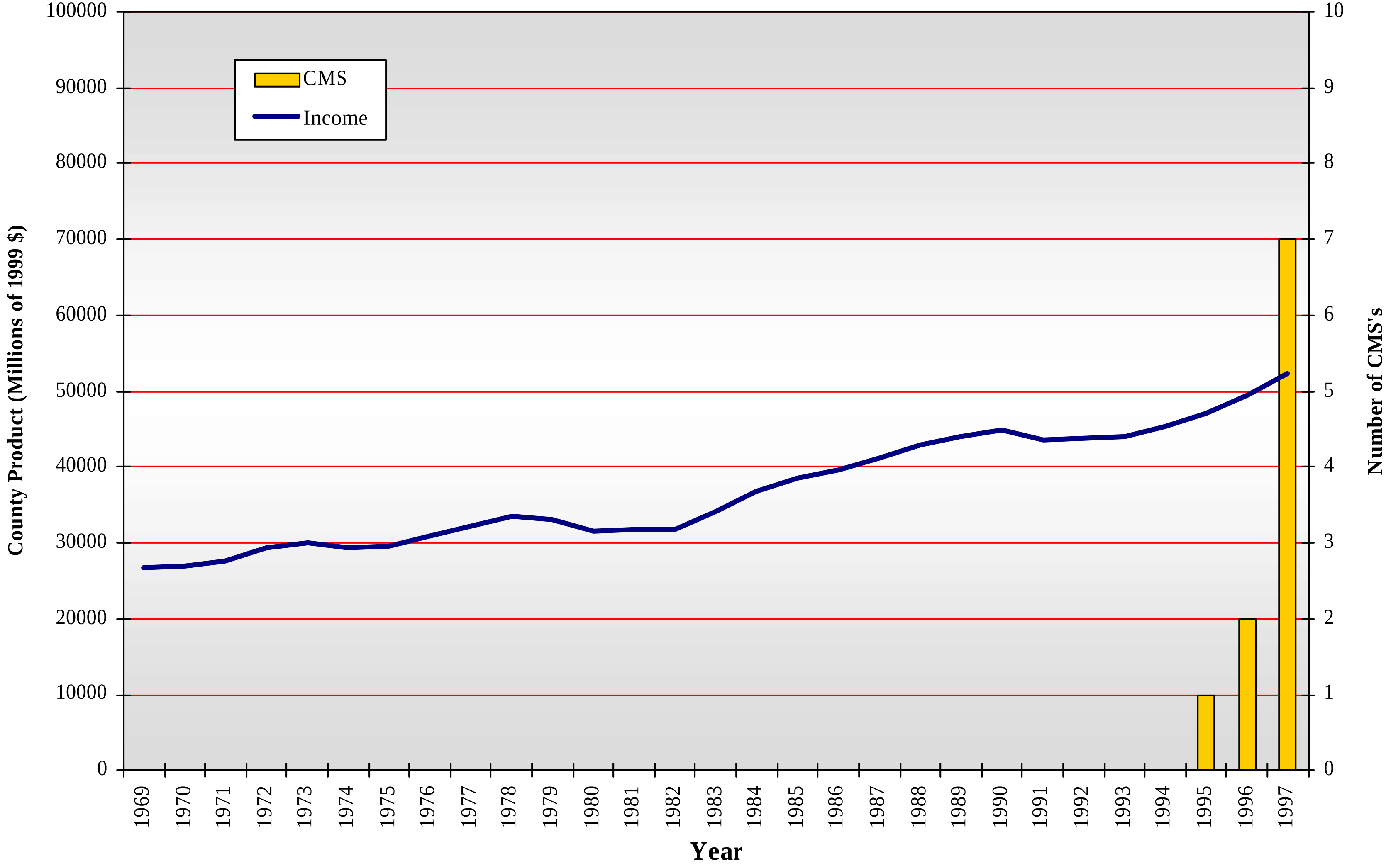
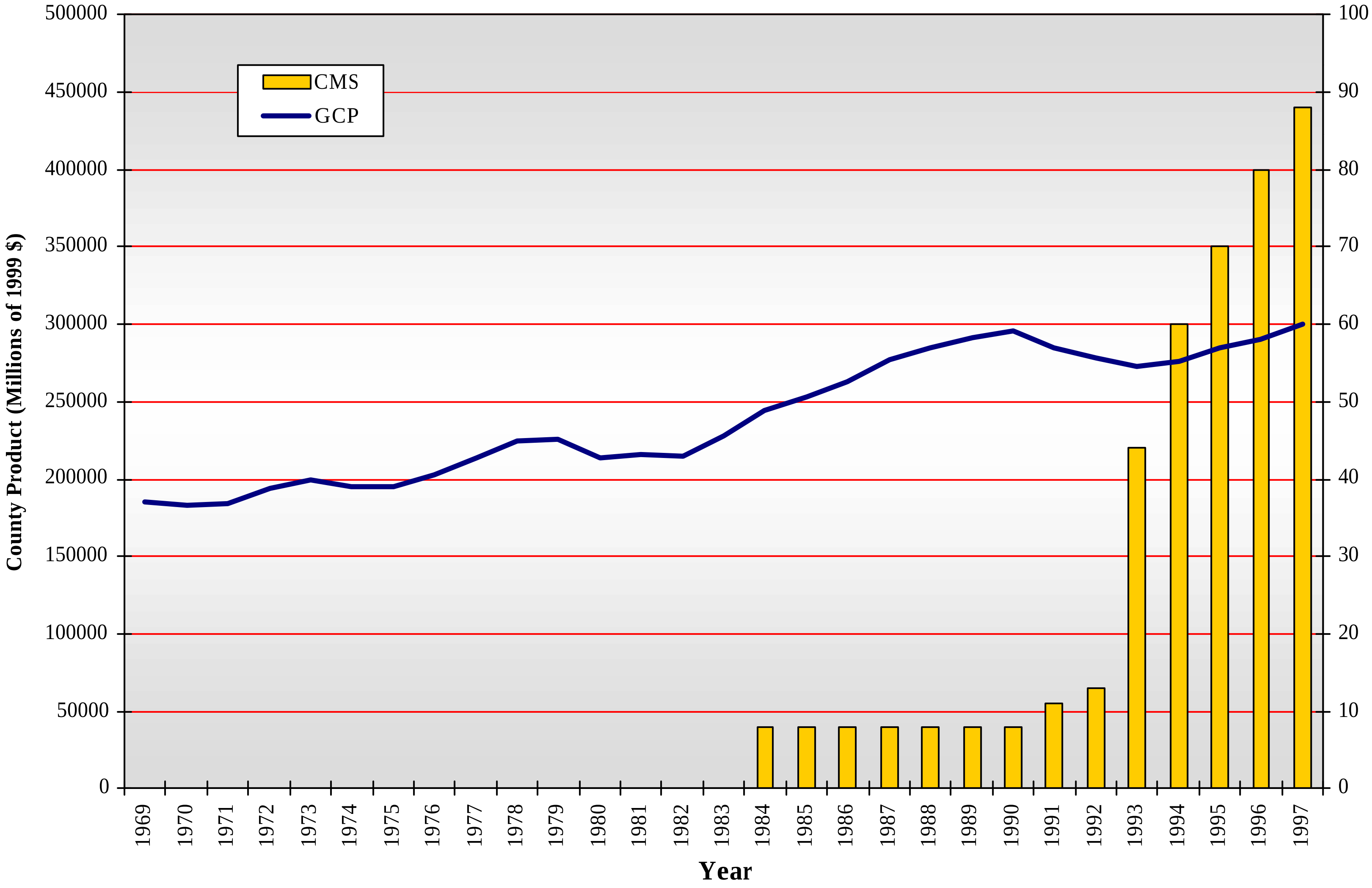
Ventura County - Gross County Product and CMS's



