Dale Jorgenson

Cost of capital. The unanticipated growth resurgence of the U.S. and the world economies in the 1990's and the new century has transformed the economics of growth. In his Presidential Address to the American Economic Association in 2001 Jorgenson demonstrated that the cost of capital, a concept he originated, is the key to understanding the growth resurgence. The rapid decline in prices of information technology (IT) equipment and software is the main indicator of the rate of technical progress in IT-producing industries. The IT price decline is the critical component of the cost of capital in assessing the powerful impact of the resulting IT investment on economic growth. Massive substitutions of IT inputs for inputs of labor and other types of capital are explained by the remarkable decline in IT prices.

In 1963 Jorgenson introduced all the important features of the cost of capital employed in the subsequent literature. His principal innovations were the derivation of investment demand from a model of capital as a factor of production, the incorporation of the tax treatment of income from capital into the price of capital input, and econometric modeling of gestation lags in the investment process. In 1971 Jorgenson surveyed empirical research on investment in the *Journal of Economic Literature* .[1] In the same year he was awarded the John Bates Clark Medal of the American Economic Association for his research on investment behavior.

Predominant role of investment. In 1966 Jorgenson took a crucial step beyond the aggregate production function employed by Robert Solow (1957) in accounting for economic growth. He represented technology by means of a production possibility frontier, allowing for joint production of consumption and investment goods from capital and labor services. This provided the key channel for incorporating constant-quality prices of IT equipment and software into growth accounts for the U.S. created by Jorgenson and Kevin Stiroh in 2000. Jorgenson and Stiroh also constructed constant-quality indexes of capital and labor inputs by weighting the components of each input by their marginal products. The marginal products for capital input incorporate Jorgenson's cost of capital. The cost of capital includes asset-specific rates of decline of the price of investment goods, which are essential in accounting for the impact of investments in IT equipment and software.

In 1987 Jorgenson, Frank Gollop, and Barbara Fraumeni allocated the sources of U.S. economic growth to the level of individual industries. Industry outputs are functions of capital, labor, and intermediate inputs, each defined as a constant-quality index of the corresponding inputs. The innovations of Jorgenson, Gollop, and Fraumeni drastically increased the relative importance of investments in human and non-human capital as sources of economic growth. Their approach to growth accounting was adopted as the international standard in *Measuring Productivity* , the OECD manual by Paul Schreyer published in 2001. This incorporated the work of an expert advisory group chaired by Edwin Dean, former Associate Commissioner for Productivity at the U.S. Bureau of Labor Statistics. [2]

Growth resurgence. In 2005 Jorgenson traced the American growth resurgence to its sources in individual industries in his book, *Information Technology and the American Growth Resurgence* , co-authored with Mun S. Ho and Stiroh. This book employed the framework originated by Jorgenson, Gollop, and Fraumeni, but augmented this framework by adding detailed information about investments in information technology equipment and software. Jorgenson and his co-authors demonstrated that input growth, due to investments in human and non-human capital, was the source of more than 80 percent of U.S. economic growth over the past half century, while growth in total factor productivity accounted for only 20 percent. Jorgenson and Khuong Vu established similar results for the world economy. [3]

Jorgenson, Ho, and Stiroh (2005) demonstrated that the boom of 1995-2000 was accompanied by acceleration in labor productivity growth. Although the IT investment boom faded considerably after the dot-com crash of 2000, labor productivity growth accelerated further during the slowdown of 2000-2005. Jorgenson, Ho, Jon Samuels, and Stiroh (2007) have traced this to a sharp rise in productivity growth in IT-intensive industries, principally in services. The locus of innovation in the U.S. economy has shifted dramatically from IT-producing industries in manufacturing to IT-using industries in trade and services. This remarkable transition was made evident by successful incorporation of IT investment into the framework originated by Jorgenson, Gollop, and Fraumeni (1987).

