U.S. Labor Supply and Demand in the Long Run

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I. Introduction

In this paper we model U.S. labor supply and demand in considerable detail in order to capture the enormous heterogeneity of the labor force and its evolution over the next 25 years. We represent labor supplies for a large number of demographic groups as responses to prices of leisure and consumption goods and services. The price of leisure is an after-tax wage rate, while the final prices of goods and services reflect the supply prices of the industries that produce them. By including demographic characteristics among the determinants of household preferences, we incorporate the expected demographic transition into our long-run projections of the U.S. labor market.

The U.S. population will be growing older over the next quarter-century, and elderly households have very different patterns of labor supply and consumption compared to their younger counterparts. Our projections for the period spanning 2004 to 2030 thus incorporate the expected fall in the supply of labor per capita. These changes in labor supply patterns are the consequence of population aging, rather than wage and income effects. Despite the anticipated aging of the U.S. population, moderate population growth will provide growing supplies of labor well into the twenty-first century. Improvements in the quality of U.S. labor input, defined as increased average levels of educational attainment and experience, will also continue for some time, but will gradually disappear over the next quarter-century.

We represent labor demand for each of 35 industrial sectors of the U.S. economy as a response to the prices of productive inputs—labor, capital,

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and intermediate goods and services. In addition, labor demand is driven by changes in technology. Technical change generates productivity growth within each industry. Rates of productivity growth differ widely among industries, ranging from the blistering pace of advance in computers and electronic components to the gradual decline in construction and petroleum refining. In addition, changes in technology may be skill-biased. Labor-saving technical change reduces labor demand for given input prices, while labor-using technological change increases labor demand. Over the next 25 years, productivity growth for the U.S. economy as a whole will be below long-term historical averages. However, productivity growth in information technology equipment and software will continue to outpace productivity growth in the rest of the economy. The output of the U.S. economy will continue to shift toward industries with high rates of productivity growth. Labor input biases of technical change are substantial in many industries. Labor-using, rather than labor-saving, biases predominate. Labor-using technical change will continue to be a stimulus to the growth of labor demand, and differences in the biases for different industries will play an important role in the reallocation of labor.

We incorporate the determinants of long-term labor supply and demand into a model of U.S. economic growth. We refer to this model as the IGEM,[1] which stands for the Inter-temporal General Equilibrium Model. Markets for labor, capital, and the aggregate output of the economy equilibrate through the price system at each point of time. In the labor market, for example, wage rates determine the labor supplied by the current population and the labor quantity demanded by employers in the many sectors of the economy. In the IGEM model and in the U.S. economy, year-to-year changes in the level of economic activity are primarily the consequence of the accumulation of capital. However, over the next quarter-century the driving forces of economic growth are projected to be demography and technology—as encapsulated in the neoclassical theory of economic growth.

In the IGEM, capital formation is determined by the equilibration of saving and investment. We model household saving at the level of the individual household. Consumption, labor supply, and saving for each household are chosen to maximize a utility function, defined as the stream of future consumption of goods and leisure, subject to an inter-temporal budget constraint. The forward-looking character of savings decisions allows changes in future prices and rates of return to affect the current labor supply. The availability of capital input in the U.S. economy is the consequence of past investment. This backward-looking feature of capital accumulation links current markets of capital input to past investment decisions.

II. A Long-Run Model of the U.S. Economy and the U.S. Labor Market

Our household model generates demand for a detailed list of personal consumption expenditures given in Table 6.1. Household preferences are structured in a nested, or tiered, manner. At the top tier, utility is a function of non-durable goods, capital services, consumer services, and leisure. Lower tiers allocate non-durable goods to specific categories, like food and clothing, and consumer services to transportation, finance, and other services. Household consumption patterns for goods and leisure are derived from the Consumer Expenditure Survey (CEX).[2] The items in Table 6.1 are based on the consumption categories in the National Income and Product Accounts (NIPAs).[3] These items are linked to the supplying industries listed in Table 6.2.

As the owner of the economy's wealth, the household sector makes a second contribution to the demand side of the economy through the demand for investment goods. Household sector savings are allocated between domestic and foreign investment, and the domestic portion is distributed among investments in assets such as building structures, capital equipment, consumer durables, and inventories. Capital stocks and capital services are derived primarily from the Fixed Asset Accounts of the Bureau of Economic Analysis,[4] which include information on investment by 60 asset categories. Data on labor input by industry are derived from detailed demographic and wage data in the annual Current Population Surveys and the decennial Censuses of Population, as described by Jorgenson, Ho, and Stiroh (2005).

We separate the production sector in the IGEM into 35 individual industries. The complete list is given in Table 6.2, together with the value of each industry's output in 2000 and the corresponding Standard Industrial Classification codes. Each industry produces output from labor,

Table 6.1
Personal Consumption Expenditures and leisure, IGEM categories, 2000.
Leisure, IGEM Categories, 2000

	IGEM categories	Billions of dollars	Category
1	Food	568.6	3
2	Meals	376.5	4
3	Meals-Employees	9.9	5,6
4	Shoes	46.3	12
5	Clothing	267.4	14,15,16
6	Gasoline	164.4	75
7	Coal	0.2	40
8	Fuel oil	17.9	40
9	Tobacco	72.2	7
10	Cleaning supplies	115.8	21,34
11	Furnishings	38.3	33
12	Drugs	156.3	45
13	Toys	62.7	89
14	Stationery	23.4	35
15	Imports (travel)	3.3	111
16	Reading	51.7	88,95
17	Rental	247.4	25,27
18	Electricity	101.5	37
19	Gas	40.8	38
20	Water	48.8	39
21	Communications	130.6	41
22	Domestic service	16	42
23	Other household	48.5	43
24	Own transportation	210.8	74,76,77
25	Transportation	56.9	79,80,82,83,84,85
26	Medical Services	921.3	47,48,49,51,55
27	Health Insurance	70.6	56
28	Personal services	76.2	17,19,22
29	Financial services	517.7	61,62,63,64
30	Other services	114.8	65,66,67
31	Recreation	255.5	94,97,98,99,100,101,102,103
32	Education and Welfare	354.1	105,106,107,108
33	Foreign Travel	80.9	110
34	Owner maintenance	90	authors' imputation
35	Durables flow	1394.4	authors' imputation
	Leisure	13786.3	authors' imputation

Source: U.S. Bureau of Economic Analysis and Consumer Expenditure Survey (U.S. Bureau of Labor Statistics).
Note: National Income and Product Accounts Personal Consumption Expenditure category refers to the line number in Table 2.4 of Survey of Current Business 2002.

Table 6.2
Industry Output and Value Added, 2000

Code	Industry Name	Output	Value-Added	SIC
1	Agriculture	388994	195781	01-02, 07-09
2	Metal Mining	15603	7167	10
3	Coal Mining	23081	14175	11-12
4	Petroleum and Gas	136651	72669	13
5	Nonmetallic Mining	18894	10619	14
6	Construction	995279	419200	15-17
7	Food Products	487587	156127	20
8	Tobacco Products	35853	10108	21
9	Textile Mill Products	61629	21811	22
10	Apparel and Textiles	84273	62899	23
11	Lumber and Wood	115974	43305	24
12	Furniture and Fixtures	87965	39619	25
13	Paper Products	175955	72942	26
14	Printing and Publishing	233523	137723	27
15	Chemical Products	422655	183438	28
16	Petroleum Refining	235145	26422	29
17	Rubber and Plastic	170270	77459	30
18	Leather Products	10616	4028	31
19	Stone, Clay, and Glass	111040	53522	32
20	Primary Metals	191627	59691	33
21	Fabricated Metals	279540	125540	34
22	Industrial Machinery and Equipment	472251	193646	35
23	Electronic and Electric Equipment	433257	195913	36
24	Motor Vehicles	427709	83072	371
25	Other Transportation Equipment	186241	87121	372-379
26	Instruments	183293	104351	38
27	Miscellaneous Manufacturing	52715	21889	39
28	Transport and Warehouse	553535	263335	40-47
29	Communications	430330	231027	48
30	Electric Utilities	245950	166618	491, %493
31	Gas Utilities	81196	26421	492, %493, 496
32	Trade	1965715	1187180	50-59
33	FIRE	2009429	1240039	60-67
34	Services	3455269	2197343	70-87, 494-495
35	Government Enterprises	256268	167722	
36	Private Households	1394410	1394410	88
38	General Government	1194160	1194160	

Source: U.S. Bureau of Economic Analysis and U.S. Census Bureau.
Note: All figures in millions of current dollars. % indicates part of an SIC code.

capital, and intermediate inputs, using a technology that allows for substitution among these inputs. Although technology can be represented by means of a production function, we find it much more convenient to use a dual approach, based on a price function that gives each sector's output price as a function of its input prices. Technologies are structured in a nested or tiered manner, with intermediate inputs divided between energy and materials; both energy and materials are further subdivided among inputs that correspond to the 35 commodity groups produced by the 35 industries.