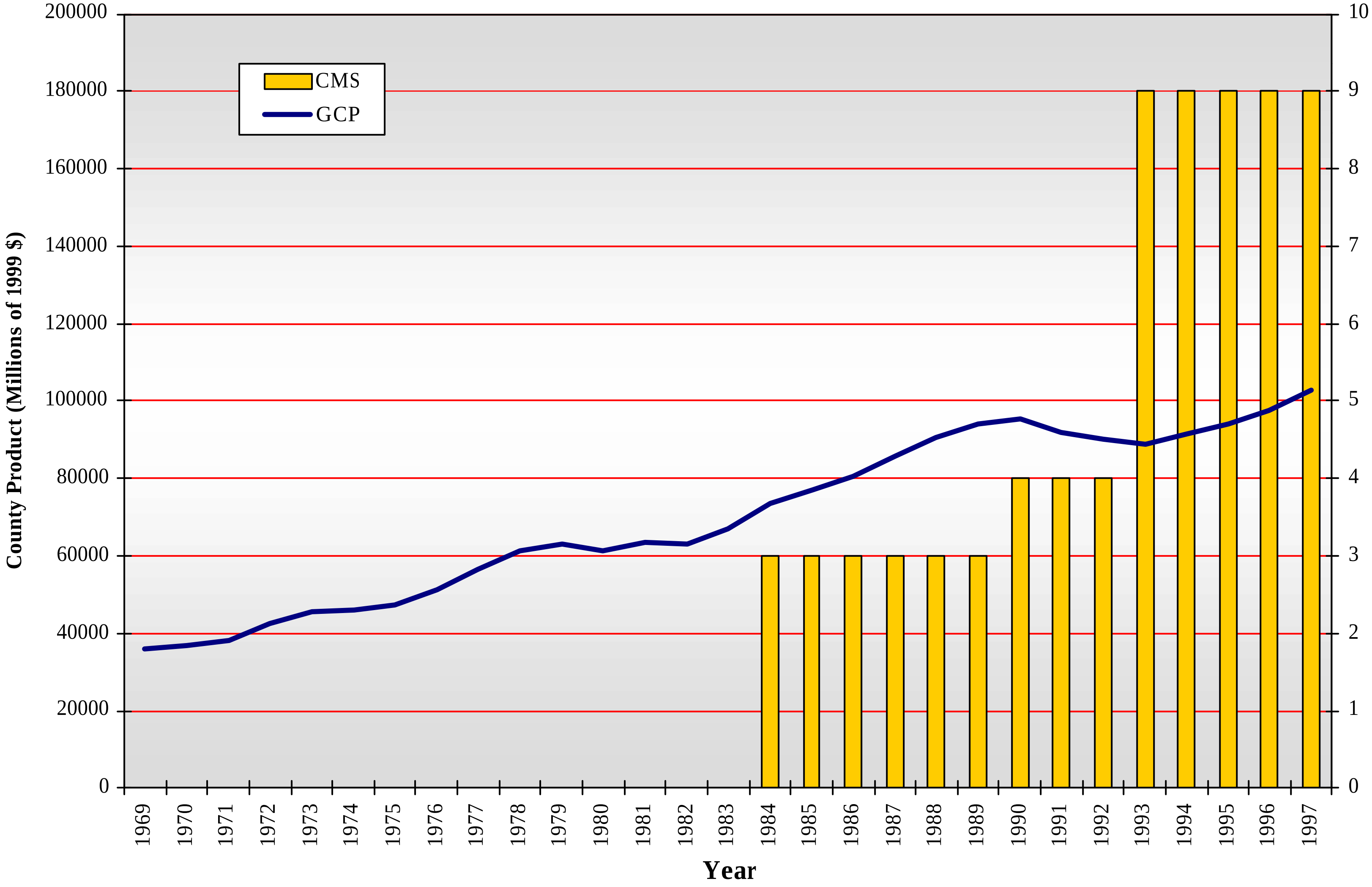
Alameda County - Gross County Product and CMS's



