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A CGE model for California tax policy
analysis: a review of literature

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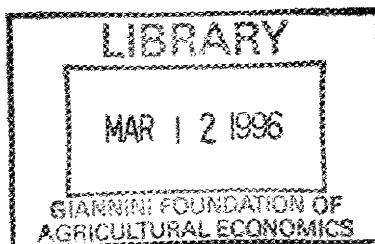
DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS
DIVISION OF AGRICULTURE AND NATURAL RESOURCES
UNIVERSITY OF CALIFORNIA AT BERKELEY

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**A CGE MODEL FOR CALIFORNIA TAX POLICY ANALYSIS:
A REVIEW OF LITERATURE**

by

Peter Berck and Andrew Dabalen



California Agricultural Experiment Station
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A Review of Literature**

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1 Introduction

In a recent law—SB 1837 (chapter 383 Statutes of 1994)—the California legislature required the Department of Finance to use dynamic estimation techniques to analyze “probable behavioral responses of tax payers, businesses and other citizens” to large tax change proposals. This report is a review of the use of Computable General Equilibrium (CGE) models to make dynamic analyses.

Since large tax policy changes are likely to affect the whole of California economy, we recommend the use of a general equilibrium, rather than partial equilibrium or fixed price model, to understand their economic and revenue effects. We recommend the use of a dynamic model so that the effects of tax policy on migration, investment, infrastructure, and human capital can be included in the analysis.

Section 2 of this review presents a brief description of the main structures of all CGE models. The reason for using general rather than partial equilibrium or fixed price models is explained. We highlight behavioral and technical assumptions that are commonly made in these models.

In section 3, we look at models that have examined tax-incidence issues using CGE techniques. We also review two innovations that make CGE models dynamic: investment behavior and labor migration.

Based on our review of the literature, we find that net-of-tax rate of return and wages are important determinants of capital stock (investment) and labor supply, respectively. The literature also supports the view that government-provided inputs increase the productivity of private sector business. The two most discussed governmental inputs to production are infrastructure and education. Infrastructure is viewed as reducing transport

costs, expanding market size and encouraging concentration (agglomeration) of economic activities. Business is likely to locate in places with good infrastructure. Educational services are used by individuals to increase their human capital. Producers are attracted to places with workers who have high productivity brought about by high human capital. These statements suggests that investment will be higher in such areas. Section 4 takes up the review of these issues. Section 5 highlights some limitations of CGEs. The Appendix, which is section 6, contains exact formulas for the variable that is considered crucial to investment.

2 What is a CGE?

A CGE model is a set of equations that describes the economic activities of consumers, producers, government, and traders in the markets for factors of production, output, and net imports. The model asserts that the supply and demand in each of these markets is equilibrated by a market-clearing price. The model is called computable because one uses a computer to find the prices that clear the markets. The following paragraphs describe a very simple CGE and explain what is computable and what is general. They also contrast a CGE to an Input-Output (I-O) model and a Social Accounting Matrix (SAM) model.

CGEs and all other empirical tax models aggregate the vast array of goods available in the economy into a small number of sectors. That is, instead of considering all types of paper and chemicals as different goods, these models lump them all together as the single sector, paper and chemicals. Similarly, labor and capital are used as aggregates, typically one type of capital good for each sector and a few types of labor, perhaps skilled and

unskilled. Thus, there are only a few dozen different goods—the product of each sector and each factor is an economic good. A CGE model asserts that prices will make the supply and demand for each of these goods to equal. The model is used to find how prices and quantities will respond to a policy change, such as a tax change.

2.1 Consumers

Consumers receive income from firms and buy products from domestic or foreign firms. The CGE model incorporates the economic theory that consumers choice of goods is made within their budget constraint. The solution to the consumers problem is their demand curve (quantity as a function of price) for each marketed good and their supply of labor. The model is called general, rather than partial, equilibrium because the income of consumers is determined within the model.

2.2 Producers

Producers are assumed to maximize profits. That is, in each sector, producers choose the inputs—capital, labor, and intermediate goods—that leads to the output that makes the most possible money. This choice is a function of the prices of the output and the inputs. Writing the demand for inputs as a function of prices gives the demand for factors, and writing the output as a function of prices gives the supply curve. When dynamic producer behavior is introduced, production and investment (more later) are said to be induced by adjustment costs. These costs can be either actual external costs (oil shocks, new discoveries, etc.) or forgone output.

2.3 Government

Government is taken as having behavior exogenous to the model. It chooses a set of tax policies and spending policies. It is then, sometimes, constrained to balance its budget. In the case of California, there is a constitutional requirement to balance the budget. Consequently, subtle issues that arise when models allow governments to run deficits will be ignored.

2.4 Foreign Sector

Agents outside the modeled area, called foreign, even though that would include the non-California U.S. as well as other countries in this model, are taken as having a known net demand curve for each good. Net demand is a device to capture exports and imports in the same equation. When price (in California) is low, foreign agents will have a positive net demand. That is, they will buy domestic (i.e., California) product. When price is high, they will have a negative net demand; that is, they will sell foreign (non-California) product into the domestic market. Real CGEs make provisions for two-way trade, but that need not concern us here.

2.5 Market Assumptions and Equilibrium

The market-clearing equations for a CGE are that there are a set of prices that make:

- the consumer demand plus the government demand plus the industry demand for intermediates plus the net export demand equal to the supply of each good, and
- demand equal to supply for each factor.

2.6 Comparison to I-O and SAM Models

Neither an I-O model nor a SAM model are very useful, by themselves, for tax policy incidence computations.

An I-O table shows the inputs needed to make an output. It assumes that the technology for making that output is a fixed coefficient technology; that is, each unit of output of good one requires exactly α units of good two. I-O models are used to compute multipliers for exogenous changes in economic activity. For example, suppose that an outside entity bought an extra airplane from California. An I-O analysis would reveal how much additional labor went into making the aircraft, and it would also reveal how much labor went into making the electronics that were an input to making the aircraft and how much labor went into making the chips that were in the electronics that went in to making the aircraft, ad-infinitum. Thus, in an I-O analysis, one can easily get that an aircraft order leads to three times as many jobs indirectly (through the electronics) as it leads to directly. In a CGE model, either the labor for the new aircraft would have to come from another sector of the economy or it would have to come from additional hours or workers lured to work by higher wages. The same is true with all other factors of production. Thus, an I-O model is a very special case—the case where labor and other factors are available in limitless supply at the current price.

A SAM model is an extension of an I-O model to include consumers and government. In a SAM model, the gross receipts of a firm are distributed to government (taxes) and consumers (rents and employment income). These agents, in turn, spend these receipts on goods. Thus, in a SAM model, an extra aircraft will also generate additional demand for goods through

the consumption demand of consumers. That is, the aircraft will result in an increase in after-tax income which will result in more purchases at the grocery store (giving more grocery store jobs) which will result in more food being bought and consumed, hence more agricultural chemicals and so on. As in an I-O model, the method in which these demands are met is taken as outside the scope of the model.

In both SAM and I-O work, there is only one way to make each output, so a tax can have no effect on the input mix. That is, a tax on capital cannot lead the firm to use less capital per unit of output. In fact, the linearity of these models assures that either a tax has no effect on the production sector other than raising prices or it shuts the sector down completely. Since labor is supplied without regard for price in these models, all taxes have the same effect, which is to say no effect, on labor. Thus I-O and SAM models cannot be used alone for tax work.

Put somewhat differently, an I-O model is a particular and unrealistic representation of the production side of an economy. A SAM model extends an I-O model to income distribution, taxation, and consumption. A CGE encompasses both of these and generalizes them by making demand and supply of goods and factors dependent on price. Since taxes add to prices, one must have a price-dependent model to do tax work.

2.7 Static versus Dynamic Issues

A CGE is said to be static when the number of laborers and total amount of available capital do not respond to economic incentives. This is thought to be the case in the short-run, perhaps a year or so. When labor and capital respond to economic incentives over time, the CGE is dynamic. The

responses of capital are investment and depreciation. The responses of labor are migration, labor-force participation, and more hours worked. The simplest way in which a model is made dynamic is for it to be solved for more than one year. The capital stock and labor variables are adjusted in each succeeding year by the amount of investment and changed number of workers and hours.

3 Dynamic CGE Models for Tax-Policy Analysis

There is a long history of using CGE models, even dynamic CGE models, for tax-incidence work. The spirit of most dynamic models can be traced to the formulations in the papers by Bell and Devarajan [19, 20]. Without going into details of these papers, the exposition is as follows. Consider the problem as was first formulated by Little and Mirrlees [65]. Imagine a government, say, a developing country, that is negotiating for a project with the World Bank. Both parties would like to know if the project is socially profitable. To do so, it is important to use prices that reflect true social scarcities. If the government had all the information it needed about inputs and outputs, valuing the project would not be difficult. However, for various reasons, the true market prices of inputs and outputs are not always known.