Our representation of the technology embedded in each sector includes its respective rate and biases of technical change. The rate of technical change captures improvements in productivity or growth in output per unit of input. The biases of technical change correspond to increases or decreases in the shares of inputs in the value of output, holding input prices constant. The evolution of patterns of production reflects both price-induced substitution among inputs and the impact of changes in technology. We project the historical patterns of technical change represented in our database in order to incorporate future changes in technology into the demand for inputs of labor, capital, and intermediate goods and services.

The production of each commodity by one or more of the 35 U.S. domestic industries is augmented by imports of that commodity from the rest of the world to generate the U.S. domestic supply of goods and services. This supply is allocated to U.S. industries as an intermediate input and to final demand for consumption by U.S. households and governments; investments by U.S. businesses, households, and governments; and net exports. Since imports are not perfect substitutes for commodities produced domestically, we also explicitly model the substitution between imports and domestic production. The rest of the world absorbs exports from the United States, and the net flow of resources in each period is governed by an exogenously specified current account deficit.

The final sector explicitly considered in our model is the government sector, which taxes, spends, and makes transfer payments. Public consumption of goods and services is one component of final demand, while public sector borrowing is one of the uses of private savings. The flow of goods and factors among the four sectors of the U.S. economy—house-

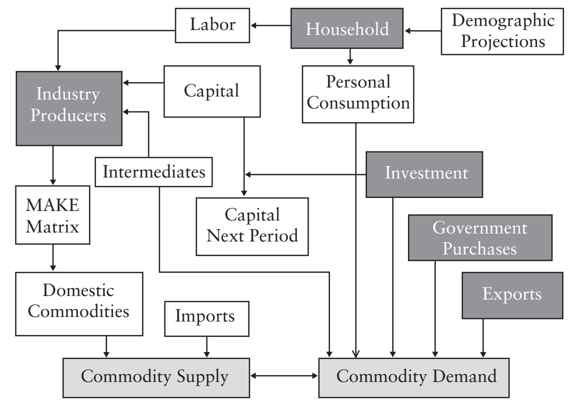

Figure 6.1
Flow of Goods and Factors in the IGEM

hold, business firms, government, and net exports to the rest of the world—is illustrated in Figure 6.1. Prices adjust to equate the supply from domestic and foreign producers to the demand from households, investors, government, and exports in each period.

Our model of the U.S. economy is implemented econometrically. Parameters describing the behavior of producers and consumers are estimated statistically from a data set that we have constructed specifically for this purpose. These data are based on a new system of national accounts that integrates the wealth accounts with the National Income and Product Accounts.[5] The capital accounts include investment goods, capital services, capital stocks, and the corresponding prices. These data are described in detail by Jorgenson, Ho, and Stiroh (2005). Similar data have recently been released for members of the European Union by the EU KLEMS project.[6]

III. Exogenous Variables in the Projections

Our model of the U.S. economy simulates the future growth and structure of the economy over the intermediate term of 25 years. Of course, our model's time path of outcomes is conditional on projections of exogenous variables. Among the most important of these variables are the total population, the time endowment of the working-age population, the overall government deficit, the current account deficit, world price levels, and U.S. government tax policies. Many of these variables are developed from published sources, "official" and otherwise. In addition, we project the evolution of technology in each of the 35 industries that make up the model's production sector. These variables are projected from the historical data set that underlies the production model and its estimation.

The key exogenous variables that describe the growth and composition of the U.S. population are population projections by sex and individual year of age from the U.S. Census Bureau.[7] During the sample period the U.S. population is allocated to educational attainment categories using data from the Current Population Survey[8] in a way that is parallel to our calculation of labor input. Each adult is given a time endowment of 14 hours a day to be used for work and leisure. The number of hours for each sex-age-education category is weighted by labor compensation rates and aggregated to form the national time endowment presented in Figure 6.2.

Our projections use Census Bureau forecasts by sex and age. We assume that the educational attainment of those aged 35 or younger will be the same in the projected period as in the last year of the historical sample period; that is, a person who becomes 22 years old in 2014 will have the same chance of having a bachelor's degree as a person in 2004. Those aged 55 years and over carry their educational attainment with them as they age; that is, the educational distribution of 70-year-olds in 2014 is the same as that of 60-year-olds in 2004. Those between 35 and 55 years of age have a complex adjustment that is a mixture of these two assumptions to allow a smooth improvement of educational attainment that is consistent with the observed profile in 2004. The result of these calculations, shown in Figure 6.2, is that the U.S. population is expected to grow at just under 1 percent per year through 2030, reaching a level slightly in excess of 365 million inhabitants. The gradually slowing improvement in the average level of educational attainment implies that the time endowment grows at a modestly faster rate of around 1 percent through 2030.

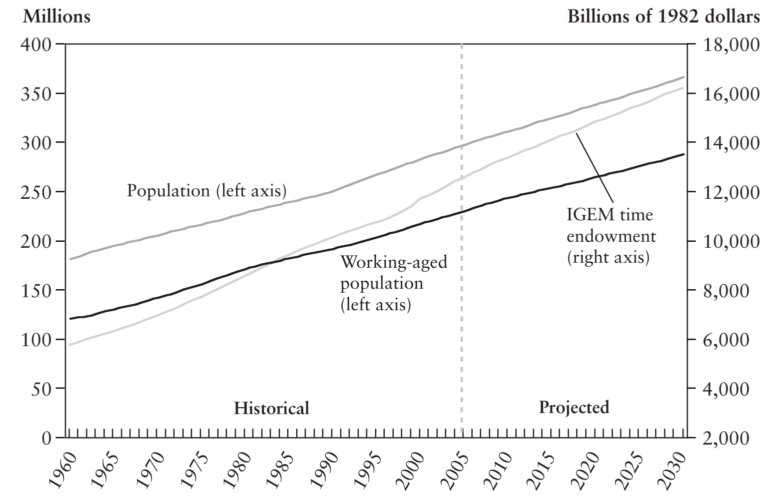

Figure 6.2
Population and Household Time Endowment for the United States
Source: Consumer Expenditure Survey of U.S. Bureau of Labor Statistics and the Current Population Survey from the U.S. Census.

We project productivity growth for each of the 35 industries, using the state-space approach of Jin and Jorgenson (2007). To illustrate this approach, Figure 6.3 gives historical data for the period 1960–2004, based on the estimates of Jorgenson, Ho, Samuels, and Stiroh (2007). These data update and revise the estimates of Jorgenson, Ho, and Stiroh (2005). Figure 6.4 presents projections of productivity growth for the period 2004–2030, using the state-space approach. Positive productivity growth reduces output prices, relative to costs of inputs, while negative growth raises output prices relative to costs.