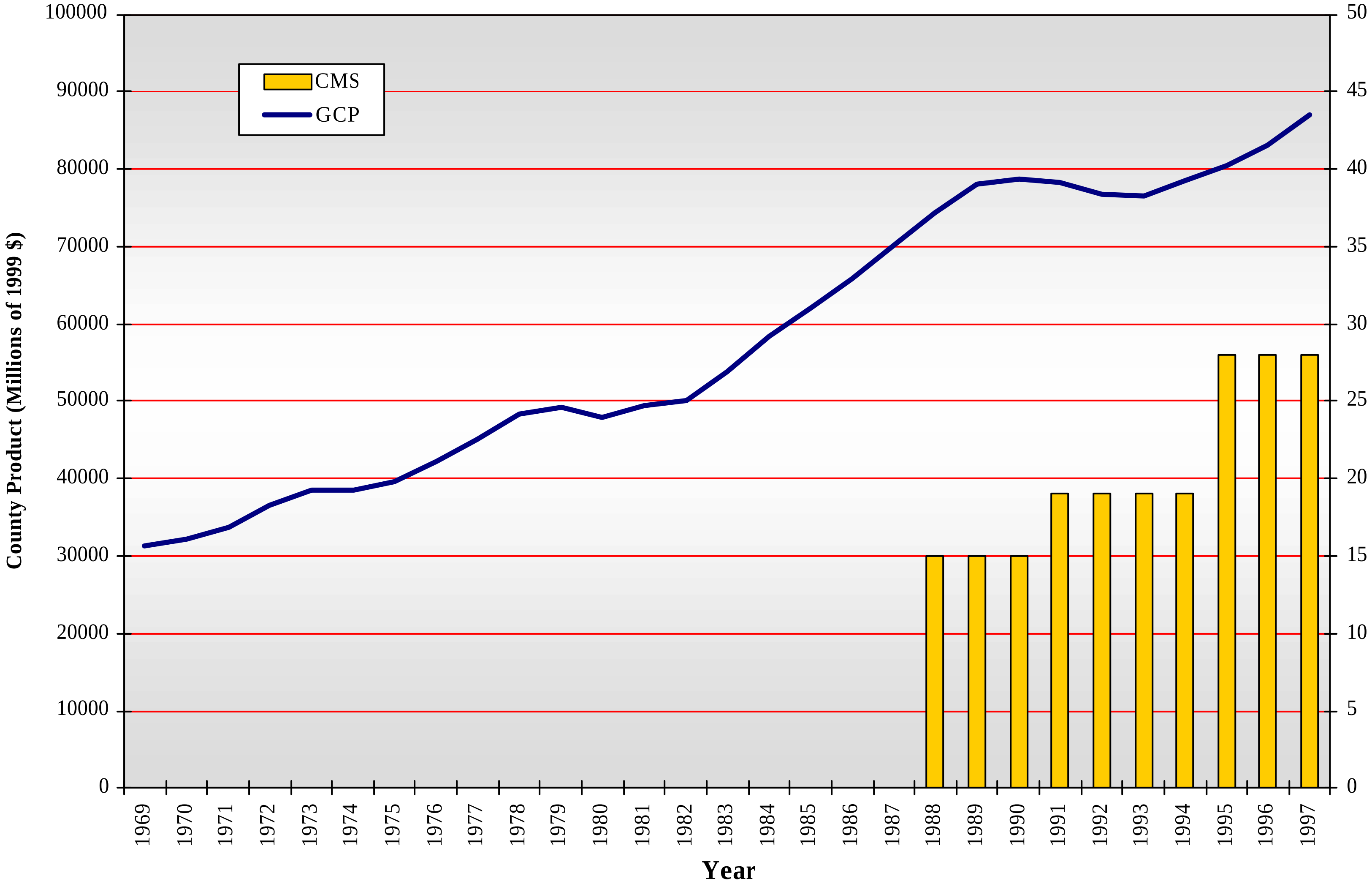
Los Angeles County - Gross County Product and CMS's



Orange County - Gross County Product and CMS's



San Diego County - Gross County Product and CMS's



Santa Clara County - Gross County Product and CMS's