Facing such difficulty, Little and Mirrlees proposed valuing all tradeable inputs to the project at the “border prices” (that is, what these inputs would sell at in world markets) and all nontradeable inputs at their opportunity cost. The problem is that, to determine the opportunity cost of, say, a worker who would work on this project require that we know her alternative employment. One strategy, which Bell and Devarajan and all subsequent CGE model builders have followed, is to acknowledge that a project confers

benefits and costs over multiple periods. One can then solve for the prices of these inputs over multiple time periods. In the process, one respects the true social benefit-cost accounting recommended for projects by the World Bank, while maintaining the dynamic properties of the model.

Bell and Devarajan thought that a project serves the role of a shock to an economy that was at an equilibrium. If the economy is small and open, such as that of Cyprus which they use for exposition, it may finance its investments by borrowing from outside. To prevent it from accumulating unlimited debt, they made borrowing costly. In that way, the society that undertakes the change is compelled to meet the costs of the change.

The first comprehensive survey on applied general equilibrium models that was done in 1984 by Shoven and Whalley [92] found nine tax models. These models were used to evaluate drastic changes in the tax system, such as consumption rather than income tax or complete indexation of the U.S. tax system for inflation. At the time of this survey, the emphasis was on making substitution elasticities different from unity (a consequence of Cobb-Douglas forms) and it was considered novel to have factor mobility [92, p.1029].

The second major survey was done by Pereira and Shoven [72]. They surveyed dynamic models. That is to say that factors' mobility—migration and investment—were now commonplace enough to merit a survey of their own. Altogether 16 models were reviewed, not all of them dynamic. The contents of their modelling assumptions concerning consumers, producers, foreign trade, government, and the type of tax policy can be found in [72, pp. 404–411]. Below we summarize some fundamental issues that all these models share in terms of their structure.

Before we turn to that, remember that, in general, estimating economic

effects, say, growth, of broad policy changes such as taxes must take into consideration two issues. The first involves how well the data (such as factor shares, depreciation rates) that are observable and generated by the economy are calibrated. The second set of issues concerns how one incorporates elasticities of substitution in production and preferences as well as labor supply elasticities, all of which are not easily observable. The challenge for people who model these large policy changes is evaluating the sensitivity of growth and interest rates to these hard-to-observe parameters ¹.

In a recent study, calibrated for U.S. data, Stokey and Rebelo [96] showed that large growth effects from distortionary taxes are consequences of what one assumes about input factors. If labor supply is inelastic (i.e., the number of workers is fixed) they showed that the magnitudes of growth and interest rates in a model with flat-rate taxes are sensitive to the shares of labor (or human capital) and physical capital in the inputs producing sectors. Furthermore, the interest rate, the rate of growth and government revenues do not respond to changes in elasticities of substitution in production between capital and labor. If the number of workers is not fixed, however, the effect of taxes on the interest rate is almost entirely captured through labor-supply elasticity. The importance of elastic labor supply in producing large growth effects is greater the smaller the share of capital in physical and human capital producing sectors. Finally, Stokey and Rebelo warn that calculated growth effects of taxation are also sensitive to assumptions about the rate of depreciation and tax treatment of depreciation.

¹See Stokey and Rebelo [96].

3.1 Consumers

In the survey by Pereira and Shoven, 11 models that include at least some dynamic structures were reviewed. The greatest progress has been made in modeling dynamic household behavior. Sometimes households are said to behave as if they maximize a separable and time-invariant utility function over the consumption good. Other times, it is postulated to have a life cycle. Accordingly, households are divided into groups by age and their lifetime plans for consumption and savings specified. Within that time period, they maximize an intertemporal budget constraint that equalizes their present value of income and expenditures.

3.2 Producers

Incorporating dynamics into producer behavior has been less successful, despite some promising innovations. In the studies where dynamic behavior has been introduced, firms' production and investment decisions are sensitive to adjustment costs. The latter are meant to capture imperfect mobility of capital across industries and costs to install capital [72, p. 416]. The downside of these innovations has been to reduce the level of disaggregation of the production side of the economy.

3.3 Government

In some dynamic models, the government may be allowed to run deficits to finance expenditures in excess of tax revenues. Others determine the path of deficits/surpluses and government expenditures by solving the government's objective function: maximizing a social welfare function. Financing of deficits is dealt with either through additional tax revenues or bond is-

sues. But, as noted above in section 2, under subsection on governments, a California CGE will be calibrated under balanced budget.

3.4 Trade

The foreign sector in this class of models assumes a balanced trade. On one hand, none has yet built in international capital flows because doing so is considerably harder. On the other hand, modelling commodity import demand is not only done, but considered important in applied general equilibrium for policy-impact analysis. By far the most popular approach in open-economy specification for trade is Armington assumption.

3.4.1 Armington Model

This is a disaggregated model which identifies goods by country of origin. The import demand is separable and determined in a two-step procedure. Within a market, trade patterns change only with relative price changes. The elasticities of substitution between all pairs of goods are assumed to be both identical and constant, which amount to strong restrictions on demand.

Its advantages include calculation of cross-price elasticities between imports using only estimates of aggregate price elasticity of demand for imports, a single elasticity of substitution and trade shares. It is flexible, easy to use, and gives results that are judged plausible and statistically significant.

Some have argued that these advantages come at a cost. Alston et al. [4] tested the restrictions implied by the Armington specification for U.S. wheat imports to China, Brazil, Egypt, former Soviet Union and Japan and rejected them. These authors argue that the real consequence of Armington

assumption—when such an assumption does not in reality hold—is equivalent to omitting an explanatory variable. In their case, and probably in many others too, these omitted variables are prices of substitutes. For clarity, consider the wheat import example. A complete specification of the demand for wheat imports by any of the countries mentioned would have the quantity demanded to be a function of the price of wheat in the United States, price of wheat in the rest of the world, and the price of substitutes such as barley. Alston et al. conclude that the Armington model does not accommodate the price of substitutes as important variables and, for that reason, it underestimates—relative to double-log and Almost Ideal Demand System (AIDS) models—the own-price elasticities of goods that are traded.

Low estimated substitution elasticities were also found by Shiells and Reinert [91], between U.S. domestic production for 22 mining and manufacturing sectors and imports from Mexico, Canada, and the rest of the world, using data for the period 1980–1988.

In another study, Reinert and Roland-Holst [74] used Armington specification to check for substitutability between imports and domestic goods with the help of U.S. trade data for 163 mining and manufacturing sectors. General results indicate that substitution possibilities between U.S. domestic goods and imported goods were limited; the elasticities ranged from 0.14 to 3.49.

There are two things to note here. First, it may be true that, in partial equilibrium econometrics models such as Alston et al., the omission of substitutes may have significant effects on estimated elasticities. We do not think that, in the general equilibrium case where sectoralization is more aggregated, the Armington assumptions are crucial to the results. Second, even if the assumptions were crucial to the outcome, our results could be

considered as lower bounds of a range of estimates.

3.5 Dynamic Issues

3.5.1 Investment

By investment, we mean net additions to capital stock. It is the difference between the capital stock this period and that of last period net of depreciation.

The most commonly used theory of investment, called the q-theory, for applied work takes its inspiration from the work of Tobin [100]². As defined by Tobin and subsequent studies, q is the ratio of the stock market value of the capital stock of a firm to the replacement cost of the same capital. By replacement cost, we mean the reproduction cost of the firm's capital that is reported in form 10-K, as required by Securities and Exchange Commission. Two things should be kept in mind about replacement costs in general. First, its reporting is limited to firms whose inventories plus gross property, plant, and equipment exceed \$100 million and comprise 10% of assets. Second, because it is reported by the managers of the firm, it necessarily includes subjective estimates³.

The q-theory formulation links the monetary (financial) sector to the

²See Sargent [86] and Summers[97] for a good discussion.

³When the reporting requirement was first mandated by the Securities and Exchange Commission [89], it was hoped that replacement costs would help "professional analysts and investors to determine the costs of inventories and productive capacity of assets as a measure of the current economic investment in these assets at the balance sheet date." The replacement cost model concerns itself with the current cost of substituting the best available asset (capital) which will duplicate the output of the services of an old asset in its present condition. It is supposed to account for the reproduction cost of each asset while paying attention to technological improvements. Presumably, the replacement cost less liabilities is supposed to be an indication of the firm's net worth. But this ignores the income generated from the assets which may well be the true indicator of net worth, as pointed out in Frank et al.[47].

goods producing (real) sector. It says that, if there were no distortions, such as taxes, firms will invest whenever a dollar spent buying capital raises the market value of the firm by more than a dollar.

There are factors that have made q-theory appealing to those interested in modelling investment behavior. It allows output to be variable and determined by the behavioral processes we presuppose for the firm(s). Unlike its neoclassical counterpart (discussed below), it is forward-looking.

1. Empirical Investment Models:

- Tobin's q:

In the old style of q-theory, q was the value of firms divided by the capital stock. This old style of q-theory did not take taxes into account. It only looked at the value of stocks per unit of capital. Accordingly, the significant variable was a crude ratio of the market value of the firm relative to the book value.

More precisely,

$$\frac{I_t}{K_t} = g(q_t);$$

where

I_t : investment in period t

K_t : capital stock in period t

q_t : shadow price of capital.