For 2004–2030 our baseline projections reveal steadily improving productivity in 30 of the 35 sectors in the IGEM. Electrical machinery, which contains electronic components such as the semiconductor devices used in computers and telecommunications equipment, leads the list in projected productivity growth. Although this industry's projected productivity growth rate exceeds 3 percent, this represents a slight reduction in the rate of productivity growth of just under 4 percent for the

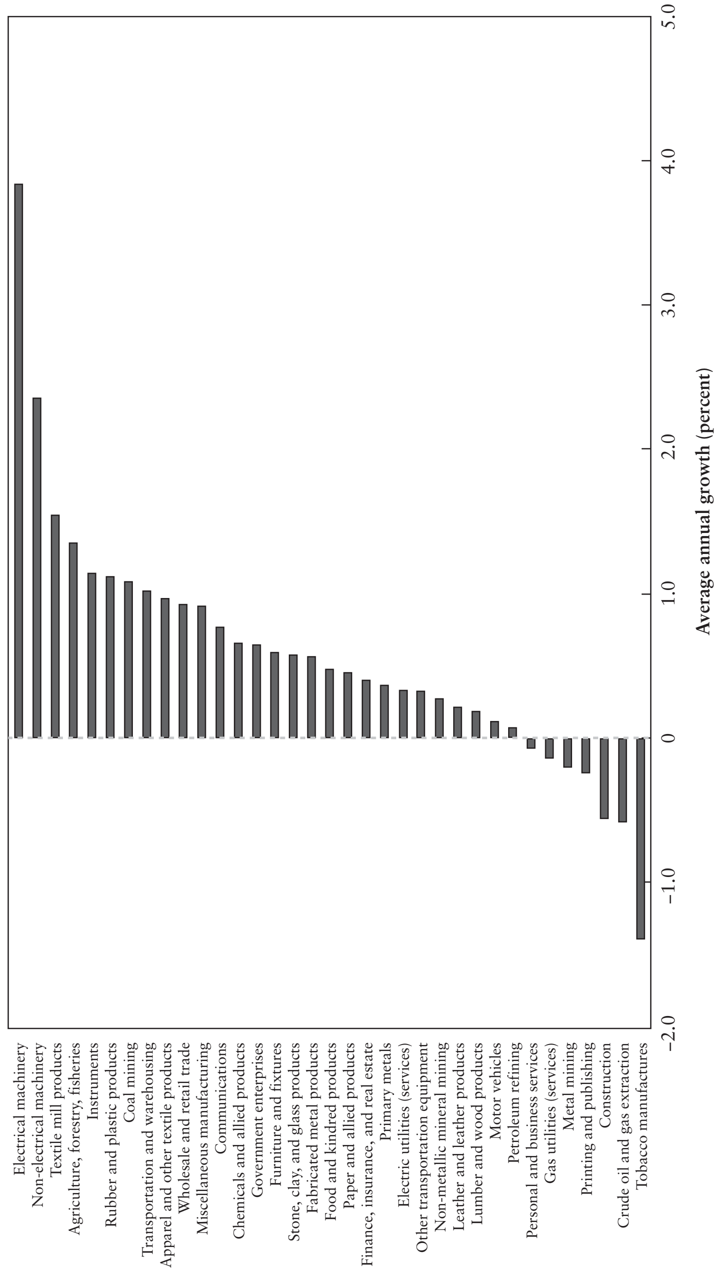

Figure 6.3
Growth in U.S. Total Factor Productivity, 1960–2004
Source: U.S. Bureau of Economic Analysis, National Income and Product Accounts.

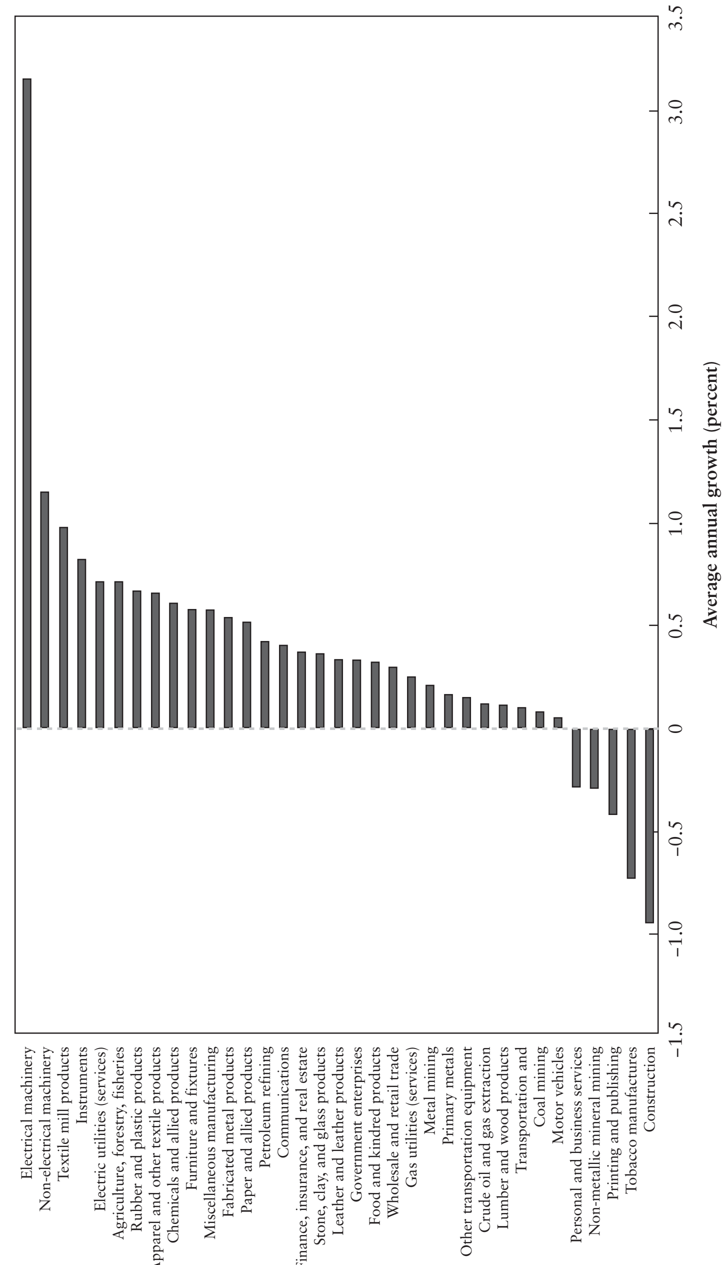

Figure 6.4
Projected Growth in U.S. Total Factor Productivity, 2004–2030
Source: U.S. Bureau of Economic Analysis, National Income and Product Accounts.

historical period 1960–2004. Non-electrical machinery, including computers, has the second highest rate of productivity growth in both the historical period and the projection period, but the projected growth rate between 2004 and 2030 is considerably lower than the historical rate.

Below we show that the overall rates of productivity growth projected for the U.S. economy are substantially below those attained for the historical period 1960–2004. It is also important to recognize productivity losses as well as productivity gains at the industry level. There are several sectors with negative projected productivity growth, including the very large construction industry and the relatively small tobacco industry. Both industries also have declining productivity during the 1960–2004 sample period.

Projections of the input biases are accomplished in a similar manner to the projections obtained for productivity. Figure 6.5 gives historical data for the period 1960–2004, while Figure 6.6 gives our projections for the period 2004–2030. Recall that the definition of skill-biased technical change is the effect of changes in technology on the share of labor input in the value of industry output, holding prices of labor input, as well as capital, energy, and materials inputs, constant. It is important to keep in mind that we have fitted and projected biases of technical change for capital, energy, and materials inputs, as well as labor input, but these are not presented in this paper due to space considerations.

During the historical sample period of 1960–2004, technical change is predominantly labor-using rather than labor-saving. Metal mining, a relatively small industry, has a very large labor-using bias of technical change, while coal mining has a large labor-saving bias. Biases of technical change differ substantially among industries, and both labor-using and labor-saving changes occur with some frequency. It is important to project rates of technical change to determine the growth rate of individual industries and the economy as a whole. However, it is also important to project biases of technical change in order to capture the impact of changes in technology on the distribution of labor input among sectors.

