Preface

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The stagflation of the 1970s greatly undermined the Keynesian Revolution of the 1930s, leading to the New Classical Counterrevolution that has transformed the economics of the business cycle. The unanticipated American growth revival of the 1990s has similar potential for revolutionizing economists' perspectives on economic growth. It is not surprising that the combination of more rapid growth and lower inflation has touched off a strenuous debate about whether the improvements in America's economic performance can be sustained.

This volume presents my econometric studies of economic growth in the information age. The point of departure is my Presidential Address to the American Economic Association, "Information Technology and the U.S. Economy," delivered at New Orleans, Louisiana, on January 6, 2001. In chapter 1 I show that the remarkable behavior of information technology (IT) prices is the key to understanding the growth resurgence of the American economy. This can be traced to developments in semiconductor technology that are widely understood by technologists and economists.

The economics of information technology begins with observation that semiconductors have become cheaper at a truly astonishing rate. Modeling the behavior of semiconductor prices is a severe test for the econometric methods used in the official price statistics. A hedonic model gives the price of semiconductor products as a function of the characteristics that determine performance, such as speed of processing and storage capacity. A constant quality price index isolates the price change by holding these characteristics constant.

Mainframe and personal computers have come to rely heavily on semiconductor storage devices or "memory chips" for main memory. Similarly, computers rely on microprocessors or "logic chips" for central processing. However, semiconductors account for less than half of computer costs and computer prices have fallen much less rapidly than semiconductor prices. In 1985 the Bureau of Economic Analysis (BEA) introduced constant quality price indexes for computers and peripheral equipment into the U.S. National Income and Product Accounts (NIPA). Rosanne Cole et al. (1986) of IBM constructed the computer price indexes employed by BEA.

In 1985 the Program on Technology and Economic Policy that I direct at Harvard University organized a conference to discuss the BEA-IBM constant quality price indexes for computers. Ralph Landau and I edited the conference proceedings, *Technology and Capital Formation* (1989). This volume established the foundation for my research with Kevin Stiroh (1995) on the impact of computers on economic growth. In chapter 2 we show that the concept of the cost of capital, presented in my volume *Capital Theory and Investment Behavior* (1996), is the key to modeling the economic impact of information technology.

Swiftly falling IT prices provide a powerful economic incentive for substituting capital for labor, as well as substituting IT equipment for other forms of capital. The rate of the IT price decline is also a key component of the cost of capital, required for assessing the impacts of rapidly growing stocks of computers. Constant quality price indexes are used as deflators for investments in computers. These investments are cumulated into stocks of computer capital. Finally, constant quality service prices, incorporating the cost of capital, are employed to convert the stocks into flows of computer services.

The production possibility frontier was the principal innovation in "The Embodiment Hypothesis," chapter 2 in my volume, *Postwar U.S. Economic Growth* (1995). The most compelling advantage of this model is the explicit role that it provides for constant quality price indexes. The frontier captures substitution between capital and labor inputs, as well as substitution between investment and consumption outputs. Using this concept, Stiroh and I have generated evidence of massive substitutions of computers for outputs of consumption goods and other investment goods, as well as similar substitutions of services of computers for labor inputs and other capital inputs.

The eleventh comprehensive revisions of the U.S. national accounts, released by BEA in 1999, reclassified the output of software as an investment good. These revisions also incorporated a constant quality price index for prepackaged software developed by Steven Oliner and Daniel Sichel (1994). In chapter 3 Stiroh and I extend the production possibility frontier to include telecommunications equipment and software as well as computers. We employ a hedonic model of the prices of digital telephone switching equipment from the U.S. national accounts.

The rapid progress of econometric research on prices of information technology has left some significant gaps. While hedonic models of prices for computers and peripheral equipment now cover all forms of investment in these IT products, constant quality prices for telecommunications equipment and software cover only part of the investment. In chapter 3 Stiroh and I show that the impact of the resulting biases in IT price indexes is to underestimate the growth of output and overestimate the growth of total factor productivity.

