Title

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Publication Date

2004-04-01

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California PATH Research Report
UCB-ITS-PRR-2004-11

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 of Transportation, Federal Highway Administration.

Final Report for Task Order 4132

April 2004

ISSN 1055-1425

CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

Final Report

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1 BACKGROUND

This research builds on the contributions of MOU 357, 3001 and task Order 4119 all of which focus on methodological and measurement issues in benefit cost assessments of ITS applications. The important contributions of this work are not only providing methods for calculating benefits and costs but also an empirical assessment of the set of projects that have been implemented. In all of this work, as well as most other project evaluation studies, two strong assumptions are made. First, the project is implemented successfully and second the impact of the transportation project is felt wholly within the transportation choice sets of consumers and producers. In the first of these assumptions, a project could potentially be declared unsuccessful when the technology may in fact be quite appropriate and potentially provide significant benefits, but the way it was implemented may have lessened some of the potential benefits. The study of implementation is one of understanding processes and how people integrate with new methods and technologies.

In trying to understand the implementation process requires detailed case studies of ITS and TMC applications. There are three steps needed, first how did the decision to adopt ITS and TMC in particular take place, second how was the introduction carried out within the agency or district and third, how was the value and performance of the application assessed? The set of three steps represents the process of implementation; selection of project, integration of the investment into the firm or agency and a final evaluation of how it is contributing and what might need to be changed in order to improve the return from such an investment.

Understanding process requires case study. How things are done, how decisions are made, where the pressures are and what resources are mobilized to facilitate the investment are all real concerns. There will also be groups, stakeholders who may be or feel threatened by such a proposal and others in an organization who can affect the extent of success of the investment in a TMC. Failure to communicate the purpose, means and anticipated outcomes of such an investment may simply lead to people ignoring it and hence, inadvertently, diminishing its overall success. In a case analysis it is the process that is at issue. Selecting three or four ITS applications that include TMCs in all or most cases for which to undertake a case assessment will provide a reasonable portfolio to reveal lessons and success drivers as well as factors that lead to less success.[1]

The case study analysis was the precursor to the second and third parts of the research direction in this proposal. In our investigation, the emphasis is on the measures of benefits that arise from the integration of ITS investments (or their effects) into the consumption activities of individuals and the production processes of firms. In all previous analysis, any changes to the transportation system are assessed in terms of modal, route or travel timing shift.[2] All of the changes are assumed to occur wholly within transportation choices with no impact on other activities that affect households or individuals. Yet we know that changes in the service levels and costs of transportation influence many other choices we make in our lives including housing location, entertainment and social activities, education etc. These are more general impacts and we know

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[1] The case studies are contained in report, "Assessing the Value of TMCs and Methods to Evaluate the Long term Effects of ITS Implementation: Case Studies"

[2] This analysis is contained in reports: *Traffic Management System Performance A case study of Mn/DOT's Traffic Management System, The Insurance Value of Freeway Service Patrols: A Stated Preference Analysis and Effectiveness of VMS Using Empirical Loop Detector Data* .

from other research that the results from a partial equilibrium analysis, the traditional approach, can differ markedly from a more general equilibrium analysis such as proposed here. In this final report we provide an approach to modelling the relationship between the economy, mobility/accessibility and ITS investments. This approach is

2 Introduction

In a general equilibrium approach we include transportation characteristics, ITS in particular, as one of the activities or bundles of consumption. By modeling it in this way we are able to assess the extent to which changes resulting from ITS investments will cause people to change mode, trip timing, job location or affect other parts of their consumption activity. For example, in a traditional model, if an ITS investment resulted in less trip time for an individual for a given set of trips, and if the individual made no added trips, the benefit measure would simply be the reduced travel time. But if the individual or household used this time saved for other activities such as visiting friends or relatives, shopping or new activities, these benefits would never show up in the [traditional] evaluation. Since a significant amount of ITS investments are made to reduce congestion and work-trip related travel time, it is unlikely the number of trips would change. Therefore, the underestimation of benefits may be significant. Yet the ability to improve economic welfare from improved mobility and/or accessibility should be included in any benefit-cost assessment.

The purpose of this paper is to explain a model of a general equilibrium nature, which can provide a set of calculations of the effects of improvements in infrastructure of either a conventional or ITS type on economic welfare. Such calculations are important inputs to the long-lived investment decision and in ranking investment alternatives. Economic welfare will be the outcome of the effects of the investment on the productive and consumptive activities and the model must capture interactive effects of economic growth, mobility/accessibility and choice of [economic] activity, including mode.

In conventional assessments of transportation infrastructure investment, a traffic model is used to examine the extent to which an investment has led to some improvement in mobility or throughput.[3] This model implicitly assumes that the economy drives mobility, in other words the causation runs from economic activity to mobility. Conventionally this is measuring the pure substitution effect and assumes the output effect is negligible. The approach is also very much supply side oriented as the gains from any investment is measured as an improvement in productivity.