Two other important assumptions that determine the shape of the economy are the government and trade deficits. Our projection of the government deficit follows the forecasts of the Congressional Budget Office for the next 10 years, and then is set on course to a zero balance by 2030.[9]

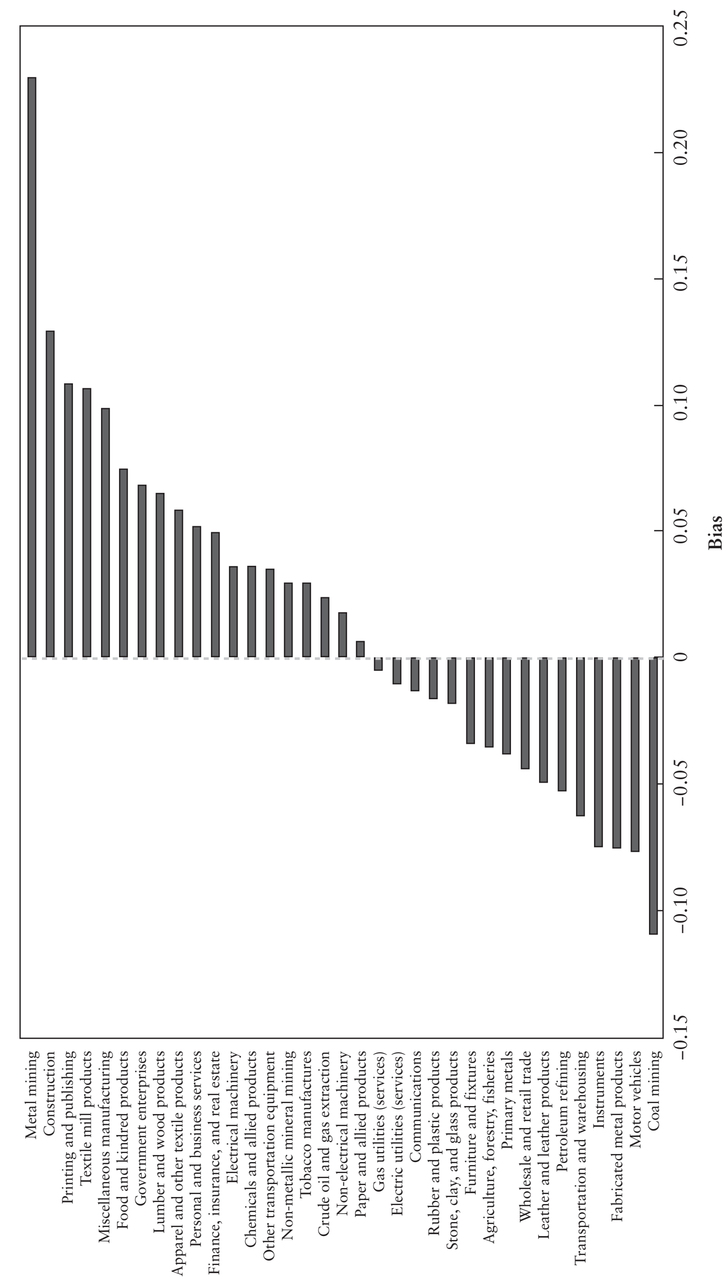

Figure 6.5
U.S. Labor Input Biases due to Changes in Technology, 1960–2004
Source: Current Population Survey and U.S. Census Bureau.

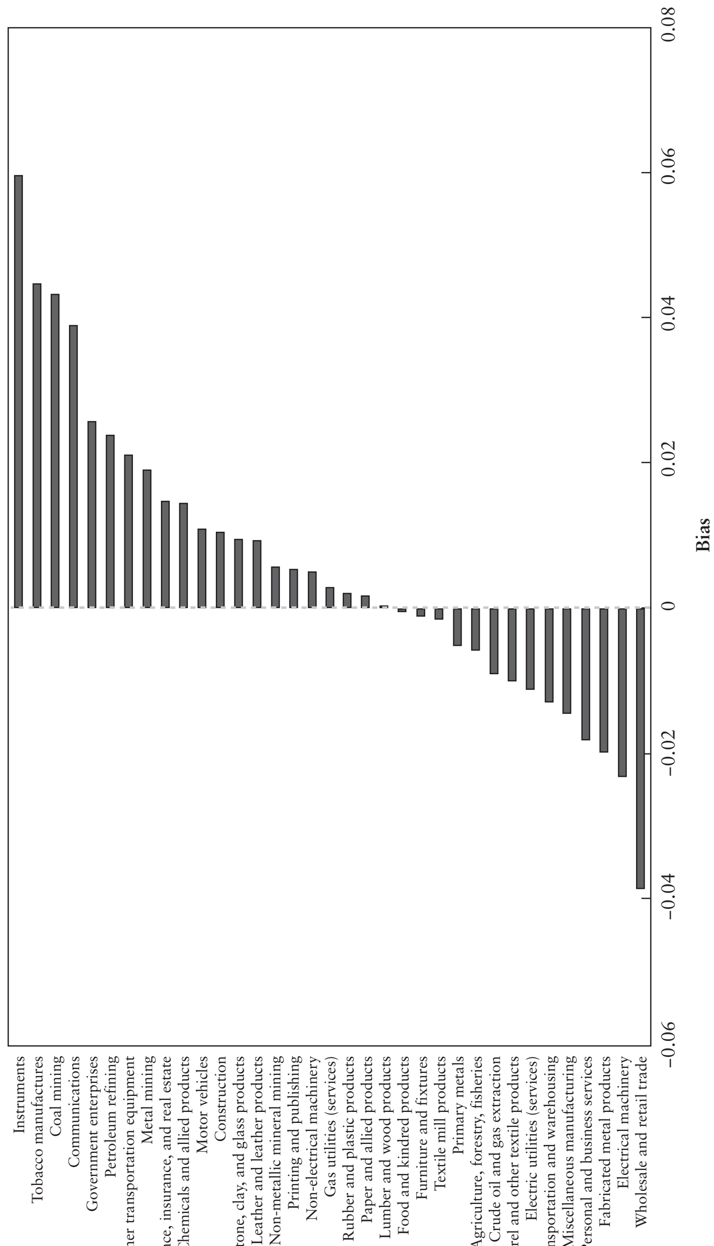

Figure 6.6
Projected U.S. Labor Input Biases due to Changes in Technology, 2004–2030
Source: Current Population Survey and U.S. Census Bureau.

The current account deficit is assumed to shrink steadily, relative to the GDP, so that it also reaches a sustainable balance by 2030. These simplifying assumptions allow the simulation to produce a smooth time path. The government and current account deficits are determinants of long-run growth to the extent that these deficits influence capital formation, but are substantially less important than the exogenous demographic and technology variables we have described.

IV. Projection of U.S. Economic Growth

Our baseline path for the U.S. economy generates a labor force participation rate, defined as the ratio of labor input to the time endowment. We have used this to extrapolate the ratio of hours worked to discretionary hours available from the working age population. The participation rate presented in Figure 6.7 reached a peak in 2000, before the shallow recession of 2001 and the "jobless" recovery that followed. The historical

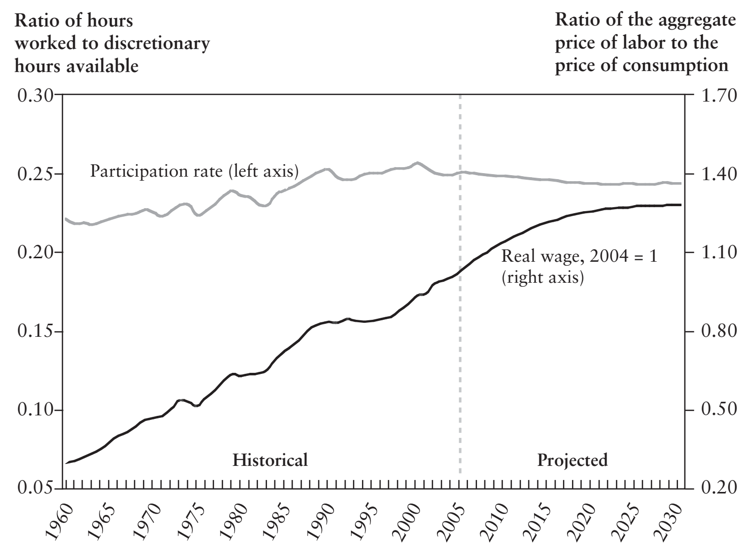

Figure 6.7
U.S. Labor Participation Rates and Real Wages, 1960–2004, with Projection to 2030
Source: Current Population Survey and U.S. Census Bureau.

data from 1960 to 1990 show substantial gains in labor force participation. No such gains in participation are in prospect for the next quarter-century. At the same time, projections beginning in 2004 do not suggest a large decline in labor force participation.