Besides not fitting the facts of U.S. economy as Summers showed, there are some other problems. For practical work, the usefulness of the q-theory of investment is made difficult by the unobservability of replacement cost of capital. It also does not allow for

explicit analysis of the repercussions of temporary versus permanent changes in tax policy ⁴.

The unobservability of replacement cost of capital is often handled by accepting the numbers reported by firms to the SEC on form 10-K as good approximations of cost of capital. The main improvement to q , therefore, has involved adjusting it for various taxes. To include taxes, it is necessary to redefine how different taxes will affect the basic q , and by consequence investment. The tax adjusted q , often called Q , is currently the most widely used variable in econometric studies ⁵.

⁴See Summers [97] and Schaller [88].

⁵Empirical studies of investment behavior have so far been either stock- or flow-oriented.[1] On one hand, the stock-oriented studies assume an exogenous rental price of capital and then proceed to determine the level of investment that would be chosen at that price. The flow-oriented models, on the other, hand aspire to determine the rate of investment directly. The optimal rate of investment is determined by equating marginal value of newly installed capital and its marginal cost.

The real difference between the approaches though is over the time horizon of interest. Stock-oriented models say something about the long-run pattern of investment while the flow-oriented approaches inform us of the short-run behavior.

Since these methodologies tell us something about the trade-offs which the firm must deal with, we shall go over them briefly. We begin by looking at a firm that produces an output each period. The output sells for an exogenously given price. Given that price, it wants to produce the output that will give it the most amount of net cash flow (that is, total revenue less direct costs). In addition, the firm wants to increase its capital stock. Such a decision entails putting aside part of the output, or equivalently a fraction of revenues, for that purpose. Increasing capital stock is costly. We call such a cost, the shadow price of capital. One way to think about it is by looking at how much your net cash flow increases if you increase your capital stock, say, by a unit. Obviously, this cost will depend on how often you invest and how much output you forgo in each of the periods you invest. In economic theory, the rule suggested for profit-maximizing firms is to set the cost of a unit increase in investment to the shadow price of capital.

In some instances, the price of capital is said to be constant over time. This would be true, mostly if our unit of analysis (a firm, the economy of a state) is smaller relative to a larger reference in which the unit is located (the industry, the world economy). In such a case, the determination of investment is simple. If the economy or the firm starts with an initial level of capital, say, K_0 , and an additional unit of capital adds positively to net cash flow, the firm will add the unit. It shall continue to do so until an additional unit stops adding positively to cash flow. This is the stock-oriented approach. Since it

- Q-theory:

Recall that q is the ratio of the market value of capital to the replacement cost of the same capital. Although in principle it is observable, there is reason to suspect the accuracy of the denominator of the ratio ⁶.

concerns itself less with how long the firms take to get to the point of breaking even (only that they will eventually do so) its time horizon is considered long term.

In other cases, one takes the ratio of the shadow price of capital to that of a unit of forgone output to be constant. One then compares such a price ratio to the cost of adding a unit each period. As long as the costs are less than the price, the firm will adjust its capital stock, even though costs are an increasing function of investment (hence, the name adjustment cost model). It will stop, again, at the point where it breaks even. Notice that the subtle difference between this case and the previous one is that here the firm is compelled to break even each period it undertakes to install the units of capital. For that reason, it is said to be a short-run view of investment.

Another alternative has been to view the economy as producing only two goods: consumption and investment. In the working of this economy, the trade-offs are between consuming more now and investing less or vice versa. If we start from an initial allocation between consumption and investment, we can then determine the direction of investment, for any change in relative prices between these goods.

⁶Some scholars, such as Abel [1], have, therefore, estimated q by using data of something that is observable and, to a good approximation, has a pattern much like q .

The empirical models such as that of Abel, rely on adjustment-cost investment theory. There are two parts to it. If investment is proceeding at a rate of 0, the rate of return to a unit of capital should exactly equal its cost (here, called replacement cost). Suppose, for heuristic purposes, the rate of return and the replacement cost are \$1.00 each. Next, as investment increases, the cost of a new unit of capital increases. The addition above the \$1.00 is called the adjustment cost.

In Abel, the adjustment-cost model postulates a relationship between the output (of the consumption good) of the firm, the investment, good and two inputs (labor and capital). Suppose now that the price of a consumption good is 1 and that of capital is q . Labor costs w . Assuming that the firm maximizes profits allows us to write the investment equation to be solely a function of q . Note that, although we are using Abel's notation, in truth his q should strictly be considered Q because he does adjust for investment tax credit and depreciation allowance.

Since q_t is not observable, Abel uses the discounted marginal product of capital as an approximation. The exact specification used by Abel is

$$q_t = \sum_{s=t}^{\infty} \frac{y_s}{[1 + r + \delta]^{t-s}};$$

where

y_s : is the marginal product of capital

r : is real interest rate

Summers' investment model for the corporate United States was among the first to take various taxes into account. In his model,

$$\frac{I_t}{K_t} = f(Q);$$

For empirical estimation, he assumed the linear functional form,

$$\frac{I_t}{K_t} = \alpha + \frac{1}{\beta}Q;$$

where α and β are parameters from a quadratic adjustment-cost function.

If the markets are assumed to be perfectly competitive, one can derive a formula for Q ⁷. The precise formula will differ depending on what kinds of taxes one takes into consideration. For most of the components of Q , as posited in the Appendix, measurement problems should not arise. For publicly traded firms, only unobservable K presents problems. In Summers formula, K is taken to be the sum of equipment, structures, and inventories all valued at current replacement cost.

In Schaller the definition of Q , as provided in the Appendix, is

δ : is depreciation rate.

In a more recent and theoretical paper, Abel and Eberly [2], suggest circumventing the unobservability of q by restricting one's analysis to competitive firms with linear technologies of production. In this way, q can be shown to be equal to average value of capital which is observable in the stock market or a function of output price, real interest rate, and parameters of the production function.

⁷In the Appendix, we write down the complete formula as well as that found in Schaller [88].

very similar to that of Summers. However, his calculation of the capital stock takes the following structure:

$$K_t = K_{t-1} \left(\frac{P_t^I}{P_{t-1}^I} \right) (1 - \delta) + I_t.$$

Here, K includes equipment and structures but may or may not include inventories, all valued at replacement cost. Apparently, whether or not one includes inventories in the capital stock accounting in Q makes a difference in the results of the investment equation.

In Ciccolo and Fromm [34], the market value of the firm is defined in terms of its profitability. The numerator, or the market value of capital stock, is proposed to be a function of output, output price, wages and cost of capital, depreciation, and the relative change in the price of capital goods. The denominator is calculated from the capital structure of the firm, which is the same as the different financial obligations (equity, debt) that are held by the firm.

Using panel data for several U.K. companies for the period 1975–1986, Blundell et al. [25] found Q to be significant in explaining company investment. Similar results were obtained by Alonso-Borega and Bentolila[3] from a study of 68 Spanish firms for the period 1983–1987. The most complete firm level data appear to be the study by Hayashi and Inoue [57] for a sample of Japanese firms. In their work, the investment equation is a scalar index of

multiple capital inputs (and not the sum of investments). The denominator in the Q-ratio is the capital aggregate, not the sum of nominal capital stocks as is usually done. The data that they used were detailed enough that they were able to break down capital stock into several categories (nonresidential, machinery, etc.) and use different depreciation rates. Capital aggregate used is the Divisia index. The latter is a rule for obtaining the aggregate level of capital stock. The rule says that an increase in aggregate capital between two time periods is the change in aggregate stock induced by a unit increase in a capital good multiplied by the change in the level of the capital good. If we have more than one capital good, we sum the product just stated over all these goods.

- Jorgenson's investment model:

The main competitor to the q- and Q-theories of investment is Jorgenson's model⁸. It is based on specifying an optimal accumulation of capital based on the rate of return. There are two versions to Jorgenson's model. In one instance, capital gains are considered transitory and, therefore, excluded from calculations of the rate of return. In the other, capital gains are included. In either case, desired capital—which is another term for investment—is proportional to the ratio of value of output to the price of capital services. Written formally, this translates into the

⁸The person often credited with this model is Dale Jorgenson. For a review of his investment model as well as variants of Keynesian alternatives, see Jorgenson [59].

following equation:

$$A_t = f\left(\frac{pQ}{c}\right)$$

pQ = Gross Value Added and can be found in National
Income and Product Accounts

c = cost of capital service, and, is the product of
cost of capital, r , and price of investment goods, q

r = the ratio of after-tax corporate profits plus net
monetary interest to the value of outstanding securities.

The value of outstanding securities is share earnings per
price ratio for manufacturing corporations reported by
Standard and Poor.

In a more complete form,

$$c = q \left[\frac{1 - uv}{1 - u} + \frac{1 - uv}{1 - u} r \right];$$

where,

A_t : is gross investment

p : is price of output

Q : is output

c : is price of capital services, which, in turn, is a
function of several variables including

q : is price of investment goods

u : is tax rate, (in the Appendix)

- v : proportion of depreciation deductible from income for tax purposes
- w : proportion of cost of capital deductible from income
- r : is cost of capital.