We know from aggregate productivity studies that public capital has a positive affect on industry productivity; with a differential affect across industries. This literature illustrates the potential for economic growth with public investment but it is also at an aggregate level so more micro projects cannot be assessed nor is it possible to distinguish project investment from improved project management. This literature is also focussed on the highway sector and does not provide good information on the relative role of rail, water or air transport for either cargo or passengers.

The model described in this paper lies between the highly detailed microscopic network models such as Paramics and the more aggregate econometric models just described. It uses larger geostatistical areas such as counties as the unit of observation. It describes the relationship between the level and structure of economic activity, the type and extent of infrastructure investment, including ITS and the changes in economic welfare as the sum of producers and

[3] A good example is the IDAS model.

consumers surplus. Producers' surplus will be affected by the changes in logistics costs in production and distribution while consumer surplus will be affected by the changes in mobility and accessibility and their subsequent impact on other choices in the consumption bundle.

The model is founded within a neoclassical growth model in order to account for the impact of investment changes on growth potential and opportunities. The two effects of a transportation investment, conventional or ITS, are a direct effect in making is less costly to do the same things (mobility effect) and creating opportunities to bundle choices in a different way (accessibility effect). The model allows for a recursive relationship between transportation investments and the level of economic activity. As investment takes place there is the direct effect of lowering costs, this leads to improvements in the economy and these changes in the level of economic activity in turn lead to new choices and changes in the demand for transportation.

The model is spatial in that is covers multiple counties and can be used to assess the interaction or spillovers between counties. In a general equilibrium model with factor mobility as changes take place in one region there can be factor flows to other regions depending on the complementarity or substitutability between factors. Thus not only are affects between markets considered but the vertical relation between factor and product markets are also considered. Finally, the time path of the changes are also traced out for industrial, factor and transportation variables. Before developing the model in a more formal way, it is useful to explain the economic growth models into which the model is placed.

3 INFRASTRUCTURE AND ECONOMIC GROWTH:

In standard models the relationship between infrastructure investment as viewed through the traditional lenses provided by cost benefit analysis and production function estimation are built upon the traditional neoclassical model in which technology is taken as exogenous, and factors are paid the value of their marginal product. In the dynamic neoclassical framework, as typified by the Solow-Ramsey growth model, this leads to the striking conclusion that economic growth, defined as *long run* growth in per capita income(or equivalently average labour productivity) is independent of policy variables such as the savings rate or the level or public sector investment. Policy variables can affect transitional growth rates, but not long run growth rates. Beginning in the mid 1980's there have two significant developments that are directly opposed to the view of policy which emanates from this perspective, and has important implications for policies toward public sector infrastructure. First, the new growth theory pioneered by Lucas, Romer, Helpman and others has the characteristic that the *rate of productivity growth* is directly dependent upon the *level* of a policy variable such as the level of education of the workforce, the amount of R&D investment, the savings rate, the tax rate, and the level of public sector investment. Second, in parallel with the theoretical developments in growth, an extensive empirical literature has developed which is based on cross sections or panels of the comparative international growth experiences of countries in the post-1960 period. In this literature a number of variables were identified as being correlated with the rate of economic growth, including the rate of savings, the level of investment, inflation rates, the degree of openness of the economy, population growth, and other policy variables. In the growth regression there are important unresolved issues as to the causal links running between economic growth and the variables found to be robustly correlated with growth. Nevertheless some important empirical conclusions have emerged which bear directly on the role of infrastructure (public and private) in economic growth.

In the next two sections the basic endogenous growth model is reviewed and contrasted with the more traditional framework. Then we discuss what the cross sectional growth literature has revealed with regard to the potential role for infrastructure investment in economic growth, and also discuss some quantitative modeling of the link between infrastructure and growth. In the final section we discuss the possible implications of this literature for the more traditional policy approaches to infrastructure.

3.1 Infrastructure Investment and Endogenous Growth Theory:

There are two versions of endogenous growth theory –one version known as the A-K model typified by a class of models introduced by Lucas is in his now famous 1986 paper, and the Romer-Helpman models based upon an endogenous process of productivity growth. Both types of models have found empirical support by at least some investigators and bear directly on the question of the role of public sector investment. We discuss each in turn.