It is important to keep in mind that the rate of population growth will be declining throughout the projection period of 2004–2030. The U.S. working-age population will be growing at a very similar rate to the population as a whole during our projection period. During the 1960–2004 historical period, the working-age population grew considerably more rapidly than the U.S. population as a whole. Finally, the time endowment, which adjusts the population for changes in composition by educational attainment and labor market experience, will continue to grow more rapidly than the working-age population. However, changes in composition will gradually disappear as average levels of education and experience stabilize.

Real wages, defined as the ratio of the price of labor input to the price of consumption goods and services, are also presented in Figure 6.7. Contrary to historical trends often described in the popular business press, real wages have risen steadily throughout the postwar period with especially rapid growth rates during the period 1995–2004. Our projections of real wages rise steadily during the period 2004–2030, but at a decreasing rate. This declining rate of increase mimics the historical data from 1973–1995, prior to the U.S. growth resurgence that began around 1995 and continued into the 2000–2004 period. A slowdown in the growth rate of real wages will occur despite the continuation of historical productivity trends summarized in section III.

We next turn to the sources of U.S. economic growth during the historical and projection periods. Figure 6.8 presents historical data on the sources of U.S. economic growth during 1960–2004 recently compiled by Jorgenson, Ho, Samuels, and Stiroh (2007). The overall rate of growth is an impressive 3.34 percent per year. The most important source of growth is capital input, which contributes 1.70 percent or well over half of growth during the historical period. The next most important source of growth is labor input, which contributes 0.95 percent per year. These contributions are the growth rates of capital and labor inputs, each

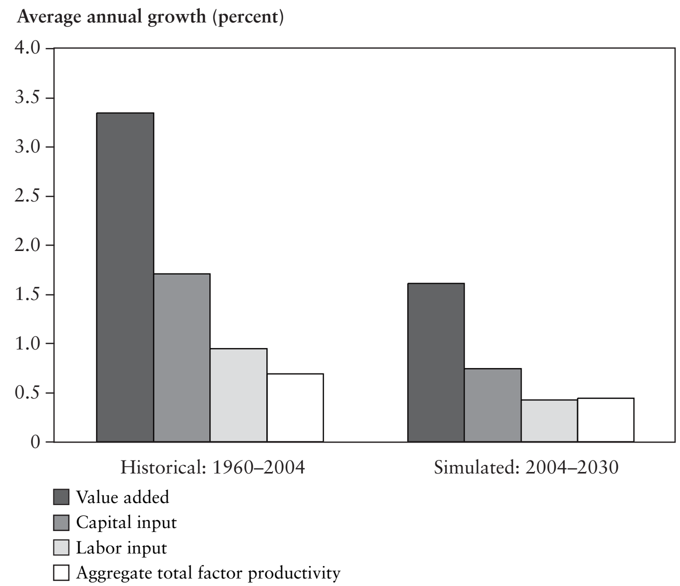

Figure 6.8
Sources of U.S. Economic Growth
Source: Current Population Survey, Fixed Asset Accounts and National Product Accounts of U.S. Bureau of Economic Analysis, and U.S. Census Bureau.

weighted by the corresponding share in the value of output. Total factor productivity growth contributes 0.69 percent per year or slightly more than 20 percent of growth during the historical period.

We project that the growth of the U.S. economy during the 2004–2030 period will be only 1.61 percent per year. The contribution of capital input will remain the most important source of growth at 0.74 percent per year. The growth of total factor productivity will decline very slightly to 0.44 percent per year, and will outstrip the sharply lower contribution of labor input of 0.42 percent. While the contributions of capital and labor inputs will still greatly predominate among the sources of U.S. economic growth, the relative importance of total factor productivity growth will jump substantially. This reflects the strength of the projected productivity trends described in section III.

We conclude our discussion of projected U.S. economic growth with a description of the growth of output and labor input at the industry level. Figure 6.9 presents growth rates of labor input for each of the 35 industries in the IGEM during the historical period 1960–2004. Slightly less than half the industries experienced an increase in labor input, led by personal and business services. However, many industries experienced sharp declines in labor input, led by leather and leather products, apparel and textile products, and gas utilities. The growth rate of labor input overall was 1.64 percent per year.

We have projected a substantial slowdown in the growth rate of labor input for the projected 2004–2030 period to 0.70 percent per year. Figure 6.10 provides a breakdown by industries. Positive growth in labor input predominates in the projections. Relatively small sectors with low projected productivity growth like tobacco and petroleum refining will show substantial increases in labor input. As widely anticipated, the large service sectors like finance, insurance, and real estate, will greatly predominate in the growth of labor input. Primary metals and metal mining will continue to release labor input to a future U.S. economy that is increasingly constrained by the slow growth of the labor supply.

Labor input biases are an important component of changes in demand for labor input. Labor-using technical change results in an increase in the share of labor input, holding prices of labor, capital, energy, and materials inputs constant. This effect dominates in our projections, as well as in the sample period. The share of labor input in instruments will increase by 0.06 during the projection period 2004–2030, reversing a similar decline in the share of labor input during the sample period 1960–2004. Metal mining, a small sector that had a large labor-using bias of technical change during the historical sample period, has a smaller labor-using bias during the projection period. Biases of technical change are an important component of labor input demand, along with the steady rise in the price of labor input relative to other inputs.

Growth in industry output completes our picture of future U.S. economic growth.

Figure 6.11 gives historical data on output growth for the period 1960–2004. Economic growth during the period 1960–2004 differed widely among industries, with a relatively narrow range of industries

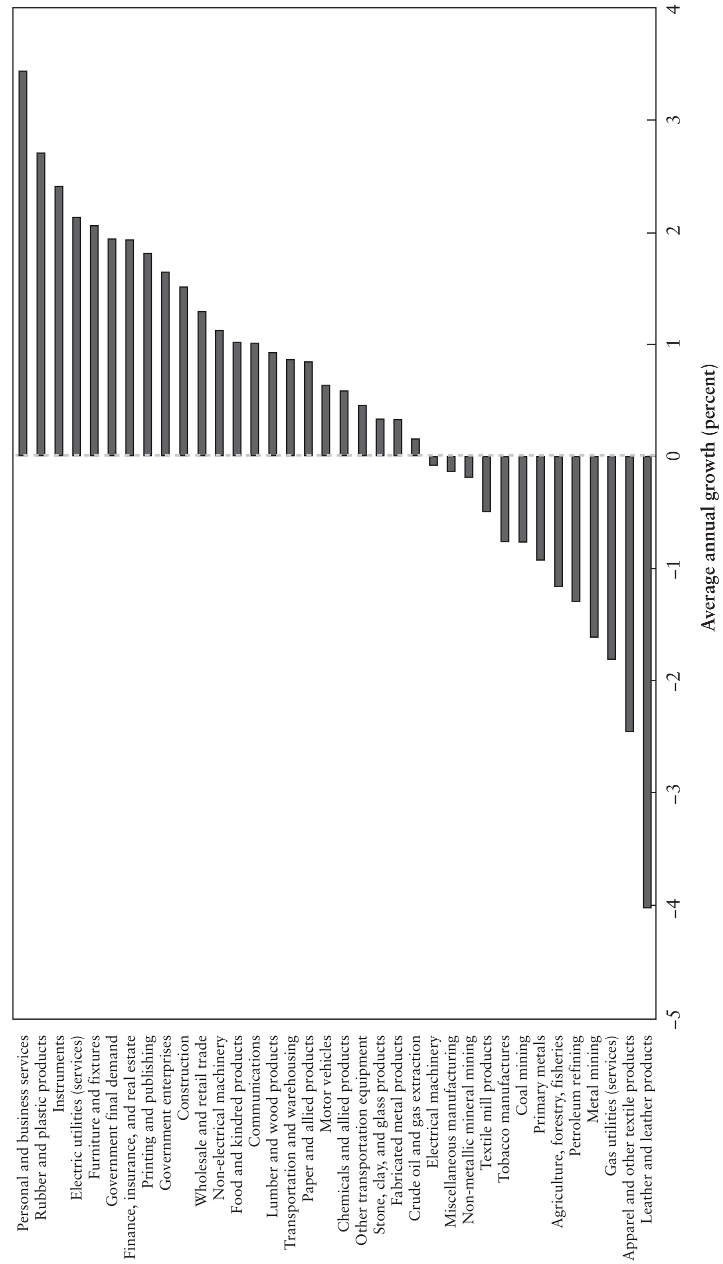

Figure 6.9
Growth in U.S. Labor Output, 1960–2004
Source: Current Population Survey and U.S. Census Bureau.