In the Appendix, the complete econometric model is specified. The only difference between the model in the Appendix and the one shown here is that, in full econometric estimation, Jorgenson-type models include past values of the main determinant of investment—the ratio of the value of output to price of capital services, $\frac{pQ}{c}$.

To summarize, there are three investment models. Tobin's q depends on the ratio of stock-market- to book-value of the firm. Summers' Q adjusts Tobin's q for taxes. Jorgenson's model depends on the ratio of value added to tax-adjusted cost of capital, c .

2. Investment in Open Economies

Sometimes, particularly when one assumes that an economy is both open and small relative to the world economy, modelling of investment has to take the issue of exchange rates very seriously. The argument is rather simple. When countries trade, they prefer to be paid in some currency—mostly their own and, other times, in another country's. Such an exchange has the following structure. A country, call it A , determines how much it wants to invest in another country, call it B . Country A then has to sell its own currency in exchange for country B 's, with which it then buys machinery and all that is necessary to

install a plant in the latter country. Because such flows of investment between countries with different currencies is common, introducing real exchange rates into the model matters. In our California CGE, we shall not worry about that because the rest of the world (that is, the rest of the U.S.) has the same currency.

3.5.2 Labor Mobility

The impact of tax policy on labor-supply decisions has been an area that has been studied extensively. The theoretical results, however, are ambiguous regarding the direction of change⁹. The ambiguity is brought about by two simultaneous processes following an increase or cut in a wage tax. Consider a single worker whose after-tax wage goes up. The increase in wages would render the time spent not working expensive. This is so because every hour not worked now involves more monetary losses. On one hand, we should expect this increase in income (income effect) to induce less hours worked. On the other hand, the increase in wages allows our worker to have the same income for less hours. She could, therefore, maintain her previous level of well-being by allocating more hours to leisure (substitution effect). When put together, these two opposing actions make the theoretical resolution of the problem difficult. The outcome depends on which one of the effects dominate.

Suppose we consider more than a single worker. As well, let the economy be large. Imagine, too, that some workers were not in the labor force before the tax cut. Following the latter, we may find some workers who were not in the labor force joining it. While this is happening, some who were in

⁹See, for instance, Rosen [82] and Snow and Warren [93].

may be cutting on the number of hours they worked. How the total number of hours worked comes out is not then clear. While we are at it, let us introduce the possibility of increased after-tax wages inducing migration. Even if all the migrants enter the labor force, we need to know how many hours the existing labor force has chosen to supply to know the direction of the change. Although the net hours worked appear to be more difficult to determine, whether or not there is positive migration into the economy with less taxes is not obvious either.

From theory alone there are several labor supply responses to an after-tax wage change. First, we may see a reduction in labor supply because substitution effect dominates. Second, labor supply may be positive because income effect dominates¹⁰. Third, no changes may be evident because the two effects offset each other exactly. Fourth, an increase in migration may or may not happen. Though theoretically plausible, a negative or zero labor-supply response to a cut in wage tax seems rather hard to accept. But rather than speculate, we look at the empirical literature for a verdict.

1. Labor Force Participation and Hours Worked:

Most of the recent econometric studies on labor supply draw from the influential work of Jerry Hausman [56]. Using such methods, Triest [103] found the labor-supply response, measured in number of hours worked, of prime age married men in the United States to be invariant to net wage and virtual income. A removal of federal and state tax effects from the estimated model reduced the mean hours worked from 2,208 to 2,150 (a 2.6% reduction). Yet, the same cannot be said about

¹⁰Sandmo [85] has a model of many consumers facing redistributive or progressive taxes that assert the dominance of substitution effect.

married women. The direction and magnitude of their labor supply response depended on further assumptions. As an example, when the data on nonparticipants in the labor force were included, the estimated elasticities became much larger.

Robins [76] looked at four U.S. government experiments on the effects of negative income tax on household labor supply. The after-tax wage elasticities were found to be significantly negative for men and single female household heads¹¹, suggesting that households reduced the hours worked if income taxes increased. Similar results come out of the work of Cogan [35], using the data for the New Jersey-Pennsylvania negative income tax experiment. The estimated elasticities for women, in Robins' study, were found to be positive. The implication here is that women would join the work force, following a reduction of hours by their spouses, so as to maintain the family income. The positive elasticity of labor supply to after-tax wages for married women has also been reported by Eissa [45] and Stelcner and Breslaw [95].

Using Denver Income Maintenance Experiment data, MaCurdy [68] found large substitution and income effect estimates for a consumption and labor-supply model with taxes and uncertainty.

The uncomfortable indeterminacy of tax effects on labor supply response, according to Gwartney and Stroup [55] and Lindbeck [64], is perhaps a peculiar problem of partial equilibrium analysis. They

¹¹See Killingsworth [61] and Macrae and Macrae [67] for a contradictory statement.

contend that a consideration of general equilibrium effects leads to non-ambiguous results, especially if tax receipts can be used by the government to provide public goods that offset the income effect. In such an environment, only substitution effect remains. We should then expect to see positive net wage elasticities.

Unfortunately things are not as straightforward as proponents of general equilibrium think they are. Other studies have shown that, even in simple theoretical models, general equilibrium analysis does not necessarily eliminate income effects as argued by Betson et al. [21], Bohanon et al. [27], Gahvari [49] and Wilde et al. [108].

What Triest found for the United States appears to hold for other industrialized countries as well. In Sweden, Blomquist and Hansson-Brusewitz [24] report an increase in hours worked of 0.4%–1.5% by married men, if marginal income tax rate is decreased by 5%. For France, Bourguignon and Magnac [28] found the net-wage elasticity of 0.1 for married men to be negligible. But the equivalent elasticity for married women was 0.30 and statistically significant. In Italy, too, only labor supply of married women was found to be elastic with respect to wage and income variation. The estimated coefficient of 1.087 was statistically significant. At 0.044 and a standard error of 0.04, Colombino and Boca [36] found married men's labor-supply function to be inelastic with respect to wage and income variation. Finally, net-wage elasticities for married women in Netherlands ranged from 0.65–0.79

while those of married men were in the 0.12–0.10 interval¹².

2. Labor Migration

The first comprehensive review of the literature on internal migration in the United States was done by Michael Greenwood [54] approximately twenty years ago. At the time, Greenwood identified four factors that were said to influence the decision to migrate¹³:

- (a) locational costs, which encompass transportation and psychic costs
- (b) expected future earnings—the idea being that, if an individual were to move from location A to B , he/she does so only if Net Present Value of Earnings at A , (NPV_A) is less than (NPV_B)
- (c) information costs, according to which people are said to migrate to places about which they have more information
- (d) personal characteristics, such as level of education, age, and race.

Notice, however, that these factors cannot be taken to have independent influences on migration. For instance, a determination of NPV by a migrant cannot be done without locational and informational costs. Besides, these costs are almost surely different across individuals on account of their personal characteristics.

¹²These values are considered small by van Soest et al.[105]. However, Blomquist and Hansson-Brusewitz think that even an elasticity of 0.08 is not really small. They argue that, if changes in marginal tax rates can result in changes in net-wage rates in the order of 40%, then an elasticity of 0.08 can have very large effects on hours worked.

¹³Those who are interested in elaborations on these matters are referred to this survey and its very lengthy bibliography.

The studies that have appeared since then seem to be of the opinion that regional wage differentials (actual and expected), comparative unemployment rates and unemployment compensation, public policies and amenity differentials are a few of the critical determinants of interstate migration [63]. In fact, for Stark [94], details at the micro level (such as intra-household interactions, individual attitudes toward risks, relative deprivation,¹⁴ and differential access to information) should be considered paramount.

Treyz et al. [102] model internal U.S. migration as a function of differential net present value of income between regions, amenity levels, moving costs, and expected regional growth rates. They found through a simulation exercise that a 1% exogenous increase in three variables—employment, real wage differentials, and an index of relative industrial wage mix—increases the population of the area by 1.96% in the long run (here, taken to be 20 years), if migration induced by this increase is not allowed to affect these variables¹⁵. Furthermore, they found that the effects of expected employment opportunity have a greater migratory pull than those of relative wage differentials¹⁶. If one considers dynamic feedbacks (i.e., the possibility that induced migration may reduce relative employment opportunities to the levels they were before the 1% increase), then population rises by only 0.835% in the long run.

¹⁴See Taylor [99] on this as well.

¹⁵The effects from relative wage differentials and the index of industrial wage mix are 1.26% and 1.53%, respectively.

¹⁶For a study that stresses the importance of relative wage gains in the context of canadian interprovincial migration, see Robinson and Tomes [77].

Barro and Martin [14, 16] use a neoclassical production function incorporating migration to answer two questions. What are the determinants of migration in the United States, and is it responsible for interregional convergence? The answer to the last question is negative. As for the determinants, they found population density and heating degree-days to have a negative effect while per capita income at a given starting period had a positive impact. More specifically, they argue that a 10% differential in income per capita raises net immigration only by enough to raise the area's population growth by 0.26% per year.