3.1.1 **The A-K model of economic growth:**

In the A-K model the basic theory relies on a specification in which all factors of production can be endogenously accumulated, and thus there are no constraints placed on aggregate growth by an exogenously specified supply of either the labour input, or the supply of natural resources. When one of the factor inputs is labour the theory takes the view that the proper interpretation of the "labour input" is as flow of factor services from a stock of human capital. In addition the stock itself is endogenously determined over time by investments in training or education. Imagine therefore an economy described by a single aggregate production function in which output is a Cobb-Douglas constant returns function of two inputs, physical capital K and public capital G. Labour as an input is dropped to keep the presentation of the basic idea as simple as possible. We write this production function as

$$Y = AK^{a}G^{1-a}$$

Some of this output is consumed, but the fractions s_i, i=k,g, of output are allocated as new gross investment in physical capital, infrastructure capital and human capital. The accumulation of new net stocks are given by the dynamic equations defining the rate of change of the two stocks:

$$\Delta K = s_k Y - dK$$
$$\Delta G = s_g Y - dG \, .$$

Assume that each of these stocks depreciate at the common exponential rate δ. This model has a well-defined steady state growth rate of output and factor allocation. With a constant productivity level A, the ratio of K to G in the steady state is given by the ratio of the savings rates;

$$K / G = s_k / s_g \, .$$

The steady state growth rate is given by

$$g = A s_k{}^{a} s_g{}^{1-a} - d \, .$$

The implication then is that an increase in the savings rate in public capital, s_g will increase the steady-state growth rate, or growth rate of income per capita in the economy, with an elasticity (for small δ) approximately equal to the elasticity of public capital in the aggregate production function--in the literature previous discussed these elasticities are estimated to be the range of 0.02 to 0.20.

The implication however is quite different than that in the static model--here the effect is of a savings rate on the *permanent per capita growth rate of the economy*--quite different than the usual static interpretation given the marginal product of a factor input. In general, if for whatever reason public capital formation is too low relative to private capital, the potential returns to shifting savings toward public capital can be quantitatively substantial. It is possible to get a rough idea of the orders of magnitude involved here. If α is on the order of 0.10 for example, then an increase in the public sector savings rate from 0.04 to 0.05 would increase the growth rate of per capita income by 2.5 percentage points! The implication of such models is that the policy leverage through changes in levels of investment is potentially extremely large.

3.1.2 **Endogenous Productivity Models**

The Helpman-Romer style models focus primarily on R&D as a potential source of endogenous productivity change in the economy, while other authors have stressed the role of human capital as a similar mechanism. In both cases the potential for long run endogenous growth arises because of the intertemporal spillover that occur in the knowledge creation process. This spillover occurs because the stock of knowledge existing at a point in time is assumed to be a public input in the Samuleson sense into the production of new knowledge. Intuitively, an 'idea today' is potentially available and useful to anyone generating knowledge tomorrow at zero marginal private cost. R&D and human capital play a role as the private inputs that go into the creation of new knowledge process, and are complementary inputs to the existing stock of knowledge. One can easily make similar arguments for transportation, communication and health infrastructure if these serve important limiting roles in the general process of knowledge creation.

To make these ideas more concrete consider a simple model in which the only factor input is public infrastructure G, and it lasts for only one period[4]. Consumable and marketable output Y is generated by a traditional production function

$$Y = AL^{b}$$

The growth in knowledge, and thus the growth in productivity A, is endogenously determined and by a spillover from infrastructure to the knowledge creation process. Approximating the knowledge capital stock by A[5], the process of *knowledge creation* is identified by a dynamic process, in which the rate of knowledge creation is

$$\Delta A / A = lG$$

thus public infrastructure contributes to new knowledge creation. Now assume the economy devotes a fraction s of output to gross investment in infrastructure so that in any period $G = sY_{-1}$ The growth rate of the economy is given under these circumstances by the growth rate in A as the L is assumed to be constant. Thus

$$g = lsY_{-1}$$

In this case the theory has a number of predictions. The growth rate is increasing in the size of the spillover parameter λ, the fraction of resources devoted to infrastructure s, and the recent size of

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[4] In equivalent terms the depreciation rate is 1.
[5] This is a standard assumption in the literature.

the economy as measured by GDP. Policy could potentially impact on either the spillover parameter and most certainly on the resource allocation parameter s, with effects in both cases on the growth rate of the economy that would be permanent were the policy permanent.

3.1.3 **Threshold and Take-Off Effects**

In the literature on economic development there is a long tradition of associating certain minimum levels of infrastructure with a Rostow type take-off phase in economic growth. The new literature has developed a number of theories along these lines. Equation (6) is amended so that growth in the TFP level only occurs if G exceeds some critical minimum, say G_{min}. With these type of threshold externalities economies can exhibit multiple growth equilibrium, and in particular low level growth traps, in which the economy never gets out of a low growth equilibrium due to insufficient infrastructure investment.