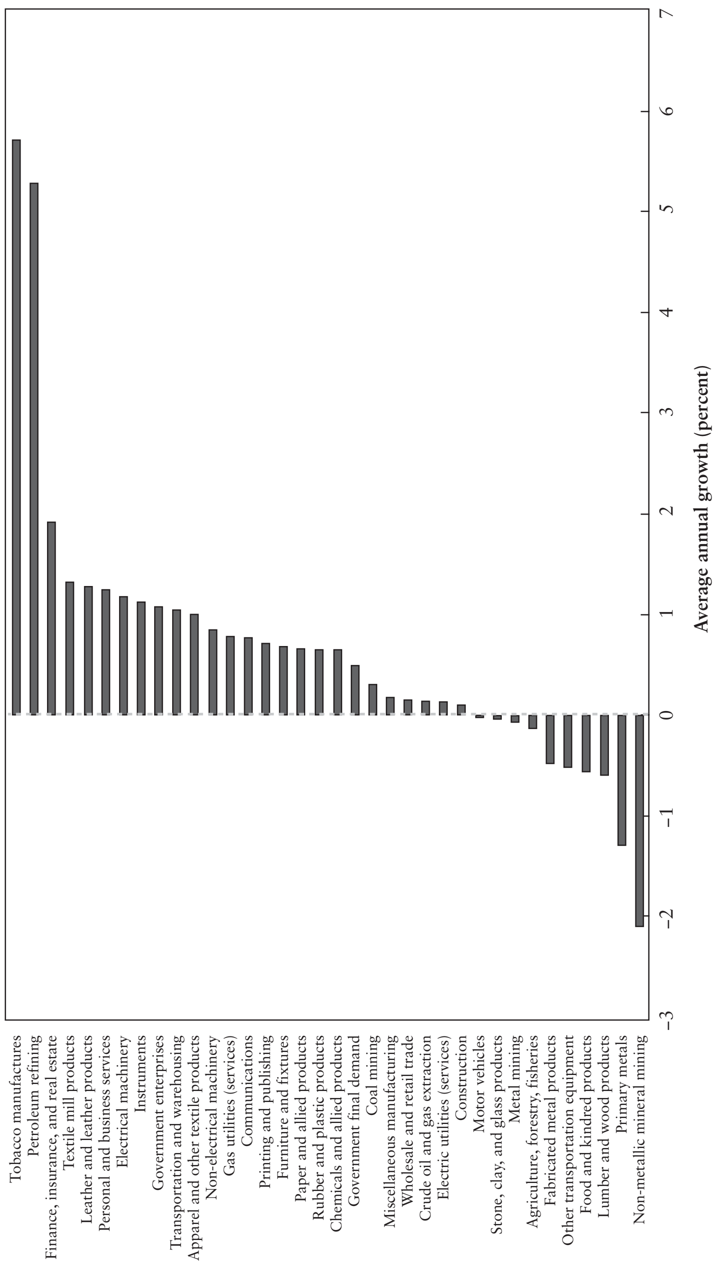

Figure 6.10
Projected Growth in U.S. Labor Output, 2004–2030
Source: Current Population Survey and U.S. Census Bureau.

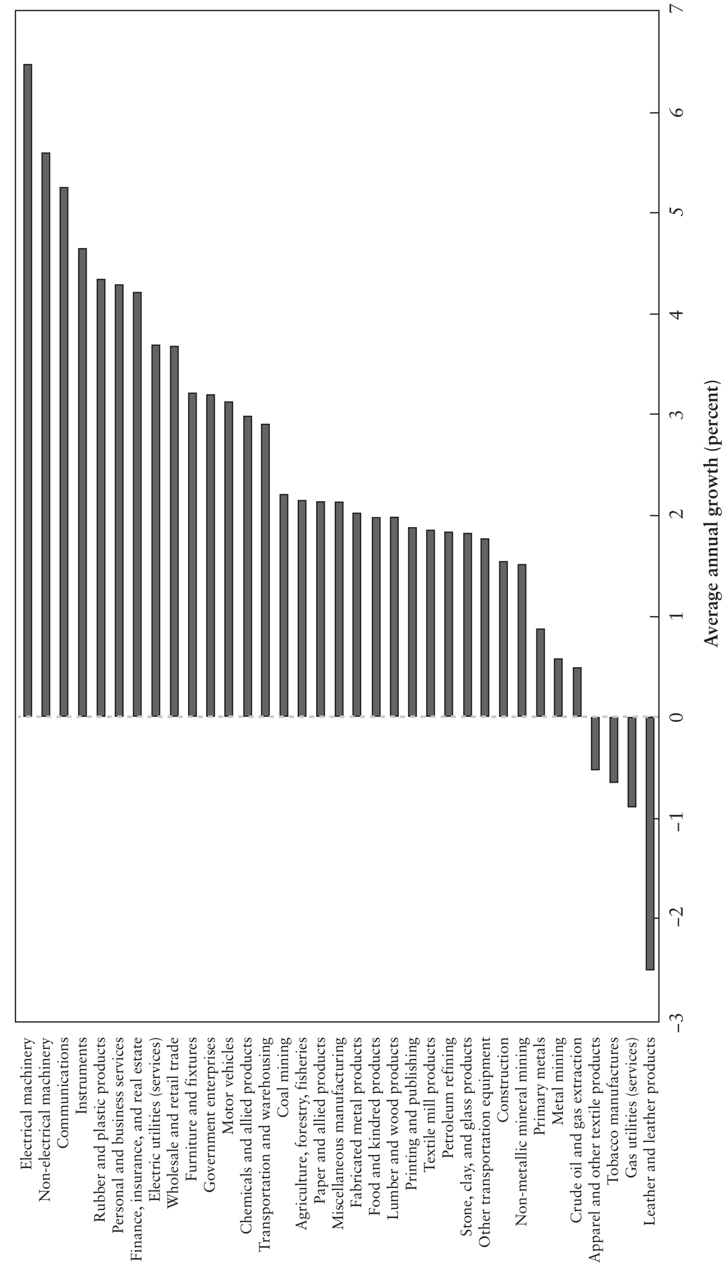

Figure 6.11
Growth in U.S. Domestic Output, 1960–2004
Source: U.S. Bureau of Economic Analysis, National Income and Product Accounts.