According to Greenwood et al. [53], if wages and prices adjust quickly to demand and supply shocks, then an interregional system is in equilibrium and any observed differences in wages and prices are simply compensating differentials¹⁷. Put differently, regional differences in wages and prices do not necessarily reflect utility differences that can be arbitrated away through induced migration. Instead, they argue that they may reveal more about amenity differentials between regions. The authors do not quite tell us the universe that these amenities cover except to remark that 12 of 13 and 10 of 17 western and southern states, respectively, are amenity rich.

Topel [101] agrees that interregional differences are not entirely capitalized into wages and property values. Two points come out of his study. First, elasticity of interarea supply of workers is larger for

¹⁷See also Evans [46] for a review of equilibrium theories of migration.

permanent demand shifts than for transitory ones. Second, the local market effects on wages; that is, the demand increases that lead to wage increases are smaller among more educated and mobile workers.

Kraybill and Pai [62] admit that some of the increase in aggregate employment under Ohio job tax credit program when there are no retaliatory programs from the rest of the United States are due to in-migration. They do not, however, say what proportion of the 27,106 jobs created are taken by in-migrants. They note too that, when retaliatory policies are enacted by the neighboring states, wage and employment growth are minimal and so the few jobs (1,572–2,012 in total) created are entirely due to sectoral reallocation of workers.

Vaillant [104] looked at how five federal and state taxes affected state employment growth directly. She found the employment effects of state personal income taxes to be large. Quantitatively, a 1% decrease in the fraction of income a worker keeps after taxes leads to almost 1.8% (1.77% to be exact) fall in employment. For the purpose of our review, it is noteworthy that the observed employment change is due entirely to cross-state migration. The response is even higher for men. That is, a 1% decrease in net-of-tax share of wages leads to a 3.63% drop in the working male population of a state.

Weyerbrock's [107] study is a six-region CGE model. The regions—United States, European Community, Eastern Europe, former Soviet Union, European Free Trade Area, and the rest of the world) are linked

by flows of labor and trade. Although this is an explicit CGE model in which the primary focus is labor migration between Eastern and Western Europe, it makes the crucial assumption that migration is exogenous. The modelling strategy is to introduce in an ad hoc way a certain number of immigrants into EC and then observe how factor markets are affected under different wage regimes. Put differently, the thrust of the study is to carry out thought experiments of the following sort. Suppose 3.5 million immigrants enter the EC and the labor market wage in EC is flexible. What then happens to urban-rural wages, rates of return on capital, employment, and income? How would the answers to these questions change if the labor market regime was dominated by fixed wages?

Some of the main results are that, if the wage rate is fixed, some unemployment will take place. There is also a fall in average rural wages, a rise in rates of return to capital, and a decrease in per-capita income of between 2.15%–4.31% depending on whether 3.5 million or 7.0 million immigrants enter the EC. If the labor market is mediated by flexible wages, however, most of the adjustment problems cited above can be substantially reduced. With flexible wage regime and no growth, per capita-income loss amounts to a mere 0.35%. If growth is allowed for, per capita-income in fact increases by 0.85% if 3.5 million move into EC (0.70% with 7 million). In addition, trade volumes and gross domestic product (GDP) go up.

Robinson et al. [78] examined an 11-sector 3-country regional CGE

trade model between United States and Mexico that explicitly accounted for labor migration. The model has as its focus the trade-offs between trade gains, agricultural program costs, and migration flows following an agreement to liberalize trade between the two countries. There are three labor-flow possibilities: rural-urban migration within Mexico, urban unskilled Mexican to urban unskilled U.S. labor market, and rural Mexican to rural U.S. labor migration. Migration itself is modelled as a function of wage differentials across these linked labor markets. The results were derived for different liberalization scenarios.

In one, all agricultural programs in both countries remain protected, but industry trade is liberalized. The model then predicts that Mexican rural to U.S. rural migration increases by 4,000 workers while Mexican urban to U.S. urban goes up by 142,000. But, if all trade is liberalized (i.e. all tariffs and quotas are eliminated), the corresponding migration flows are 21,000 and 406,000, respectively. These flows are even higher, at 31,000 and 685,000, respectively, when all trade is liberalized and support programs to Mexican farmers are eliminated. The figures are reduced though, to 8,000 and -61,000, respectively, if there is partial liberalization accompanied by Mexican capital growth. The latter policy includes imposition of tariffs on agricultural imports into Mexico at half the tariff equivalent of base year quotas, cutting Mexican agricultural subsidies by half, eliminating deficiency program in Mexico and a 10% capital growth in Mexico.

Other factors that are cited as responsible for internal migration in the

United States include attractive local provision of public goods such as higher educational spending, especially if it is not at the same time accompanied by higher local property taxation [31, 33, 39], and costs of living, especially housing costs [32]. Schachter and Althaus [87] estimated an in-migration and out-migration model, using the systems equations method. The variable they chose to explain is gross migration of Whites for the period 1975–1980. The sets of equations included not only climatic amenities, but government services and taxes. The quantitative results of relevance to us are that high taxes deter in-migration. A \$100 increase in average per capita state and local tax collections in a state would lead to an out-migration of about 1% (0.64%–0.9% to be exact). It is not clear whether this effect is for the whole period or annually, though. A surprising finding of this study is that a \$100 increase in government services would give rise to negligible in-migration but a 0.65% increase in out-migration. The same increase in annual public payments to Caucasian households reduces in-migration by about 1%. The explanation given by the authors for these counterintuitive results are speculative. Perhaps, they argue, the potential migrants disapprove of the policies that give rise to such an economic environment.

3.6 Market Clearing

The models' equilibrium and market clearing equations use the same notion as stated in section 2 above. The interpretation of economic equilibrium in a dynamic context, however, uses the notion of expectations. Accordingly, prices in each period depend on expected future prices and tax variables,

both of which are fully anticipated. In the few cases, where prices and tax variables are not perfectly anticipated, revisions of new prices are built in.

3.7 Tax Reforms as Natural Experiments

From the preceding discussion on Q-theory, it is generally believed that investment is sensitive to net returns on capital. Cummins et al. [37] used tax reforms beginning in 1962 to estimate the responsiveness of business fixed investment to the determinants of net returns. The study found the effects of Q to be economically more significant than those obtained in other studies that used traditional techniques. Especially revealing is the finding that, subsequent to every tax reform since 1962, the cross-sectional pattern of investment changed significantly and that this is even more pronounced among firms that faced the greatest tax changes. The finding of Cummins et al. is important because it suggests that, should California change its tax structure, its investment levels may rise significantly, even though we may observe little change in overall U.S. investments.

Auerbach and Hassett [9] also find that taxes have played an independent role in affecting postwar U.S. investment behavior, particularly in machinery and equipment. This is important for policy because recent such as DeLong and Summers [40] studies have shown that equipment investment is important for sustained growth¹⁸.

3.8 Some Empirical Results From Selected Policy Issues

Dynamic tax models have revealed some interesting insights that static models were not able to capture.

¹⁸One should see a skeptical response by Auerbach et al. [10].

3.8.1 Consumption Tax

One of the models reviewed in Pereira and Shoven [72]—Fullerton, Shoven, and Whalley [48]—looked at the impact of replacing the 1973 U.S. tax system with a progressive consumption tax. They found both tax systems to be distortionary. Also, they show that sheltering more savings from the tax system could improve economic efficiency, even if marginal tax rates increase to maintain government revenue.

3.8.2 Investment Tax Credit

In Goulder and Summers [52], the issue of interest is what happens to intersectoral capital formation and economic growth if investment tax credit is eliminated. According to this study, elimination of investment tax credit will cause a reduction in the rate of investment of about 7% in the short run and 12% in the long run. If such a policy is simultaneously complemented by reduced corporate taxes, however, investment will be reduced by 3.5%.

3.8.3 Corporate Tax Integration

Corporate income tax has been criticized for creating differential rates of return to capital in different industries. Specifically, it is argued that allocation of investment in the economy is distorted in favor of lowly incorporated sectors. It also doubly taxes income at both personal and corporate levels. Therefore some have proposed integrating the two tax systems.

Pereira [71], looked at intertemporal and intersectoral efficiency and distributional effects of integrating corporate and personal income taxes. The model is specialized to U.S. economy. It accommodates optimal intertemporal investment decisions and allocation across sectors, intertemporal house-

hold consumption and savings, government deficits, and crowding out.

The results show that eliminating corporate income tax and replacing it by increased income tax rates would yield long-run benefits that are at best 0.17% of the present value of future consumption and leisure. Also, average long run gains are three times larger than average short-run gains.

The study also finds that partial integration yields negative gains. And, in its distributional effects, it is shown that, with integration, highly incorporated sectors undertake more capital formation and low-income households become worse off.

3.8.4 Ohio Job Tax Credit Program

In a recent study, Kraybill and Pai [62] evaluated the effects of a job tax credit program that Ohio began in 1992 in response to a similar program launched in Kentucky in 1989. According to the program, the state government is permitted to decrease the state corporate income tax liability of new or expanding firms by an amount equal to 100% of the personal income tax withheld for every new employee for a period lasting 10 years.

Some of the features of the model include endogenously determined labor supplies and capital stock, inclusion of investment multipliers, and a state and local government balanced-budget requirement. The initial credit was the creation of 32,000 jobs in the goods-producing sector.