3.1.4 **Implications and Contrast:**

If there were empirical support for either of these models the policy significance would be fundamental. In practical terms however it difficult to distinguish these new growth theory affects from more traditional growth effects. In the traditional growth model of the Solow sort amended to include public infrastructure the production function is given by

$$Y = F(K, G, L)$$

where L is a primary factor labour. Constant returns to scale of F in all inputs and the exogenous determination of the growth of L, are jointly sufficient to imply the existence of a steady state growth rate. Changes in the steady state rate of investment in either K or G will have *no effect* on steady state per capita income growth. It can however have a substantial transitional effect. An increase in s_g , the fraction of output devoted to public capital formation will have a temporary positive effect on the growth rate of per capita income. It is possible to show that the initial increase in the growth rate is approximately proportional to the factor share parameter of public capital in the aggregate production function. Furthermore the so called 'half-life' duration of the out-of-steady state impact is directly proportional to the share parameter. In practical terms the transition period has been estimated to be between 10 and 20 years when the share of capital in output is in the 0.33 range and much longer for more comprehensive definitions of capital which include human capital and public infrastructure. Given the rather long period over which a transitional impact can occur it would be incorrect to say there are no growth impacts of public sector infrastructure policies within the traditional framework. Moreover given the long length of the transition it makes it difficult to distinguish empirically between the 'new growth' theory versus old growth theory. It is noteworthy that some versions of the A-K model yield a strong scale effect so that large countries can grow faster than small countries. A number of authors have shown that this type of result can be easily overturned without changing many of the basic insights.

In the case of the endogenous productivity version of the theory is important to emphasize the difference between this theoretical specification in which infrastructure externalities spill on (or constrain) the knowledge creation process, versus the more conventional static production function in which the level of infrastructure has an effect on the level of output. An Aschauer type production function for example is consistent with the *levels* spillover channel for pubic capital, but would not be consistent with the dynamic specification given above. In fact a traditional production function regression of the Auschauer sort, were the true model as given by an endogenous productivity growth specification as in (6), one would not expect to find much in the way of contemporaneous links between changes in output and changes in public capital. The dynamic growth effects implied by (6) may take much longer to observe. This is why the growth regression approach may be a more promising research strategy relative to growth accounting based on an assumed neoclassical link between output and public capital.[6]

3.2 Implications for Cost Benefit Analysis

If the endogenous growth approach is validated what are its implications for conventional cost benefit approaches to infrastructure evaluation? In some respects the result is not much different than are the implications of the Aschauer literature. In both cases the literature implies there are unmeasured spillovers that are potentially economy-wide in scope and cannot be picked up in microanalysis. Adding some arbitrary marginal social benefits to reflect these in a C-B analysis is one way to proceed. The major difference in the case of the endogenous growth approach pertains to the timing of the realization of the external benefits. In the new theories the impact on output is permanent but largely concentrated in the future as the growth rate responds to a higher stock of knowledge capital. Given the potentially long lags in the process, with the usual discount rates applied it is not clear that quantitatively adding these additional growth effects would have a large impact on evaluations of individual projects. Certainly more problematic is the threshold view of public infrastructure common in the development literature. If thresholds are significant then marginal analysis is likely to be seriously misleading.

3.3 The Growth Regression Approach

In the last decade economists have made considerable headway on the empirical determinants of economic growth, measured as the rate of increase in per capita real income, appropriately PPP adjusted. From the early time series work on production functions and growth accounting exercises, Total Factor Productivity Growth(TFP) was identified as the most important determinant of economic growth rates in most countries. Moreover the determinants of TFP growth were left unexplained. This quite unsatisfactory state of affairs has given rise to an alternative methodology that seeks to identify the sources of long-term growth, now knows as the growth regression approach. The primary input to a growth regression is a data set that is based on the growth experience of a large number of countries from roughly 1960 to more recent years. This data is used in either a cross sectional or panel regression with the growth rates of individual countries on the left hand side of the regression and a number of explanatory variables on the right hand side. The growth regression literature got started more or less about the same time as the New Growth Theory. The New Growth Theory conveniently provided a theoretical rationale for the explanatory

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[6] In the case of each of these theories there is a major issue that needs to be addressed before one can take the theory seriously.

1. In the A-K models just how plausible are the technological assumptions that require non-decreasing returns in all factors of production, and the absence of any primary factors in the production function? The existing returns to scale evidence offers little that relates to the public infrastructure issue. Some estimates of aggregate production functions that include physical and human capital have been made, but they do not typically cover infrastructure capital.
2. In the endogenous productivity models what is the precise externality that causes a spillover from public infrastructure to knowledge creation? Note that 'infrastructure is not usually defined to include education and health. The communications and transport examples seem to be fairly obvious ones, and their is some evidence that appears consistent with this. In general however the external links running from infrastructure to growth in knowledge are rarely if ever made precise.

variables that the growth regression approach commonly included on the right hand side, but could not be justified by either neoclassical growth theory, or traditional production function approaches.

Not surprisingly there is considerable diversity in both the growth experience of countries and in the extent of public sector investment in the economy. Even within the OCED countries there is considerable variation, with public investment as a share of GDP ranging from 1.3 percent in the U.K. to 5.8 percent for Switzerland.[7] Within the industrialized countries there has been a considerable decline in public sector investment from the 1970's to 1980's with many countries showing declines of 2 percent or more in the share of GDP devoted to public sector investment. These macro trends are also what were driving the "Auschauer" debate. It has also spilled over substantially into the growth regression literature.