In chapter 1 I include investments by the government sector, as well as investments by business and household sectors, in the measure of IT outputs. My output measure also includes the imputed value of IT services in the household and government sectors. (The value of these services employed in the business sector is included in business income and does not require a separate imputation.) This measure of output is similar to the concept of gross domestic product employed by BEA. However, my measure of IT services incorporates all the components of the cost of IT capital, while the BEA measure includes only depreciation.

A key innovation in the model of production employed in chapter 1 is the allocation of total factor productivity growth between information and non-information technology. I show that the contribution of information technology roughly doubled between 1990--1995 and 1995--1999, but that the contribution of non-information technology increased even more. However, the rise in the growth of total factor productivity accounted for less than a third of the two percent jump in U.S. economic growth after 1995. Almost half the jump was due to a surge in the growth of capital input, while the rising contribution of labor input accounted for the rest.

As a consequence of the advance of information technology, many of the most familiar concepts in growth economics have been superseded. The aggregate production function employed by Robert M. Solow (1957, 1960) heads the list. The production function gives a single output as a function of capital and labor inputs. There is no role for separate prices of investment and consumption goods and, hence, no place for constant quality prices of information technology in measuring the output of investment goods.

Similarly, capital stock is no longer adequate to capture the rising importance of IT. This measure of capital input completely obscures the restructuring that is the wellspring of the American growth resurgence. Accurate modeling of substitution among different types of capital input, especially information technology and other forms of capital, is essential in assessing the impact of investment. Finally, hours worked omits the rapid shifts in the evaluation of skills as a consequence of advances in information technology. This has been superseded by a measure of labor input that reflects substitution among workers with different skills.

The second major theme of this volume is international comparisons of patterns of economic growth in the information age. This is also the primary focus of my volume, *International Comparisons of Economic Growth* (1995). In chapter 5 Eric Yip and I present empirical support for a neo-classical growth model characterized by persistent differences in productivity, capital quality, labor quality, and hours worked per capita among countries. This can be contrasted with the econometric version of Solow's (1956) neo-classical model employed in the seminal paper by Gregory Mankiw, David Romer, and David Weil (1991) where these critical differences among countries are suppressed.

Yip and I assemble the empirical evidence for our neo-classical growth model by constructing consistent data on the sources of economic growth for the G7 countries, covering the period 1960--1995. Our methodology is based on the same innovations as those employed in modeling the U.S. economy in chapter 1. The cost of capital plays a central role in capturing the impact of investment in tangible assets. We employ a production possibility frontier for each country in order to incorporate the available data on investment in information technology.

Yip and I find that the United States has retained its lead in output per capita among the G7 countries throughout the period 1960-1995. The United States has also maintained its lead in input per capita, while relinquishing the lead in productivity to France. Investments in tangible assets and human capital account for the overwhelming proportion of economic growth in the G7 countries and also explain the predominant share of international differences in output per capita.

The third major theme of this book is the econometric modeling of economic growth in the information age. An econometric model of the production possibility frontier was the central contribution of "Transcendental

Logarithmic Production Frontiers," chapter 4 in the companion volume, *Econometric Modeling of Producer Behavior* (2000). This econometric model represents the technology of the U.S. economy in my book with Kun-Young Yun, *Lifting the Burden: Tax Reform, the Cost of Capital, and U.S. Economic Growth* (2001). We estimate the parameters of this model from a data set that includes the BEA-IBM constant quality price for computers.

In "Inflation-Proof Depreciation of Assets," chapter 8 in the companion volume, *Tax Policy and the Cost of Capital* (1996), Alan Auerbach and I augment the cost of capital framework by introducing the marginal effective tax rate. The cost of capital summarizes information about the future consequences of investment in tangible assets essential for current decisions. The marginal effective tax rate characterizes the consequence of investment decisions that is particularly suitable for comparisons among alternative tax policies. Efficient capital allocation requires the equalization of marginal effective tax rates on all assets.