The state output growth, investment, and exports differ according to whether or not there is a retaliatory program from neighboring states. When surrounding states do not introduce tax abatement programs similar to Ohio's, the study finds that real output goes up by 1.6% annually, investment increases by 2.6%, and exports expand by 3.6%. If there is full retalia-

tion, however, the growth rates are 0.27% for real output, 0.1% for exports, and a 0.6% for investments. Furthermore, annual wages decline for all skill categories compared to the case when there is no retaliation.

3.8.5 Property Tax Policy Study in Oregon

In 1990, voters in Oregon passed a ballot measure that placed a ceiling on local property tax rates at 1.5% of their market value. And any resulting shortfalls in local education expenditures were to be met with transfers from general state funds at the expense of other programs. [106]

The study is a counterfactual projection of the following sort. Suppose that assessed property values remained at 1990 levels. What then is the impact of measure 5 on state fiscal year 1996?

According to the results, education tax revenues decrease by 74%, while compensating transfers to education from state general funds increase by 90%. At the same time, state non-education tax revenues go up by a mere 1.1%–1.2%.

3.8.6 Capital Gains Tax and Revenue

An important source of tax payers' marginal tax-rate differences is state income taxes. The incentive effects of this difference is important in light of observed growing reliance of states on income taxes. The paper by Bogart and Gentry [26] is a study that looks at the relation between the marginal tax rates on capital gains and revenue realizations in the contiguous states plus Washington, D.C.

In the opinion of Bogart and Gentry, using state-level data improves upon previous studies that used either aggregate time-series or cross-section

data in that aggregating across individuals in a state eliminates endogeneity problems that arise if one used data on a cross section of individuals. Besides, the data span several years in which significant federal tax changes occurred. Additionally, interstate variation in marginal tax rates constitute a large fraction of total variation among tax payers. Finally, the fact that these differences persist over time implies that investor expectations of future tax rates would not be expected to create problems for identifying the way realizations respond to tax rates.

The controversies surrounding capital gains realizations is whether the estimated coefficient is greater or less than 1 in absolute value. If the elasticity is less than -1, decreasing capital-gains tax rate would lead to an increase in revenue from capital-gains taxation. Using a random-year effects model, Bogart and Gentry calculate an elasticity of -0.65, which is greater than -1. This means that cuts in capital-gains tax rates do not lead to sufficient generation of revenue to offset the losses from tax cuts. These estimates are, however, reduced form, and equations estimated without random-year effects give rise to elasticities less than -1. So a word of caution is called for in interpretation. Besides, even if -0.65 is the estimate that is favored by Bogart and Gentry, it is not that far from the typical time-series estimates of -0.5 to -0.9 ¹⁹.

3.9 Economy of Interest: U.S. vs States

A dynamic model for U.S. tax incidence needs to be sensitive to very different factors than a dynamic model for California tax incidence. The major differences between working with a state rather than the nation are the

¹⁹See Auten and Cordes [11].

endogeneity of interest rates, the degree of labor migration, and regional specificity of investment.

From the point of view of California, the interest rate is simply a fixed number that California law cannot change. No matter how much California encourages personal savings, interest rates will not fall. This is simply because California is too small a part of a thoroughly integrated national (and international) capital market. Put another way, if California makes a change in its tax law that encourages savings, the extra savings will flow to national and international capital markets and have no noticeable effect on investment in California. Thus, dynamic modelling of consumers, which makes sense in a model explaining national capital formation, would be a lot of largely wasted effort in a California model.

Modelling the United States is much easier than modelling California from the point of view of labor migration. There is very little migration in or out of the United States compared to the size of the labor force. For example, in the last 50 years, the state grew from 6.9 million to 31.5 million largely through migration. For the period 1850 to 1990, California's decennial growth rate, due mostly to migration, has averaged 55%. Thus, labor migration is a much more important issue for a dynamic state CGE than for a U.S. CGE.

Finally, investment in the United States by industry is much more stable than investment in individual states. For instance, the semi-conductor industry is heavily concentrated near San Jose. The ability of California tax law to both encourage investment in an industry and encourage an investment that was inevitable in that industry to happen in California makes investment more important in a state than in a national dynamic model.

4 Public Inputs and Productivity Growth

Since Lucas [60] and Romer [79] first identified the importance of spillovers from human capital and knowledge from private research activities, respectively, many scholars have begun looking for purposive private- and public-sector choices that hold the potential to create sustained differentials in per-capita GDP and growth rates. The appeal of such a research agenda is more than theoretical. In practical terms, it hopes to identify strategies that societies can undertake in order to reduce the glaring differences in standards of living. Currently, the list of claimed determinants of long-run growth is long. And, while all the listed variables hold exciting research possibilities, in the following pages we make narrower choices.

When discussing dynamic issues, we mentioned that investment is sensitive to rates of return and labor supply responds to after-tax net wages. Differences in quality of education and infrastructure feature significantly in productivity differences across nations or states. The claim is that firms located in regions that have a high network infrastructure would have lower costs and so higher profits, *ceteris paribus*. With regard to education, the fine-grained analysis is that firms would be willing to pay higher wages to those persons whose quality of education is better. If you also believe that economic agents go about their business in order to better themselves, then public inputs can be considered important determinants of interregional flows of capital and labor.

In the remainder of this review, we shall look at the impact that differences in public capital investments have on productivity differences across regions or states. In particular, we focus on two publicly-provided inputs: infrastructure and education. Our aim is to review the estimated magni-

tudes of the effect of these inputs on growth across regions of the United States. There is one good reason why such a study is in order. As Barro and Sala-i-Martin [17, p. 5] recently stated, “if we can learn about government policy options that have even small effects on long-term growth rate, then we can contribute much more to improvements in standards of living than has been provided by the entire history of macroeconomic analysis of countercyclical policy and fine-tuning.”

We shall proceed as follows. First we review the empirical findings of studies that have looked at infrastructure. We then take up the contribution of education to productivity improvements.

4.1 Infrastructure

The idea that infrastructure is important for regional development is not new. In theory, at least, its study has been a favorite of regional scientists²⁰. Some of the more commonly cited reasons regarding the importance of infrastructure are that it reduces transport costs and leads to increased trade volume between any two regions. The benefits are said to be more evident when public capital enters directly into firms’ production functions. In this capacity, it is theorized that such capital reduces firms’ variable costs and make them more profitable. Existing firms respond to reductions in costs by expanding while new ones enter the market. The payoffs to the region that undertakes investments in public capital include increased incomes, employment, and growth. With some lag, it is argued that structural shifts and agglomeration effects, i.e., the emergence of concentration of industry in one (or several locations) enjoying increasing returns, will follow.

²⁰See a recent special issue of the *Annals of Regional Science*, especially the article by Rietveld [75].

To agree that infrastructure matters, however, is not as difficult to demonstrate as how much it does matter. Recently, partly in response to the national debate on the causes of productivity slowdown ²¹, some scholars have chosen the task of isolating factors responsible for the slow down through empirical methods.

4.1.1 Estimated Magnitudes of Infrastructure

In a series of papers, Aschauer [5, 6, 7] included public capital in an aggregate production function and found the influence of public investment on private-sector productivity to be large. In one case, using total federal, state, and local capital stock (i.e., equipment and structures) data for the period 1949–1989, all in 1982 dollars, Aschauer [5] found that a 1% increase in public capital per unit of private capital increased private-sector productivity by 0.35%–0.56%. In fact, for a specific sector such as the trucking industry, the estimated contribution of a 1% increase in stock of highways, led to a 0.8% increase in the output in that industry. At the aggregate level, these coefficients were robust to choice of sample period and disaggregation of public-capital stock into military and non-military. Only when non-military capital stock was decomposed into a “core” (comprising highways, airports, mass transit, water, and sewerage systems) and others was the former found to be decisive—taking up almost 70% of public sector-influence.

Using these estimates, Aschauer [5] then sought to answer a simple ques-

²¹If public capital is as important as recent writings about it claim, then some recent trends in U.S. public capital-formation are worrisome. Two issues are noteworthy. Rates of public-capital formation in 1970s and 1980s have fallen to one-half of those in 1950s and 1960s about the same time that the average growth rate of output has fallen to one-third in the same period. The ratio of public to private capital stock has fallen steadily from 1.10 to 0.78 for the period 1964 to 1986 and does not appear to be going up soon.

tion. What difference could there have been to private investments, returns to private capital, and productivity growth if the level of public nonmilitary investment was increased by 1% for the period 1970–1986. The simulation results showed that these variables would have been 0.6%, 1.7%, and 0.7% higher, respectively, than their actual historical levels for that period. The startling result is that the simulated results remained very close to the average for the period 1953–1969. So, it would appear, from the point of view of Aschauer, that declines in public-sector investment account for nearly all of the decrease in private-sector productivity that has been much talked about in recent years.