A typical regression equation that is estimated on a cross section of countries using data averaged over a period of T years would be

$$\Delta \log\left(\frac{\mathrm{Y}}{\mathrm{L}}\right)_{0,T} = a + b\left(\frac{Y}{L}\right)_{0} + g\left(\frac{I_G}{Y}\right)_{0,T} + w(other)$$

The β term is the catch up or convergence coefficient, and γ measures the effect of public sector investment on growth rates. Note that γ is *not* the same as the marginal product of public capital. A wide range of policy variables have been tried in the other category, but all with mixed success. Most of the results have been interpreted as broadly consistent with the New Growth Theory approaches. More recently some studies have begun using panels of TFP growth rates as the independent variable, rather than simply average labour productivity, and found that similar sorts of variables explain TFP growth. However as TFP growth nets out factor input growth, a lot of what is of interest in the growth process has by construction been removed from the analysis. Countries can obviously grow due to factor accumulation and in many cases explaining input growth is as important as explaining TFP growth.

This last point is of particular significance, as it turns out that high investment rates are very strongly correlated in these studies with per capita income growth. These measured investment rates include public sector infrastructure. The major difficulty relating investment and growth has to do with causality. Since both are endogenous variables that is the cart and which is the horse? The general conclusion of the investment growth literature is that there are ultimately diminishing returns to capital formation, although the rate of decrease of the marginal product of capital appears to be very slow. This evidence tends to weigh against the A-K model of economic growth. It does not however eliminate the possibility that there are important externalities linked to physical capital accumulation. In a very influential piece DeLong and Summers(1991) identified what appear to be important growth externalities in investment in machinery and equipment--investment in structures or in land appear not to have the same external growth effects. The implication of their work, which appears to stand despite numerous attempts by critics to overturn the results, is that social rates of return to equipment investment appear to be extremely high--on the order of two to three times private rates of return. One possible explanation for their result is that equipment investment is highly correlated with industrialization and with technology transfer in many countries.

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[7] These are 1992 figures.

The interesting and apparently robust results on investment and growth however leave us uncertain as to the precise role that investment in infrastructure plays in economic growth. A number of studies in the growth regression tradition have addressed this question and have yielded mixed results. Barro(1991) for example finds that the public investment/GDP ratio is positively but insignificantly correlated with growth. Easterly and Rebelo(1993) find a positive and significant impact of general government investment on growth. They use the share of public investment in transport and communications as the public capital variable and find it to be robustly correlated with growth, but with incredibly high coefficients.

Devarajan et. al. (1996) find a negative and significant relationship between the ratio of transportation and communication expenditure to GDP for a sample of 43 LDC's. Sanchez-Robles(1998) using an index of physical infrastructure find some evidence of growth effects from the physical indices of infrastructure but also finds negative effects from expenditure share measures of infrastructure. on a sample of Latin American economies. The effects are attributed to a potentially transitory effect on growth rates of public sector infrastructure, but discounts the possibility that infrastructure can have permanent effects on the growth rate.[8]

Pritchett(1997) provides a devastating criticism of the use of public sector investment data since he argues it has little to do with useful public sector capital stocks, even in apparent steady state situations. His point is that much of measured public capital in the developing countries is non-productive due to what he calls the 'pyramid' phenomena. A lot of public spending goes into showcase 'monuments' which actually have little productive value to the economy. His views are based on a review of past World Bank financed projects. He cites for example an Africa country that had 31 projects involving roughly a billion dollars in expenditures, and in which the median ex post rate of return was 0 (zero). He provides other equally damning evidence using a variety of procedures.[9]

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[8] The Growth Regression Literature has attracted its share of criticism. Some of the more important problems include the following:

- Many of the results are derived by imposing parameter constancy across a wide range of countries, from Switzerland to Zimbabwe. If parameters are not constant, for example across different stages or levels of development, then the policy implications on variables such as public sector infrastructure may be incorrect or misleading.
- The estimates include both direct and indirect effects of public infrastructure on growth. Or in other terms the growth elasticities mix the effects of growth induced through direct factor input changes, the static externality effect, and the dynamic knowledge creation externality.
- The estimates do not distinguish between transitional growth effects of policy (movement from one steady state to another) and steady state growth effects. The implications of these alternative views of policy consequences may be extremely important.
- There are severe data problems in this type of work particularly in a sample involving developing countries. The growth regressions actually put public investment (divided by GDP) on the right hand side and not the stock of infrastructure.