New architecture for the national accounts. Jorgenson and Steven Landefeld, Director of the U.S. Bureau of Economic Analysis, have proposed a new system of national accounts that incorporates the cost of capital for all assets, including information technology equipment and software. The new system is presented in their book with William Nordhaus, published in 2006. The production account is based on Jorgenson's Presidential Address to the American Economic Association of 2001. The new system also incorporates income and expenditure, capital formation, and wealth accounts, similar to those in the United Nations *System of National Accounts.* In March 2007 Jorgenson's cost of capital was recommended by the United Nations Statistical Commission for incorporation into the revision of the U.N. system. [4]

The industry-level production account of Jorgenson, Gollop, and Fraumeni has been adopted in the ongoing EU KLEMS project. This project was initiated in 2004 by economists at the University of Groningen in The Netherlands, led by Bart van Ark, with support from the European Commission's Research Directorate-General. On March 15, 2007 , the project released databases for 25 EU members assembled by 18 EU-based research teams. These databases extend as far back as 1970 and provide industry-level productivity data for as many as 72 industry groups. In addition, constant-quality indexes of capital inputs for each industry distinguish between IT- and Non-IT-capital inputs. The prices of both IT- and Non-IT-capital inputs incorporate Jorgenson's cost of capital.

Capital income taxation. Jorgenson originated the cost-of-capital approach to the taxation of income from capital in 1963. Jorgenson's cost of capital summarizes future

information essential for current decisions about investment. In 1980 Jorgenson and Alan Auerbach introduced the marginal effective tax rate. The marginal effective tax rate characterizes the tax consequences of investment decisions in a way that is particularly suitable for comparisons among alternative tax policies. The special strength of the cost-of-capital approach is its ability to absorb almost unlimited detail on specific tax policies. This approach has been widely applied in international comparisons of capital income tax policies by organizations such as the EU, the OECD, and the World Bank.

Jorgenson's cost-of-capital approach has had important practical consequences. This approach provides a precise instrument for achieving horizontal equity in capital income taxation. The appeal of this principle is threefold. First, it achieves fairness in the sense of equitable treatment of different taxpayers. Second, under the rubric of “tax neutrality” it eliminates possibilities for increasing efficiency by redistributing the tax burden. Third, it leads to simplicity by expunging from the tax statutes the detailed specifications of transactions subject to special provisions. [5]

Econometric modeling. In collaboration with Christensen and Lau, Jorgenson constructed econometric models of production for the U.S. economy based on the transcendental logarithmic (translog) price possibility frontier in 1973. Jorgenson and Lau linked the theory of producer behavior employed in these models to technological opportunities faced by the producers in 1974, using price-quantity duality. In 1973 Jorgenson and Jean-Jacques Laffont introduced the method of nonlinear three-stage least squares employed in estimating the unknown parameters. The innovations embodied in these econometric models – price-quantity duality in production, statistical methods for estimation and inference in systems of nonlinear simultaneous equations, and flexible functional forms – have set the standard for econometric modeling of producer behavior ever since. In 1986 Jorgenson surveyed more than three hundred publications stemming from this approach in the *Handbook of Econometrics* . [6]

In 1975 Christensen, Jorgenson, and Lau introduced a parallel model of consumer behavior, based on the translog indirect utility function. This model combines flexibility in the representation of preferences with parsimony in the number of parameters. Jorgenson's cost of capital plays a critical role in modeling consumer demand for housing and consumer's durables. Demands for these commodities are represented as flows of capital services and the prices faced by consumers are prices of capital services that incorporate the cost of capital. Investments in housing and consumers' durables are derived from the accumulation equations for these types of capital.

General equilibrium modeling. In 1986 Jorgenson imbedded his model of investment demand into a general equilibrium model of U.S. economic growth in collaboration with Kun-Young Yun. The Jorgenson-Yun model incorporates a rental price of capital services based on Jorgenson's cost of capital for each class of assets distinguished in the U.S. tax system. Jorgenson and Yun incorporate a model of producer behavior based on the translog price possibility frontier introduced by Christensen, Jorgenson, and Lau. They include a model of consumer behavior based on the translog indirect utility function of Christensen, Jorgenson, and Lau. Jorgenson

and Yun employ the resulting model of economic growth to evaluate the impact of alternative tax reforms. [7]

Jorgenson constructed highly detailed models of U.S. economic growth in collaboration with Peter Wilcoxen in 1990 and Ho in 1994. These models are based on the industry-level growth accounts of Jorgenson, Gollop, and Fraumeni. The accounts include a price of capital services for each industry and each class of assets that incorporates Jorgenson's cost of capital. The models of Jorgenson, Ho, and Wilcoxen incorporate econometric representations of technology for individual industries constructed by Jorgenson and Fraumeni in 1983 and an econometric representation of preferences for individual households constructed by Jorgenson, Lau, and Thomas Stoker in 1982. Both industry and household models incorporate prices of capital services that include the cost of capital. [8]