These coefficients are derived from an environment where public capital investments are assumed exogenous. Failure to account for the direction of causality may account for such a large coefficient. In a subsequent work, Aschauer [7] did use state-level data and tried to sort out causality issues. In that work, the estimated marginal product of infrastructure (educational services inclusive) turned out to be 2.226. This estimate corresponds to an output elasticity with respect to infrastructure of 0.055 which is substantially higher than the nominal share (0.025) of infrastructure spending in output. When the variable is decomposed into a core infrastructure and education, the estimated values are 1.96 ($se = 0.496$) and 0.136 ($se = 0.422$), respectively. Still despite the claim, causality problems are not adequately resolved and the estimates were arrived at under assumptions that are too stringent.

Munnell's [70] estimate of 0.15 on public capital is noticeably smaller than Aschauer's. She uses state-level data computed from national totals for the period 1969–1988. The aggregate model is Cobb-Douglas. According to this study, a \$1.00 increase in public-capital stock will increase output

by \$0.35, which is exactly the effect a \$1.00 increase in private capital will have. When employment growth is the variable to be explained, the study concludes that a \$1000 increase in public infrastructure is accompanied by 0.2% increase in employment. The insight is that the states that invest more in infrastructure tend to have greater output, more private investment, and more employment growth.

In a study whose approach is similar to that of Aschauer and Munnell²², Garcia-Mila and McGuire [50] found the output elasticity of highway expenditures to be in the order of 0.045. Though statistically significant, this particular estimate suggests that highways do not have a large impact on gross state product (GSP).

When value-added rather than aggregate output is used as the dependent variable, the elasticities associated with public capital are 0.189, 0.200, and 0.259 for manufacturing, all sectors, and non-agricultural value-added respectively ²³.

One other observation that emerges from these studies is that we do not have a clear picture about the relationship between private inputs and public capital. Often the association is a conjectured complementarity without any verification ex post. So that, while Costa, Ellson and Martin report finding no clear relationship between private and public capital, Lynde and

²²Usually these studies specify an aggregate production function, often Cobb-Douglas, and then do a pooled time-series cross-section study of 48 contiguous states in the United States

²³See Costa, Ellson and Martin [38]. In this study, the authors were able to calculate state-specific elasticities of value added in the three sectors mentioned above with respect to public capital. For California, percentage response in value added to a 1% change in public capital as of 1972 stood at 0.021, -0.262, 0.11 for manufacturing, all and non-agricultural sectors, respectively. The cross-sectional elasticities at mean for the same sectors were 0.19, 0.20, and 0.26, respectively.

Richmond [66] find the two to be complements ²⁴

If the motivation for these papers is to determine a reasonably accurate impact that public capital has on economic growth, it is rather surprising that all of them have been formulated outside of the large literature on models of growth ²⁵. The exception is Holtz-Eakin and Schwartz [58] who, using Cobb-Douglas production function and Munnell's data, find the coefficient on public capital to be at most 0.10.

The range of estimates from these studies using very close methodologies and similar data sources is too large to be desirable ²⁶. From one point of view, such variance speaks to the infancy of our measurement skills. Or it may be that aggregate data cannot permit us to bring evidence to bear on questions like growth and development that are based on concepts, such as increasing returns and externalities, which are of aggregate importance. The evidence from studies that have looked at the public capital's contribution to productivity changes at lower units of economic organization—large cities—is not emphatic either.

Consider, for instance, two studies using exactly the same information. Using data for 38 Standard Metropolitan Statistical Areas in the United States, Deno [41] found the output elasticities for highways, sewers, and water to be 0.313, 0.300, and 0.075, respectively. The estimated value for

²⁴Lynde and Richmond used a translog cost function to estimate the contribution of public capital to private productivity. The data are time-series for the contiguous states in United States for the period 1958–1989. In one model they took total federal, state, and local public-capital expenditures as their public input. The estimated elasticity, which they found to be significant, is in the order of 0.336. When the public is disaggregated into federal on one hand and state and local on the other, the estimates were 0.067 and 0.286, respectively. They also found that the former is not statistically significant.

²⁵However, see Barro [12], Barro and Martin [15], and Glomm and Ravikumar [51] for theoretical models incorporating public capital in growth models.

²⁶Recall that Aschauer's [6] estimates imply that returns to public capital are 146% or five times that of private capital, using 1988 capital-stock levels.

the total is 0.688. With the same data, Eberts' [43] estimate for total public capital is only 0.04²⁷. Such a low estimate, 0.046 to be exact, is what comes out of Shah's [90] study too which used data for 26 three-digit Mexican industries for the period 1970–1987.

The dichotomy between these estimates is more than of passing theoretical interest. If they were to be used to draw policy conclusions, they would have dramatically different impacts. From the point of view of Deno, a 10% increase in total stock of public capital will induce a 6%–7% increase in output. If we were to believe Eberts, however, we should expect a meager 0.4% increase in output for an equivalent increase in total public stock²⁸. It seems that the fact that Deno used a translog profit function and, unlike Eberts, allowed output and variable inputs to adjust doesn't still account for why his estimate should be 17 times larger or Eberts' that much smaller. It is more likely, provisionally anyway, that these results are not robust to functional choice. This makes a more careful study built from sound economic theory and more informative data all the more necessary. For now, in keeping with our objective set out in the introduction, we turn to some empirical work on the contribution that education has made to growth.

4.2 Education

The special role that education plays in economic growth and, therefore, the wealth of nations has been recognized much earlier than the present

²⁷In another paper, Eberts [44] asserts an even stronger result: the average annual growth rate in public-capital stock has no contribution to total factor productivity for the period after 1973.

²⁸In a joint work, Duffy-Deno and Eberts [42], employing a simultaneous equations approach found a 10% increase in public investment to lead to at most 1.1% increase in per capita incomes.

attention that infrastructure is getting. The area in economics that has long been concerned with theories and empirics of this issue—human capital theory—has traditionally looked at education as an activity by which individuals acquire specific skills. Interesting questions have for sometime revolved around looking at how individual decisions to acquire knowledge affect their productivity and, therefore, their earnings. But in recent times, in part due to a vigorous pursuit of the role of increasing returns in production more generally, assertions about the centrality of human capital to growth have taken on an all-encompassing tone. Especially in a number of endogenous growth models, human capital has been asserted to be the real “engine of growth.” It is the claim of some of these studies ²⁹ that increases in the initial levels of human capital lower fertility rates and so give us benefits that accelerate growth beyond what is attributable to its capacity to add to physical capital investment.

In Romer [80, 81] human capital enters as a key input into the research sector’s production function. Because the sector is credited with producing new goods that are responsible for technological improvements, it is easy to see why people who work in it are considered important to growth. Lucas [60] as well as Becker, Murphy and Tamura and Tamura [98] stress the importance to growth of knowledge spillovers. The theoretical conjectures in this subfield have grown in elegance. The empirical verifications of them have been fairly successful when the studies have been confined to returns to individual decisions to invest in education. What has proven difficult to quantify are the potentially more important conjectures of recent theories: returns to investment in human capital by any one person exceed that

²⁹See Becker, Murphy and Tamura [18], and Rosenzweig [83, 84]

person's private returns, and these externalities have large repercussions for aggregate growth. Despite the difficulties, there has been empirical attempts and below we review a sample.

4.2.1 Estimated Magnitudes of Education

In a recent significant empirical study, Barro [13] used the percent of school-age children attending secondary school as a proxy for the level of human capital in a country to estimate the contribution of education to variations in per-capita growth rates in a cross-section of countries. The sample range of human capital proxy "explained" a range of variation in per-capita growth rates of about 5%. Mankiw, Romer, and Weil [69] conducted a similar study, using a Solow-type Cobb-Douglas aggregate production function, and found the coefficient on human capital to be one-third. Garcia-Mila and McGuire's [50] study used educational expenditures as a proxy for governmental provision of a public good that is important in production. They found a significant output elasticity of education that is in the order of 0.165.

Because the meaning one attaches to these estimated coefficients is often subtle and passed over in silence, it is important to make clear at the outset what they mean here. In Barro's case, the claim is straightforward. It simply says that the country with the lowest human capital investment grew by 5% lower than the one with the highest, using the 1960 secondary school attendance levels. Equivalently, suppose country *A* had the lowest secondary school attendance level in 1960 and grew at an average annual rate of 2% for the period 1960–1985. And say country *B* had the highest secondary school attendance levels in 1960 and grew at 8% per annum for that same period. Then, from the point of view of Barro's study, the claim is that of the 6%

difference in growth rates, 5% is due to those initial differences in human capital and only 1% is due to other variables. In Mankiw, Romer, and Weil and Garcia-Mila and McGuire the implication is that, if the average percent of secondary school attendance or education expenditures is increased by 1%, the average growth rate in per-capita income will go up by 0.33% or 0.165%, respectively. Lest you consider these effects small, remember that small increments to growth have large cumulative effects.

Quan and Beck [73] looked specifically at the effect of education spending on wages, employment, and per-capita income within the United States. They compared the Northeast and the Sunbelt ³⁰ regions. Their conclusion is surprising, if not wrong. They find that the effect of educational expenditures on the levels of wages and employment are positive and significant for the Northeast but negative and significant in the Sunbelt. In particular, while a 10% increase in K-12 education spending increases wages in the Northeast by 2%, it reduces them in the Sunbelt by 2.8%.