[9] The growth regression approach has a major deficiency in that the causal links are not clear, and indeed it is quite reasonable to argue that most of the variables are endogenously determined. Some attempts using modern VAR methods have examined this issue. A good example is McMillan and Smythe(1994) who conclude there is little evidence to suggest that changes in public capital causes private sector output or productivity to change.

3.4 Structural Models of Growth

There is a long history of fiscal policy evaluation based on both structural macro econometric models in economics, and applied general equilibrium models. It is surprising that on the public investment issue there are few examples of the use of either of these methodologies. In particular since almost everyone agrees that simultaneity between investment, output growth and productivity growth is such a serious problem, structural modeling would be a fairly natural approach to take. The problem remains, as in most of the applied policy literature based on external effects that there are few reliable estimates of the underlying structural parameters, and thus the uncertainty surrounding the results is substantial. Nevertheless there has been some quantitative modeling based on modern growth theory methods and the results are surprising, even with relatively modest assumptions as to the output elasticity of public capital. One prominent paper in this regard is by Baxter and King(1993). The results of this paper are quite remarkable in that they demonstrate how wrong static intuition can be on long run effects of policy changes. They use a calibrated dynamic general equilibrium model with full employment, market clearing and rational expectations of the to examine the impact of changes in the share of GDP devoted to public investment within a balanced budget fiscal framework. In particular distortionary income taxes are used to finance government revenues, including public sector investment. The specification of the technology side of the model is very close to the Auschauer type specification with an elasticity of private sector output with respect to public capital of 0.05 and share in GDP in the benchmark of 0.05, and aggregate increasing returns in all factors. With aggregate increasing returns dynamic models display very complicated and typically lengthy transitions. The authors summarize their results by specifying what they call the short run and long multiplier of productive public spending. The terminology is confusing since there are virtually no Keynesian aspects to the classical model used. An important parameter in the model is the intertemporal substitution effect in labour supply. Changes in public capital affect the real interest rate, which in turn affect how individuals adjust their labour supply over time. The simulations show an amplification effect, which works through the real interest rate channel. An increase in public capital raises the real interest rate, which tends to reduce consumption and increase labour supply in the short run. In addition it stimulates additional private sector investment. The net effect is a 'multiplier' on the initial productivity increase. The multiplier tends to be larger, the greater the degree of intertemporal substitution.

The numbers they get are quite interesting. They find significant short and long run multipliers looking at simulations involving a permanent 1 percent increase in the amount of public capital expenditures each year. The short run multiplier is very sensitive to the short run impact on labour supply, which hinges on the intertemporal substitution effect. The mid range estimate is around 1.10, although for some elasticity values it goes as high as 1.37. The long run effects tend to be smaller but are much different than static or partial equilibrium calculation would suggest.[10] Using alternative values of the output elasticity of public capital range from .01 through 0.4, which corresponds to the ranging found in the literature, the long run value of $\Delta Y/\Delta I_G$ ranges from 1.45 through 8.00! The long run effects on output levels are quite significant and very sensitive to the output elasticity. The transitional implication is that growth rates rise significantly during the transition. One must be careful in drawing welfare conclusions. The strong intertemporal aspects

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[10] For example simply taking the estimating marginal product of public capital as fixed and holding all private inputs constant--the usual shadow price calculation of cost benefit analysis.

of the model implies that in the short run consumption falls and labour supply increases in response to the increase in public capital which would tend to dampen positive welfare effects.

The important implication of this paper is similar to much of what we has been learned elsewhere in the application of general equilibrium methods to policy. In many cases partial equilibrium reasoning can be invalid. Moreover when a policy affects investment decisions, a static analysis can yield quite quantitatively different and potentially misleading results relative to those provided by a correct dynamic general equilibrium evaluation.

The New Growth Theories, and their empirical counterparts in growth regressions and dynamic quantitative modeling certainly suggest there is the potential for a link running from public sector investment in infrastructure to additional economic growth. Our view is, that while this potential exists, it remains an unproven hypothesis but one that warrants more research. Certainly it would be imprudent at this stage to simply bump up social rates of return on infrastructure projects as a response to these macroeconomic investigations. That said, this new literature certainly reinforces the case to be made for devoting more resources in infrastructure cost benefit evaluations to potential external and dynamic effects. It is in this spirit that the following model is developed, to capture the impacts in market breadth and market depth.

4 MODELLING ITS/CONVENTIONAL INFRASTRUCTURE INVESTMENTS

The General equilibrium model developed below is based in a growth framework just described. The model is designed to capture the full cross-market affects of an investment in ITS, or other conventional transportation investment. The model begins with an income equation for each California county is represented as:

$$Y_r^t = a_r L_r K_r^{pr} K_r^{pb} \left\{d_T \Pi_{r=i}^{k} p_T\right\}^{b_T} \left\{d_R \Pi_{r=i}^{k} p_R\right\}^{b_R} \left\{d_U \Pi_{r=i}^{k} p_U\right\}^{b_U} \left\{(1-d)_T \Pi_{r=i}^{k} p_T\right\}^{b_T} \left\{(1-d)_R \Pi_{r=i}^{k} p_R\right\}^{b_R} \left\{(1-d)_U \Pi_{r=i}^{k} p_U\right\}^{b_U} \left(\bar{K}/\bar{L}\right)_r D_r \qquad (1)$$

where Y_r^t is the income level in region r at time t.