Welfare measurement. The econometric model of Jorgenson, Lau, and Stoker successfully integrated the two principal streams of empirical research on consumer behavior by pooling aggregate time series data with individual cross section data for households. This model permits an exact decomposition of aggregate demand functions into individual demand functions distinguished by demographic and other characteristics of households. The aggregate model captures price and income effects as well as demographic determinants of consumer behavior. In 1983 Jorgenson and Daniel Slesnick introduced an approach to normative economics that exploits the econometric model of Jorgenson, Lau, and Stoker. Measures of welfare for each household are recovered from systems of individual demand functions. These are combined into a single indicator of social welfare reflecting concepts of horizontal and vertical equity.

In 1990 Jorgenson presented econometric methods for welfare measurement in his Presidential Address to the Econometric Society. These methods have generated a new approach to cost of living measurement and new measures of the standard of living, inequality, and poverty. This has required dispensing with ordinal measures of individual welfare that are not comparable among individuals, as persuasively argued by Amartya Sen in 1977. Jorgenson and Slesnick have met this requirement by constructing cardinal measures of individual welfare that are fully comparable among individuals. In 1989 Arthur Lewbel showed how to use the household equivalence scales proposed by Jorgenson and Slesnick for this purpose. [9]

Evaluation of alternative policies. In 1993 Jorgenson and Wilcoxen surveyed the evaluation of energy, environmental, trade, and tax policies based on the econometric general equilibrium models Jorgenson developed with Ho and Wilcoxen. The concept of an intertemporal price system provides the unifying framework. This system balances current demands and supplies for products and factors of production. Asset prices are linked to the present values of future capital services through rational expectations equilibrium. The long-run dynamics of economic growth are captured through linkages among capital services, capital stocks, and past investments. Alternative policies are compared in terms of the impact of changes in policy on individual and social welfare.

Jorgenson's approach to policy evaluation has transformed the economics of - environmental policy by linking environmental regulations to the cost of capital. These regulations can raise the price of new capital goods, slow the rate of capital formation, and reduce the rate of economic growth. By contrast market-based environmental policies, such as emission taxes and tradable permits, may raise sufficient revenue to reduce capital income taxes and reduce the cost of capital, thereby stimulating growth. The evaluation of environmental policy requires modeling regulations and market-based policies at a detailed level, tracing their effects throughout the economy using a general equilibrium model, and determining the impact on saving and investment. This approach was incorporated into the official guidelines for preparing economic analyses by the U.S. Environmental Protection Agency in 2000. [10]

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[1]Prior to Jorgenson's work, modeling of investment behavior had been based on various ad hoc principles, such as the capacity principle, the profits principle, and the like. His research initiated the cumulative progress in modeling investment that has continued to the present. In 2000 Fumio Hayashi demonstrated the essential role of Jorgenson's cost of capital in all later models of investment. Hayashi also showed that the cost of capital is the sole channel through which tax parameters exert incentive effects, accounting for the importance of this concept in capital income taxation. In 2000 Lawrence Lau summarized Jorgenson's research on the cost of capital in modeling investment behavior, producer behavior and productivity measurement, consumer behavior and welfare measurement, and inter-temporal general equilibrium modeling.

[2]In 2005 Jorgenson surveyed the literature on growth accounting in the information age. As a consequence of the new international standard established by the OECD, many of the most familiar concepts in growth economics have been superseded. The aggregate production function has been displaced by the production possibility frontier. Accurate modeling of substitution among different types of capital services is essential for capturing the massive substitution of IT equipment and software for other forms of capital. The capital stock measure used in conventional growth accounting obscures the wholesale restructuring of capital input that is the wellspring of the growth resurgence. Similarly, hours worked has been superseded by a measure of labor input that captures substitution among workers in response to shifts in the demands for different skills as a consequence of advances in IT.

[3]Jorgenson, Ho and Stiroh showed that the contribution of capital input was the most important source of the U.S. growth resurgence that began in 1995, total factor productivity next, and the contribution of labor input almost negligible. The acceleration of capital input growth was due primarily to the flood of IT investment after 1995. Virtually all industries responded to the accelerated IT price decline after 1995 by substituting IT for Non-IT-capital and labor inputs. Nearly half of U.S. industries actually showed a decline in contribution of Non-IT-capital input. Four IT-producing industries contributed more to the growth of total factor productivity than all other industries combined over the period 1977-2000.