Yun and I summarize the tax burden on capital income by means of marginal effective tax rates for all assets and all sectors of the U.S. economy. We show that the Tax Reform Act of 1986 significantly reduced differences in the tax burdens among corporate, non-corporate, and household sectors. Differences between short-lived and long-lived depreciable assets were almost eliminated by this legislation. However, substantial differences in marginal effective tax rates between household and corporate sectors still remain. These gaps reveal important opportunities for gains in efficiency through reallocation of capital by means of tax reform.

In chapter 6 I employ marginal effective tax rates to compare the effects of reforms of capital income taxation in the G7 countries, Australia, and Sweden during the 1980s and 1990s. In most countries these reforms reversed decades of erosion of the income tax base to provide incentives for saving and investment. Efforts were made to equalize tax rates on assets within the business sector. However, equalization of tax burdens on housing and business capital has proved to be extraordinarily difficult within the framework of the income tax. Although reforms have substantially reduced barriers to efficient allocation of capital, important opportunities for further gains in efficiency remain in all nine countries.

Yun and I focus on the determinants of investment in tangible assets, including investments in information technology. Our econometric model combines the production possibility frontier with an econometric representation of preferences. This representation was first presented in "Transcendental Logarithmic Utility Functions," chapter 1 of the companion volume, *Aggregate Consumer Behavior* (1997). Yun and I employ our econometric model of economic growth to simulate the impact of alternative tax reforms. We compare the level of social welfare for each tax reform with welfare in the absence of reform, translating these welfare comparisons into monetary terms.

In chapter 8 Mun S. Ho and I extend the econometric modeling of economic growth in the information age by incorporating a model of investment in human capital. We treat this investment as the output of the educational sector. Inputs of the sector include purchases of intermediate goods such as school supplies and energy by educational institutions, the services of tangible assets like buildings and equipment employed in these institutions, the services of human capital from teachers, and, most important of all, the services of human capital from students.

A detailed set of growth accounts for the educational sector is contained in my paper with Barbara Fraumeni, "The Output of the Educational Sector," chapter 7 of the companion volume, *Postwar U.S. Economic Growth* (1995). Our point of departure is that education is a service industry, but its output is investment in human capital. This is measured as increments to the lifetime incomes of all students enrolled in the educational system. The value of investment in education, measured in way, is roughly equal to the value of the working time of the entire U.S. labor force.

Ho and I have evaluated alternative educational policies by transforming changes in welfare associated with policy changes into changes in wealth. We consider policies that would increase educational "quality" by increasing expenditures and taxes that finance them, while holding educational participation rates constant. We also consider policies that would hold expenditures and taxes constant, while increasing participation rates. We conclude that enhancing educational quality would reduce social welfare, while increasing participation rates would increase welfare.

In chapter 7 I describe the barriers to extending econometric models of economic growth to encompass intellectual capital. The standard model for investment in intellectual capital, formulated by Zvi Griliches (1973), treats this investment as an output of research and development. The services of intellectual capital are a factor of production, like the services of tangible assets and human capital in my model with Ho. While the output of the educational sector can be defined in terms of increments to lifetime incomes of students, there is no comparable measure for the output of research and development. Pricing this output remains as a major barrier to incorporating intellectual capital into econometric models of economic growth.

The fourth major theme of this book is the econometric approach for measuring social welfare in the information age, also the focus of the companion volume, *Measuring Social Welfare* (1997). The essential idea is to recover measures of individual welfare from an econometric model of aggregate consumer behavior. These are combined into an indicator of welfare that reflects horizontal and vertical equity, as well as economic efficiency. The econometric approach is summarized in chapter 1 of the volume, "Aggregate Consumer Behavior and the Measurement of Social Welfare," my Presidential Address to the Econometric Society. Daniel Slesnick provides a much more detailed account in his book, *Consumption and Social Welfare* (2001).

Multi-million dollar budgets are involved in statistical reporting of measures of the cost of living, while millions more are spent on measures of poverty, inequality, and the standard of living. Unfortunately, these well-established programs give highly misleading results and require a complete overhaul. The key to revision of these programs is the effective exploitation of existing surveys of household consumption. In chapter 9, "Did We Lose the War on Poverty?" I give a detailed example of econometric measures of the incidence of poverty based on consumption. I show that the War on Poverty was a success, while official estimates based on income rather than consumption purport to show the reverse.