α_r is the state of technology in region r

L_r is the measure of labour services in region r

K_r^{pr} are the level of private capital services in region r

K_r^{pb} are the level of public capital services in region r

δ_m is the proportion of business (or peak) traffic by mode m (m=truck, rail and urban)

$\left(\bar{K}/\bar{L}\right)_r$ is the average capital labour ratio in region r (this can be distinguished between public and private capital)

D_r is the population density in region r

π_p (p=R,T,U) is a measure of the full price of the mode where the full price is an index of money and time prices (set out in more detail below)

Y, L, K and all full prices are *endogenous* in this equation; they are established by other relationships identified below. County income determines county savings, which in turn determines county investment. Any difference between county savings and investment results in a transfer of funds from one county to another. Thus, the aggregate amount of public and private investment must be balanced by the aggregate amount of savings. The flow of capital between counties will depend on the relative rate of return among private and public investments across counties. In equilibrium, the rates of return should equalize for private returns but not necessarily between public and private returns. The level of capital stocks determines capital services; each stock of capital is a product of beginning period capital stock, loss through depreciation and net investment in the period. The functional form of the income equation would generally be of the CES variety.[11] While this places restrictions on the substitution parameters, it maintains the workability of the model.

The model is operationalized through a series of relationships where the values of some prices are determined exogenously. First, wages for labour services are exogenous, a not unreasonable assumption, and given this factor price, the employment level and marginal factor productivity are determined.

$$\frac{\partial Y_r}{\partial L} = w_r \qquad (2)$$

Note that the income variable, Y, is subscripted by county, r, to reflect some friction for labour mobility. One could argue that clusters of counties might have common wage rates, for example in the Los Angeles area where labour can easily move in response to different wage rates. But the friction of distance and congestion could, even in these cases, lead to some differences in wages.

The choice of mode for passengers and freight and between and off-peak will be based on relative full prices. One could represent full price as:

$$p_m = p_m + (v_r t_m) + (v'_r \,(\mathrm{var}) t_m) \qquad (3)$$

where the full price is the sum of money price, p, and time costs in which the variability of time, (var)t_m, is distinguished from the amount of time to reflect risk exposure for delivery or arrival time. Such variability would require the use of real resources for people to self-insure by using more time than average trip time or to construct a contract that provides for risk sharing. It is through this specification of the full price that investments in ITS as well as other conventional transportation infrastructure that the impact is measured. With the full price specification investments can alter money or time costs; each would have a different elasticity. The full price would differ for passengers and cargo and may, and likely would, differ between peak and off-peak. Thus, the factor price equilibrium, where transportation is considered a factor in production would be:

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[11] CES or constant elasticity of substitution are commonly used in CGE modelling. In fact in many cases the production function is restricted to be Cobb Douglas.

$$\frac{\partial Y_r}{\partial M_m} = p_m \qquad (4)$$

the marginal factor productivity of mode M in region r, or between region r and n, equals the full price for mode m or for travel between region m and n. This equation illustrates that when full price changes because of, for example, an improvement in performance due to an ITS investment, the amount of travel would change. The magnitude of the change would depend on how all other relative prices changed as well. Equation 4 would have a separate specification for each mode, for each of passenger and cargo, for each of business and non-business trips and for within and between region travel. For consumption activities, or off-peak travel, equation 4 would have a marginal utility specification rather than a marginal productivity specification.

The stock of public and private capital in each region is:

$$K_{r,t+1}^{pr\ or\ pb} = K_{r,t}^{pr\ or\ pb} - gK_{r,t}^{pr\ or\ pb} + I_{r,t}^{pr\ or\ pb} \qquad (5)$$

which indicates the beginning period amount of capital stock [either public or private] will be a function of how much capital we began with , how much depreciation took place (where γ is the depreciation rate) and net investment. A separate capital stock equation would be specified for each county for each of private and public capital. Again note that to the extent that an ITS investment took place, the increase in the level of capital services would e reflected in the public capital stock equation.