[4] Jorgenson's contributions to national accounting were surveyed by Fraumeni in 2000. These contributions include the system of national accounts for the private sector of the U.S. economy proposed by Jorgenson and Laurits Christensen in 1973. In 1989 Jorgenson and Fraumeni extended the system to investment, stocks, and services of human capital and the associated market and non-market activities. Fraumeni points out that the main weakness of the current system of national accounts is that stocks of reproducible, tangible assets are not linked to the services that they produce. This deficiency is overcome by the new architecture for the U.S. national accounts proposed by Jorgenson and Landefeld.

[5]The principle of horizontal equity for capital income taxation was embodied in the Tax Reform Act of 1986 in the United States . This legislation reversed decades of piecemeal creation of specific incentives for special classes of taxpayers. The cost of capital and the marginal effective tax rate were employed in the design of similar reforms around the world in the 1980's and 1990's, broadening the base for capital income taxes and reducing tax rates. In 1993 Jorgenson analyzed these reforms for nine countries – the G7 plus Australia and Sweden . These reforms have contributed greatly to more efficient allocation of capital within market economies. Horizontal equity in capital income taxation has received a powerful new impetus from the adoption of “flat” income taxes in economies undergoing a transition from socialism to capitalism during the 1990's and continuing into the present century.

[6]In the price possibility frontier presented by Christensen, Jorgenson, and Lau the economy supplies outputs of investment and consumption goods and demands inputs of capital and labor services. The supplies and demands are functions of the prices of the outputs and inputs. Myopic decision rules for this model of production are derived by identifying the price of capital input with Jorgenson's cost of capital. An increase in the output of investment goods requires foregoing a part of the output of consumption goods, so that adjusting the rate of investment is costly. However, the costs of adjustment are fully reflected in the market price of investment goods, which incorporates forward-looking expectations of the prices of future capital services.

[7]In the Jorgenson-Yun model producers and consumers optimize, subject to an intertemporal price system. Asset prices are based on rational expectations of the future prices of capital services. Macroeconometric models used to analyze the short-run impact of tax policies and applied general equilibrium models employed to analyze the long-run impact are subject to the critique by Robert Lucas (1976). According to the Lucas critique, these models fail to account for the effect of changes in tax policies on expectations of future prices. Jorgenson and Yun have overcome the Lucas critique by associating each tax policy with rational expectations equilibrium. They compare the level of social welfare resulting from each tax reform with welfare in the absence of reform. Jorgenson's contributions to modeling the impact of tax policy were surveyed by Yun in 2000.

[8] The models of Jorgenson, Ho, and Wilcoxen incorporate econometric representations of technology and preferences as basic building blocks. Earlier approaches to general

equilibrium modeling, going back to Wassily Leontief in 1941, had “calibrated” the behavioral responses of producers and consumers to a single data point. While the calibration approach economizes radically on the use of empirical data, this requires highly restrictive assumptions, such as fixed input-output coefficients. This assumption is contradicted by the massive evidence of energy conservation in response to changes in world energy prices, beginning in 1973. More recently, it is contradicted by the evidence of widespread substitutions of IT equipment and software for labor input and other types of capital input in response to changes in IT prices.

[9]Jorgenson's contributions to modeling consumer behavior were surveyed by Stoker in 2000. His approach has provided the foundation for subsequent developments in modeling consumer behavior surveyed by Stoker in 1993 and, more recently, by Richard Blundell and Stoker in 2005. Slesnick surveyed empirical applications of the new approach to normative economics emanating from his research with Jorgenson in 2001. Slesnick compares the results of the econometric approach, based on consumption, with the official income-based measures published by the U.S. Bureau of the Census. Similar income-based measures are published by statistical agencies in many other countries. Differences between the two approaches are mainly due to differences between the distribution of consumption and the distribution of income.

[10]Jorgenson's contributions to modeling the impact of environmental policies were surveyed by Wilcoxen in 2000. As an illustration of the new approach to environmental policy analysis, Wilcoxen analyzed the hypothesis that market-based instruments for environmental policy have the potential for stimulating economic growth. Jorgenson and Wilcoxen (1993b) had shown that revenue from market-based instruments of environmental policy can be used to reduce pre-existing distortions associated with taxes on incomes from labor and capital. This can improve economic welfare even before environmental benefits are considered, generating a “double dividend”.