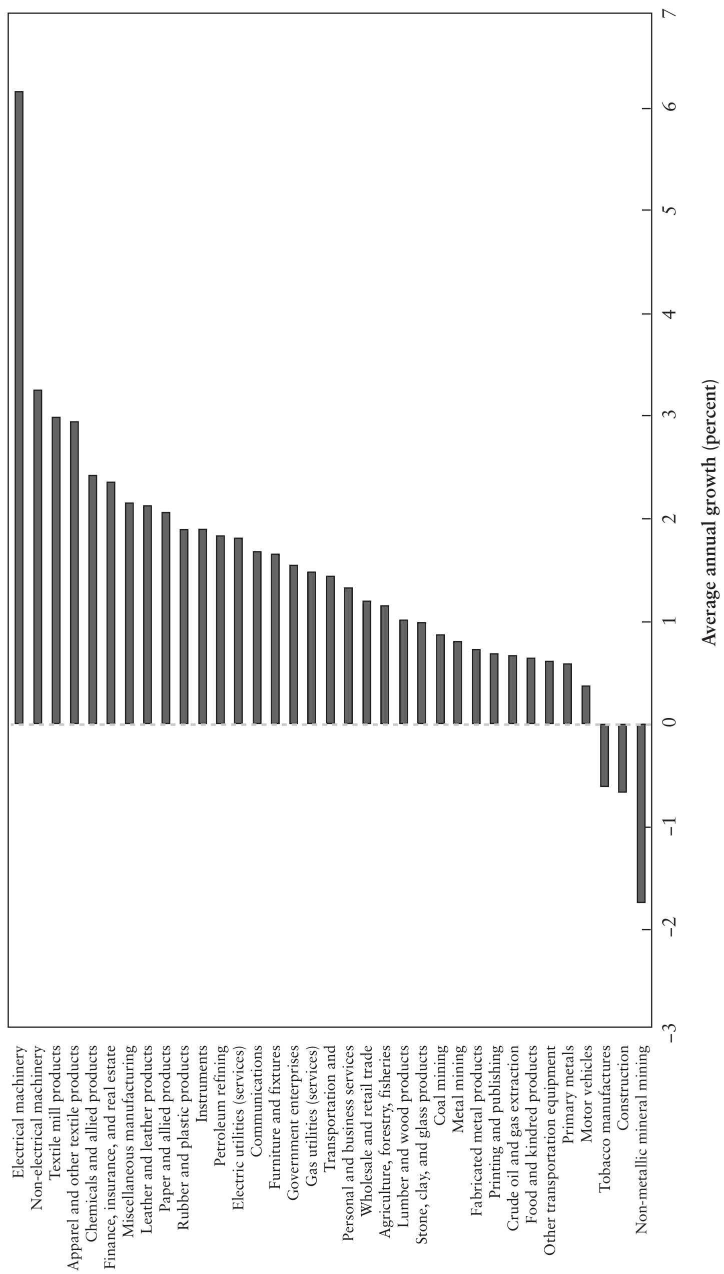

Figure 6.12
Projected Growth in U.S. Domestic Output, 2004–2030
Source: U.S. Bureau of Economic Analysis, National Income and Product Accounts.

exceeding the economy-wide average of 3.22 percent. As expected, the rapidly growing sectors were led by electrical machinery, including electronic components. Substantial growth also took place in three industries, non-electrical machinery, which contains computers; communications, the largest consuming sector for information technology equipment and software; and instruments, another major consumer. Only three industries experienced declining output growth—leather and leather products, gas utilities, and tobacco manufactures.

Figure 6.12 gives U.S. economic growth during the projection period 2004–2030.

Again, growth rates will differ substantially among industries, with electrical machinery exhibiting growth at the very rapid pace of more than 6 percent per year, comparable to the historical period of 1960–2004. Most of the remaining industries, including non-electrical machinery, one of the stars of the historical period, will scale back growth in the projection period. The relatively small leather industry will reverse the negative growth of the historical period and exceed the economy-wide average of 1.50 percent.

V. Summary and Conclusions

Our first and most important conclusion is that future supply and demand for labor in the U.S. economy will be driven by demography and technology. The supply side of the labor market will be dominated by the slowdown in the growth of the U.S. working-age population, partly offset by continuing increases in the quality of labor input due to rising average levels of educational attainment and experience. From 1960 to 1990 the participation rate of the working-age population increased fairly steadily as more women joined men as participants in the labor market. No such increases in labor force participation are in prospect for our projection period of 2004–2030.

The widely discussed aging of the labor force is reflected in the slowing growth of the working-age population, relative to the total U.S. population. The working-age population will continue to expand more rapidly than the population as a whole, and labor force participation rates will decline very slowly. However, the slowdown in the growth of the time endowment will reduce the growth rate of the U.S. economy very substantially. This will be reinforced by the decline in investment and growth of capital input that will accompany the slow growth of labor supply. It is important to keep in mind that in the neoclassical theory of economic growth embodied in the IGEM, the growth of capital input is endogenous and is equal to the growth of output in the long run.[10]

Finally, future productivity growth will remain robust, despite waves of technological pessimism that sometimes accompany cyclical downturns. Rapid changes in technology will continue to be concentrated in the industries that produce information technology equipment and software, led by electrical machinery, the industry that includes electronic components like semiconductors. This industry has had very rapid growth of total factor productivity or output per unit of unit, throughout the historical period 1960–2004. We project that this will continue for the next quarter-century, although the specific form of the underlying changes in technology will undergo the same dramatic evolution as in the recent past.

At the level of individual industries, the demand for labor depends not only on the growth of output and the substitution of capital input for labor input, but also on the character of technical change. We have emphasized the wide variations in rates of productivity growth among industries. However, labor demand at the industry level is also strongly affected by biases of technical change. We have focused attention in labor-saving and labor-using biases for each of the 35 industries in the IGEM. We have assessed the importance of these biases during the historical period 1960–2004, and projected these biases for the 2004–2030 projected period. Part of the growth of labor input in industries like instruments, tobacco, coal mining, and communications will be due to ongoing labor-using biases.

In summary, the potential growth of the U.S. economy will be slowing considerably between 2004 and 2030, and monetary policy will have to adapt to the new environment. The changes we have projected embody many features of the future labor market that are well known to economists and monetary policymakers—slowing population growth, particularly for the working-age population, and declining growth in labor quality. We have quantified these factors by relying on official population

projections from the Census Bureau and our own estimates of labor quality growth. This data has enabled us to characterize the future growth of labor supply with some precision.

The future growth of the U.S. economy depends on the contribution of labor input, that is, the growth rate of labor input multiplied by the labor share of output. However, future growth also depends on the rate of growth of total factor productivity and the contribution of capital input. In the neoclassical theory of growth embodied in the IGEM, the contribution of capital input, the growth rate of capital input multiplied by the capital share, is endogenous. To a reasonable approximation, growth rates of output and capital input must converge in the long run. The only component of the sources of growth not yet accounted for is productivity growth.

We have projected future productivity growth on the basis of the historical data on productivity growth constructed by Jorgenson, Ho, Samuels, and Stiroh (2007). We have augmented this description of future changes in technology at the level of individual industries by estimating and projecting labor-saving and labor-using biases of technical change. This enables us to conclude that future productivity growth during the next quarter-century will be substantially less than productivity growth during our historical period of 1960–2004. This completes our analysis of labor demand and its distribution by industry.

Economists and policymakers, especially in the Federal Reserve System, have made important contributions to our present understanding of the role of technology in the evolution of labor demand and the growth of the U.S. economy.[11] The remaining challenge will be to build the new understanding of technology and the sources of economic growth into the framework for the conduct of monetary policy. This new policy framework can be erected on the solid foundation provided by projections of future demographic change. The new framework will be an important addition to the Federal Reserve's highly successful policy structure for understanding and mitigating the impact of the business cycle.

Notes

1. Detailed information about earlier versions of the IGEM and a survey of applications are available in Jorgenson (1998).

2. See http://www.bls.gov/cex/home.htm. Detailed documentation for the CEX is available at http://www.bls.gov/cex/home.htm#publications.

3. See http://www.bea.gov/national/index.htm. Detailed documentation for the NIPAs is available at http://www.bea.gov/methodologies/index.htm.

4. See http://www.bea.gov/national/index.htm#fixed. Detailed documentation for the Fixed Assets Accounts is available at http://www.bea.gov/methodologies/index.htm.

5. See Jorgenson and Landefeld (2006).

6. See http://www.euklems.net/. This data set was released on March 15, 2007, and is described in "Use IT or Lose It," *The Economist*, May 19–25, 2007, p. 82.

7. See: http://www.census.gov/popest/estimates.php. Historical data are taken from http://www.census.gov/popest/archives/. These population data are revised to match the latest censuses (e.g., 1981 data is revised to be consistent with the 1990 Census).

8. See http://www.census.gov/cps/.

9. See www.cbo.gov/showdoc.cfm.

10. Jorgenson, Ho, and Stiroh (2008) have pointed out the implications of this fact for growth in an intermediate run of ten years.

11. An excellent summary of this research is provided by Oliner, Sichel, and Stiroh (2007). The implications for monetary policy are discussed by Chairman Ben Bernanke in his August 31, 2006, speech on "Productivity," available at http://www.federalreserve.gov/BOARDDOCS/Speeches/2006/20060831/default.htm.

References

Jin, Hui, and Dale W. Jorgenson. 2007. "Econometric Modeling of Technical Change." Presented at the Center for Business and Economic Research. Copenhagen: Copenhagen Business School. Available online at http://post.economics.harvard.edu/faculty/jorgenson/files/EconometricModelingTechChangehuijin_draft070203.pdf.

Jorgenson, Dale W. 1998. *Energy, the Environment, and Economic Growth*. Cambridge, MA: The MIT Press.