Savings and investment equations would have a county as well as state (or national) specification. Savings would be some fraction of income as in

$$S_r = tY_r^t \qquad (6)$$

where savings is a function, or fraction, of income in the county. County investment will depend on aggregate savings (aggregate would be state for public investment while it would be national for private capital). For any county savings need not equal investment since savings from one county could flow to another but there must be some aggregate equilibrium of savings and investment. Whether there is an imbalance will depend on the relative returns to capital in each county; counties with a higher return would have a net capital inflow. Thus, investment is some function of savings:

$$I_r = q_r S_r \qquad (7)$$

where $\theta < 1$ if there is less local investment and an outflow of capital and $\theta > 1$ if there is local investment exceeding local savings and thus a net inflow of capital. Whether there is a capital inflow or outflow depends, as indicated earlier, on the relative returns to capital in each county. The imbalance between capital inflows can be represented as

$$I_r = f_r q_r S_r \qquad (8)$$

where $\phi_r > 1$ indicates savings exceeds investment and < 1 if there is a net investment inflow. ϕ_r is represented as:

$$f_r = f\left(\frac{\dfrac{Y_r^t - \sum_k wF}{K_r}}{\dfrac{Y_x^t - \sum_k wF}{K_x}} \right)^b \left(\exp \frac{i_r}{\bar{i}} \right) \quad (9)$$

Equation 9 would be specified separately for public and private capital. It indicates a net inflow of capital depends on the net return to capital after payments to all other factors when compared across the different counties weighted by the return to capital in region r relative to the average return across all regions. The price of mobility is the full price by each mode and for a region.

A distinguishing feature of general equilibrium models is they not only consider the interaction of all markets but also distinguish the production and consumption sides of the market. A weakness in previous approaches to assessing ITS investments is that among other things, they assumed the benefits flowed from improved productivity and ignored improvements in consumer welfare. Yet the vast majority of traffic is auto passenger trips (T) both peak and off-peak. This can be specified as a household production function

$$T_{rr} = aY_{r,r}^t \, \Pi_{r,r}^t p_{r,r}^m \left(L_r / O_r \right)^s \quad (10)$$

where the number of trips, T, within region r (r,r) or between region r and s (r,s) is a function of the level of economic activity Y, and the relative full prices by different modes for a trip weighted by the employment level relative to population (O).

In order to be able to capture the impact of ITS investments there needs to be equations that relate travel time (within the full price equation) to a set of variables including capacity. The simplest way of achieving this is to use a volume capacity ration for a network as the sum of users at time t over available capacity at time t.

Closing equations for the model are:

$$\begin{aligned} Y_N &= \sum_r Y_r \\ L_n &= \sum_r L_r \\ K_r^{pr} &= \sum_r K_r^{pr} \\ K_r^{pb} &= \sum_r K_r^{pb} \end{aligned} \quad (11)$$

which are a series of identities.

4.1 Measuring the Benefits of an ITS Investment

Consider an ITS investment such as ramp meters or variable message signs. First, the ITS investment would affect the relative full prices of different routes (in terms of flows within and between particular regions), traffic and passenger and cargo. With the type of full price specification, equation 3, it is possible to distinguish different types of impacts as well as different magnitudes of impact. For example, a variable message sign may not reduce mean trip time but it will reduce the expected variance in trip time. This would change relative full prices and lead to a redistribution of traffic across modes, routes etc. These changes in turn will feed into the income equation, (1) where two types of benefits arise. First, there will be a direct benefit from lower real full prices (as in equation 3) so this would be represented as a change in mobility; doing what was done before but with fewer resources. Next because of change sin relative full prices, firms can improve productivity through factor substitution and individuals/households can alter consumption choices and increase their economic welfare. The ITS investment will also show up in the public capital equations (see 5), as the stock of public capital would be higher. This increase would lead to more capacity and an increase in the marginal product of public capital. This would again lead to some factor substitution and some redistribution of investment, as relative returns to capital would have changed (see equation 9). Once the new equilibrium is reached, the values for modal use by passengers and cargo, income level and employment would reflect the full general equilibrium affect of the ITS investment.

5 SUMMARY

This modal is a simpler version of ones that had been developed in Europe, particularly the UK and Netherlands, to assess the system wide impacts of conventional transportation investments. The purpose was to create a workable model that was not so data hungry as to preclude implementation and workability yet containing sufficient detail that the underlying drivers could be distinguished to measure the impact of ITS projects.

The value in having a general equilibrium approach is that both direct and indirect impacts are measured and the interaction of markets are a formal part of the modelling process. Having other markets included is important since as relative prices change markets will respond and economic agents, firms and households, will make new choices. The choices may not be reflected in change sin the use of transportation but in other areas. However, the underlying cause of the change was based in the transportation markets; the best example is one where an ITS investment does not alter the number of trips made but reduces the trip variance. This allows people to consume other things besides transportation because resources are freed from having to self-insure. Such an improvement in economic welfare would never be counted using conventional tools but would be, and correctly, with the model developed here.

The next steps involve developing data sets to populate the model and to fill in parameter estimates. The data sets would be based on the county as the geo-statistical unit of observation. This is a combination of economic and transportation data. Once calibrated, the model can be used to calculate the economic welfare gains from change sin transportation management and investment policies.