In chapter 10, Slesnick and I present a new measure of the cost of living based on the econometric approach to measuring social welfare. This incorporates all the information employed in the Consumer Price Index (CPI), but preserves important features of the data ignored in constructing these price index numbers. For example, the econometric approach captures changes in household spending patterns in response to changes in prices and total expenditure. In addition, it includes the effects of changes in the demographic structure of the population on aggregate spending patterns.

Slesnick and I show that inflation rates over the period 1947--1995 are virtually identical for the econometric measure of the cost of living and the CPI. Over the first half of the period the econometric approach generates slightly higher inflation rates, while the reverse is true for the second half. We find that group cost of living indexes are similar for white and nonwhite households, for female-headed and male-headed households, and for non-elderly households. The elderly have experienced slightly higher inflation rates since 1973. We recommend indexing government programs, such as Social Security, by group cost of living indexes rather than the CPI.

The fifth theme of this volume is econometric general equilibrium modeling in the information age. This is also the subject of the companion volume, *Energy, the Environment, and Economic Growth* (1998). In chapter 11 Peter J. Wilcoxen and I present an intertemporal general equilibrium model for analyzing the impact of tax policies in the United States. This preserves the key features of more highly aggregated models, like the one presented in chapter 8. However, Wilcoxen and I have disaggregated the representations of technology and preferences in order to provide a more detailed perspective on the impact of changes in tax policy.

One important dimension for disaggregation is to introduce a distinction between commodities and industries in order to model business responses to tax-induced price changes. We also distinguish among households by level of wealth and demographic characteristics, so that we can model the responses of households to tax policies as well. Finally, we model demands for different types of capital services in each of thirty-five industrial sectors, as well as the household sector. These demands depend on tax policies through measures of the cost of capital that incorporate the characteristic features of U.S. tax law described in my book with Yun.

We consider the economic impact of substituting a tax on consumption for the existing system of income taxes in the United States. We first consider the Armey-Shelby Flat Tax. This proposal levies taxes on the difference between business receipts and the sum of business purchases from other firms and payrolls. Labor income is taxed at the individual level. An important feature of this proposal is a system of personal exemptions that have the effect of setting the marginal rates of taxation equal to zero up to the exempt amount of income. The purpose of the exemptions is to introduce progressivity into the rate structure, since average tax rates rise gradually from zero to the flat tax rate as household income increases.

The second tax reform proposal we consider is the National Retail Sales Tax. The tax base is the same as in our simulations of the Flat Tax. However, the method of collection is different. The Flat Tax preserves the existing structures of the corporate and individual income taxes, but alters the tax base. The National Retail Sales Tax eliminates corporate and individual income taxes and relies on retail establishments to collect the taxes. This definition of retail establishments would include real estate developers and providers of professional services, such as legal and medical services. Most important, no personal exemptions would be provided.

The National Retail Sales tax would generate a substantial acceleration in economic growth, initially through a sharp rise in the labor supply, since capital stock is fixed in the short run. In the longer run a higher level of economic activity would be generated by added capital formation. By contrast the Flat Tax would generate a very modest rise in the level of economic activity through increases in the labor supply. Capital formation would fall initially and would remain depressed, relative to levels that would prevail in the absence of tax reform.

In chapter 12 Richard Garbaccio, Ho and I present an intertemporal general equilibrium model of the Chinese economy. The main features of the model are the same as those of the U.S. model given in Chapter 11. We account for the effects of population growth, capital accumulation, changes in technology, and changing patterns of demand in China. Our model of the Chinese economy reflects the fact that plan and market institutions continue to co-exist. Although the scope of central planning has been drastically reduced for most commodities, it still affects the allocation of energy. In addition, capital markets are largely under government control, either directly through the state budget or indirectly through the state-owned banking system.