Were one interested in making rough order of magnitude estimates concerning the significance of education and using them for making broad policy guidelines, aggregative models would suffice. With caution, one can even argue that the estimated magnitudes approximate the true social (private plus spillover effects) returns to education. The problem is that there is little to be confident about making a causal linkage between higher growth and higher enrollment rates or higher expenditures on education, which are the two common variables used in aggregate models. If we add to this observation the fact that spillovers from education are difficult to measure, it should come as no surprise that magnitudes that are derived from estimating

³⁰This region includes several states in the south, southeast, and California.

individual returns to education have been more persuasive.

In a recent study using a relatively large sample available from the 1980 Census, Card and Krueger [29] estimated rates of return to education by state of birth and cohort. Because the study is both long and interesting in what it says about returns to education, we have chosen to give it a relatively lengthy discussion.

The first goal of Card and Krueger was to determine rates of return to education to three cohorts of white men born between 1920–1949 in mainland U.S. They found that average rates of return to education at 5.1% per annum are lower for older workers than they are, at 7.4% per year, for younger workers³¹. Furthermore, the rates of return vary across regions of residence by as much as 2% per year of education. In particular, Card and Krueger found that returns are lowest in the Mountain and Pacific regions and highest in the East-South Central and West-South Central regions³².

Because rates of return vary between cohorts and regions, it was natural to try and account for such differences, an exercise undertaken by Card and Krueger, by relating rates of return by cohort and state to the characteristics of public school systems. Three school-quality measures were used: student/teacher ratio, relative teacher salary, and school term length.

As a summary statement, returns to education are significantly related to all three measures of school quality. They found that a decrease in student/teacher ratio by 10 students translated to an increase in estimated rate of return to education of 0.9% to years of schooling above the threshold level.

³¹There are three cohorts grouped into 10-year categories, so the older cohort was aged 50-59 in 1979.

³²As an example, note that, while the rates of return to education for white men born in California, at 5.76% per year, ranked 9th in the nation for the 1920–29 cohort, the returns to 1940–49 cohort, at 6.96% ranked 33rd.

To see this, consider that the threshold level of schooling is 8 years. Imagine, furthermore, that these threshold years are unaffected by school quality. Then the said reduction of student/teacher ratio would raise earnings to college graduates by 3.6%. A 10% increase in teachers' pay is associated with a 0.1% increase in the rate of return to schooling. The significance of these estimated effects due to school-quality variables stands even when differences in family incomes and tastes³³ have been taken into account. They are also confirmed by natural experiments, such as that which happened to African Americans³⁴.

A shortcoming with a focus on return to education is that changes in school quality may affect the variance but not the mean incomes. That is, it is conceivable that those who are more educated earn more but at the expense of those who are less educated. Alternatively, changes in school quality may alter the years spent in schooling thereby affecting the mean (slope) in earnings-schooling relation, without any discernible effect on the variance of earnings.

A sensitivity analysis that explored the effect of school quality on years of schooling and following that, estimating a reduced-form equation that links school quality and levels of education on earnings, yields the following results. A reduction of student/teacher ratio by 10 students predicts raising earnings by 4.2% and raising average education by 0.6 years. In contrast to the conventional return to education coefficient³⁵ of 5.38%, a 0.6 year

³³A choice between private- and public-school attendance is what is used here as the primary variable for taste.

³⁴In a related study, Card and Krueger [30] used data for southern born white and black men working in northern cities in 1960, 1970 or 1980 censuses to test the effect that dramatic improvements in school quality among black schools of the segregated southern states had on closing the earnings differential between black and white men.

³⁵In otherwords, the coefficient of education when it is added to the list of variables in

increase in average education raises earnings by 3.2%. Taken together, these results say that a reduction of student/teacher ratio by 10 students increases earnings by 30% more than would have been expected on the basis of increase in average education alone.

Similar calculations for relative teacher salaries show that a 30% increase in salaries raises average education by 0.18 years and average earnings by 1.34%, which is a 40% gain in earnings than would result from increases in education alone.

There are two central conclusions from this study. First, increases in school quality during the past century are associated with increases in years of schooling and average wages. Second, increases in earnings appear to reflect both a gain for the added years of education and an increase in the return for each existing year of education.

Since this influential study, other studies to validate the general plausibility of these findings have been undertaken using different data sets. Using the National Longitudinal Survey of Youth for the 1979–1989 cohort of white males, Betts [22] found the same school-quality variables as used in Card and Krueger to bear no significance at all to earnings differential. But estimates of returns to schooling, by Ashenfelter and Krueger [8], using a sample of twins show that an additional year of schooling increases wages by 12%–16%. However, this estimate is much higher than that reported by previous studies and, more recently, by Blackburn and Neumark [23]. In this later study, the rate of return to education is 5.3%–5.8% when there is no control for ability but only 4.2% when it is controlled for, suggesting that ordinary least square estimates of returns to schooling are biased upward

the earnings model and school quality variables are excluded.

when ability is omitted.

5 What CGEs Don't and Probably Won't Do

5.1 Account for Tax Avoidance

When a tax law change is made, it is common practice to account for legal avoidance strategies. For instance, suppose that the government were to raise the standard deduction. The static analysis would be to estimate revenue loss as the increase in the deduction times the number of people who take the deduction. The dynamic analysis would account for the additional people who would claim the now higher-standard deduction. No CGE that we know of has incorporated this type of dynamic analysis. However, this sort of dynamic analysis is standardly done in tax revenue estimating models. For instance, it is the way that Department of Finance (DOF) would estimate the revenue effects to California of such a personal income tax change. A CGE would use the output of the personal income tax model as an input.

5.2 Properly Track Idiosyncratic Industries or Taxes

Real tax law has very specific treatment for some large firms. Such firms are routinely given a tax holiday for locating in a way favored by government. The CGE models track taxes at a sectoral level, so it is not possible to say what will happen to an individual firm. The DOF corporate tax model, however, is quite specific as to which firms are affected by a change in the corporate tax. Again, the idiosyncratic effects predicted by a corporate tax model would be aggregated to the sectoral level and then used as an input

for a CGE model.

5.3 Provide Best Possible Description of Effect on an Industry

Analysts working with a CGE must expend their limited time and money to make a model that encompasses income distribution, consumers' purchases of all goods, and producers' sales of all goods. For a tax change that is broad in its effect and large enough to cause migration and investment, this is a reasonable strategy.

However, this strategy comes at the cost of not closely modelling individual industries. For example, a tax on television broadcasting, where lack of frequencies restricts competition, would work completely differently from a tax on a competitive industry such as dry cleaning. These differences in industrial organization are not picked up in a CGE. A CGE model is also not characterized by careful econometric estimation of each industries supply curve. For these reasons, a tax that falls on one narrow industry and does not make much difference for overall state revenue would be best analyzed by an ad-hoc model that considered that one industry in great detail rather than by a CGE that considers all industries but in less detail.

6 Appendix:

6.1 Formula for Q

In this section we give two representative formulas for Q , which, as we have remarked before, are distinguished by the taxes they include. In Summers,

$$Q = \frac{\left[\frac{V-B}{pK} \frac{1-c}{1-\theta} - 1 + b + ITC + z \right]}{1-\tau};$$

where

V : is the value of the firm

B : is the present discounted value of depreciation allowance owned by the firm

p : is the price of one unit of capital stock

K : is the capital stock (equipment, structures plus inventories) valued at replacement cost

c : is the capital gains tax

θ : is the dividends tax

b : is the fraction of investment externally financed at rate of return of capital

ITC : is the investment tax credit

z : is the value of depreciation allowance of \$1.00 of new capital

τ : is the corporate tax rate.

In Schaller,

$$Q = \left[\frac{V + B - A}{(1-\delta)P^I K_1 - (1-\eta - \tau z)} \right] \frac{P^I}{P} \frac{1}{1-\tau};$$

where we have ignored time subscripts and

V : is as defined above

B : is the market value of the firm's debt (this is the book

value of debt which is defined as current liabilities
and long term debt)

A : is the depreciation bond

P^I : is the implicit price deflator for gross private fixed
nonresidential investment

K_1 : is the lagged value of capital stock valued
at replacement cost

η : is the investment tax credit

τz : is the present value of depreciation allowance on a unit
of new capital

δ : is the rate of economic depreciation

P : is the implicit price deflator for output.

6.2 Jorgenson's Investment Model

$$\begin{aligned} A_t = & \beta_0 + \beta_1 \Delta \left(\frac{PQ}{c} \right)_{t-4} + \beta_2 \Delta \left(\frac{PQ}{c} \right)_{t-5} \\ & + \beta_3 \Delta \left(\frac{PQ}{c} \right)_{t-6} + \beta_4 \Delta \left(\frac{PQ}{c} \right)_{t-7} \\ & + \beta_5 (A - \delta K)_{t-1} + \beta_6 (A - \delta K)_{t-2} \\ & + \beta_7 K_t + \epsilon_t; \end{aligned}$$

Notice that all the variables were defined earlier in the text except K_t , which denote capital stock, estimated from investment data using a perpetual inventory method of a declining balance replacement, and ϵ_t , which denote a random error term. Finally, δ , denote depreciation rate or replacement-rate of capital.

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