Although there is a wide range of forecasts of future emissions of carbon dioxide in China, they are unanimous in projecting that China will become the largest emitter within a few decades. In chapter 11 we show how carbon taxes could be used to control emissions. The extra revenue raised by a carbon tax is offset by reductions in all other taxes. The effect of a carbon tax would be to reduce household income and raise the retained earnings of enterprises. Spending would shift from consumption to investment and higher investment would lead to increases in future output. There would a "double dividend" from imposing a carbon tax, namely, reductions in carbon emissions combined with future increases in output and consumption.

An important issue is whether the co-existence of plan and market institutions reduces the responsiveness of energy demand to price changes. The price responsiveness of energy demand in the United States is analyzed in the companion volume, *Econometric General Equilibrium Modeling* (1998). Between 1978 and 1995 the energy-output ratio in China decreased by 55 percent as the Chinese economy expanded at double-digit rates. Using input-output tables for China for 1987 and 1992, Garbaccio, Ho, and I show in chapter 4 that this can be explained by declines in energy-output ratios within individual Chinese industries. Energy-intensive industries in China actually increased in relative importance from 1987 to 1992, raising the Chinese energy-output ratio. Increasing imports of energy-intensive products made a modest contribution to the decline in the energy-output ratio. We conclude that demands for energy are very responsive to the price changes that have accompanied the transition to a market economy in China. Accordingly, market-based approaches to environmental policy, such as a carbon tax, are not only feasible but also likely to be highly effective.

I conclude that the steadily rising importance of information technology has created new research opportunities in all areas of economics. Economic historians, led by Alfred Chandler (2000) and Paul David (2000), have made substantial progress in placing the Information Age in historical context. Chandler traces the development of information technology in America over the past two centuries, establishing persistent features of the advance of this technology. David emphasizes similarities and differences between the diffusion of information technology and the diffusion of innovations such as electricity generation.

Several models of the semiconductor industry exist, but none successfully account for the shift from a three-year product cycle to a two-year cycle that took place in 1995. In chapter 1 I show that this is the driving force behind the resurgence of American economic growth in the last half of the 1990s. A two-year cycle would continue to propel semiconductor prices on an accelerated downward course and produce rapid productivity growth in the IT-producing industries. Reversion to a three-year cycle would reduce this productivity growth to the more moderate pace that prevailed before 1995.

Capital and labor markets have been severely impacted by the advance of information technology. Enormous uncertainties surround the relationship between equity valuations and the future growth prospects of the American economy. One theory attributes rising valuations of equities after 1995 to the accumulation of intangible assets, such as intellectual property and organizational capital. A competing theory treats these high valuations as a bubble that burst in the year 2000. The behavior of labor markets impacted by the spread of information technology also poses important puzzles. Widening wage differentials by skill have been attributed to computerization of the workplace. In this view high-skilled workers are complementary to IT, while low-skilled workers are substitutable. An alternative explanation is that advances in information technology are skill-biased, raising the wages of skilled workers relative to the wages of the unskilled.

Finally, the semiconductor and information technology industries are global in their scope with an elaborate international division of labor. Where is the evidence of accelerated growth in other leading industrialized countries? An important limitation on the availability of this evidence is the lack of satisfactory price indexes for semiconductors and information technology products outside the U.S. Several of the most important participants in the information technology industry are the newly industrialized countries of Asia---Korea, Malaysia, Singapore, and Taiwan. What does this portend for growth in developing countries like India and China?

As policy-makers attempt to fill the widening gaps between the available economic data and the information required for sound policy, the traditional division of labor between statistical agencies and policy-making bodies is breaking down. In the meantime monetary policy-makers must set policies without accurate measures of price change. Similarly, fiscal policy makers must confront rising levels of uncertainty about future prospects for economic growth that drastically affect the outlook for future tax revenues and government spending. It is increasingly urgent to resolve the uncertainties about future economic growth arising from advances in information technology. The practical need for better understanding of the impact of this technology is already generating a rising tide of research. This is sweeping away many older perspectives on economic growth, including some that were "new" only a decade ago. Economists are the fortunate beneficiaries of a fresh agenda for research that will revitalize economic thinking and enrich economics as a discipline.

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