Jorgenson, Dale W., Mun S. Ho, Jon D. Samuels, and Kevin J. Stiroh. 2007. "Industry Origins of the American Productivity Resurgence." *Economic Systems Research* 19(3): 229–252.

Jorgenson, Dale W., Mun S. Ho, and Kevin J. Stiroh. 2005. *Information Technology and the American Growth Resurgence*. Cambridge, MA: The MIT Press.

Jorgenson, Dale W., Mun S. Ho, and Kevin J. Stiroh. 2008. "A Retrospective Look at the U.S. Productivity Growth Resurgence." *Journal of Economic Perspectives* 22(1): 3–24.

Jorgenson, Dale W., and J. Steven Landefeld. 2006. "Blueprint for an Expanded and Integrated U.S. National Accounts: Review, Assessment, and Next Steps," in *A New Architecture for the U.S. National Accounts*, ed. Dale W. Jorgenson, J. Steven Landefeld, and William D. Nordhaus, 13–112. Chicago: University of Chicago Press.

Oliner, Stephen D., Daniel E. Sichel, and Kevin J. Stiroh. 2007. "Explaining a Productivity Decade." *Brookings Economic Papers* (1): 81–137.

Comments on “U.S. Labor Supply and Demand in the Long Run” by Dale W. Jorgenson et al.

Richard Berner

Dale Jorgenson has given us an important paper, describing and using a long-term model of the U.S. economy that can inform our judgment about potential growth and the factors behind these predictions. The news is not good. Over the 2004–2030 period that Jorgenson uses for this projection, potential U.S. economic growth plummets to just over 1.5 percent per year.

There are two factors at work behind this forecast:

1. Jorgenson projects slower growth in the U.S. labor supply, resulting from the now-familiar combination of slowing population growth and the reduced labor force participation that accompanies an aging population.
2. Jorgenson is a self-proclaimed productivity and technology optimist. But the projected pace of productivity growth is slower between 2004 and 2030 than in the 1990s, when information technology posted very impressive gains. In part, this slower predicted growth is because in many key industries, the bias in technical change is labor-using, not labor-saving.

We now know about the consequences of the demographic transition if cohort participation rates stay on current trends. Growth optimists were hoping that high rates of productivity growth would bail us out. Dale’s work in this paper argues that this scenario won’t take place.

Nonetheless, is there any hope for aging societies and their economic prospects?

Let’s first consider productivity. I am concerned that over the next 25 years, productivity growth in the United States may slow, but I’m not sure that Dale's estimates conclusively prove the case. Much of my skepticism about those estimates revolves around the poor quality of the output data available for certain economic sectors, and for overall and sectoral compensation; my doubt is not a criticism of Dale's model or econometrics. The data indicate that construction productivity has been declining almost monotonically, and especially since the 1990s real estate bust. I find this hard to believe. Likewise, the Bureau of Labor Statistics' programs have simply not kept up with the changing structure of worker compensation. Finally, because the estimates of biases in technical change are based on factor prices, including wages and salaries, I think we should take them with a grain of salt.

Turning next to labor supply, I think the debate about whether labor force participation for older cohorts will increase or decline in the future is still a wide open question. It is clear that only heroic increases in the labor force participation of older American adults will offset population aging. But several factors may influence just such a change, including the fact that the next wave of retirees will come from the baby boom generation, and this group has a habit of upending expectations and rewriting the rules. There are three traditional legs to the retirement saving stool: 1) employer-sponsored pension plans, whether defined benefit or defined contribution plans like 401(k)s; 2) Social Security benefits; and 3) other personal savings. Working longer, in my view, is the fourth critical leg, and future policy changes in Social Security and other retirement saving incentives do influence labor force participation. There is a fifth leg: access to health insurance. Many older adults stay in the workforce to get healthcare coverage, and retire once they turn 65 years old and become eligible for Medicare. Thus any changes to health care financing or Medicare have the potential to trigger significant change in labor force behavior.

In particular, the United States—and advanced countries generally—might also look abroad for help in filling gaps in their labor supply. Such relief could come either from flows of immigration that might alter the nation's demographic profile, or from higher-return investments that will provide more income for retirement. Fallick and Pingle's paper in this volume, and the work by Ralph C. Bryant and John F. Helliwell presented at Jackson Hole in 2004, both suggest that neither increased immigration nor

increased investment returns will be a complete panacea, but clearly each one can help improve the situation. Yet in the post-9/11 world, barriers to immigration are higher and could rise further still. Dale's rudimentary and exogenous treatment of the "rest of the world" is probably worth enhancing to analyze those questions.

More broadly, because Jorgenson's analysis focuses on the longer run, it seems critical to model the most important development in global labor markets of the past decade, namely the emergence of key Asian and other economies that are possessed of a rapidly expanding labor force, strong productivity growth, and high saving rates. As David Autor notes in his conference paper, we really do not know what impact offshoring has on the United States, and other industrial economy labor markets. Much more work is needed in this area if we are to accurately predict future labor flows.

At the present time, however, we can say some things. I think that this positive supply shock has been disinflationary—both through new sources of labor supply and the offshoring of some jobs. Of course, other factors, most importantly monetary policy, not just in the United States but around the world, have also been disinflationary. So we don't know the contributions of each factor. But the existence of such new sources of supply has put some pressure on both labor compensation and employment in both goods-producing and service-producing industries. This is because global connectivity means that workers engaged in a broad array of occupations can work effectively with both customers and colleagues several time zones removed. I know from personal experience that such arrangements work well, and that global companies are reckoning headcount in terms of worldwide numbers. Just as with U.S. labor markets, the question in global labor markets is whether these will have their own demographic transition that could reverse, or at least partially unwind, the favorable supply shock of the last 10–15 years.

I think it is quite likely that the currently favorable supply conditions in global labor markets will eventually experience some type of reversal, but it will take a long time for this shift to play out. To find out how long this might take, it is worth looking at overseas labor markets to compare and contrast our own experience. In these remarks, I'll look briefly at Three Ps: the population overseas, participation rates, and productivity.

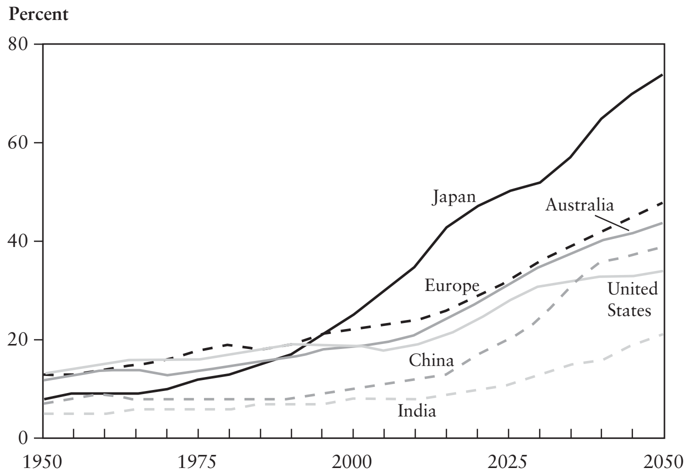

Figure 6.13
Rising Dependency Rates: Ratio of Individuals Over 64 Years of Age to Individuals Aged 15 to 64 Years
Source: Australian Government, Intergenerational Report, 2007; Australian Treasury projections and United Nations 2006 Revision Population Database, medium variant projections; Morgan Stanley Research.

As you see in Figure 6.13, dependency ratios are rising across the board, but what may happen in China and India is especially important for how the global labor supply may play out in the next few decades. China's dependency ratio, partly as a result of its one-child policy, likely will rise and eclipse our own around 2037. Labor force participation there may slow as the population ages, and China is developing a new pension system that may somewhat change labor force participation. In contrast, India has had no one-child policy, and its demographic transition toward an older population is a long way off.

Figure 6.14 compares labor force participation and productivity across countries. The isoquants define countries with the same GDP per capita. Note that in this figure, the hours worked data per capita is for the entire population, not just the workforce. French per capita GDP is below that in the United States, primarily because the French choose to work fewer hours per week. Yet productivity in France is actually very similar to U.S. productivity. Figure 6.15 documents the differences in the French and

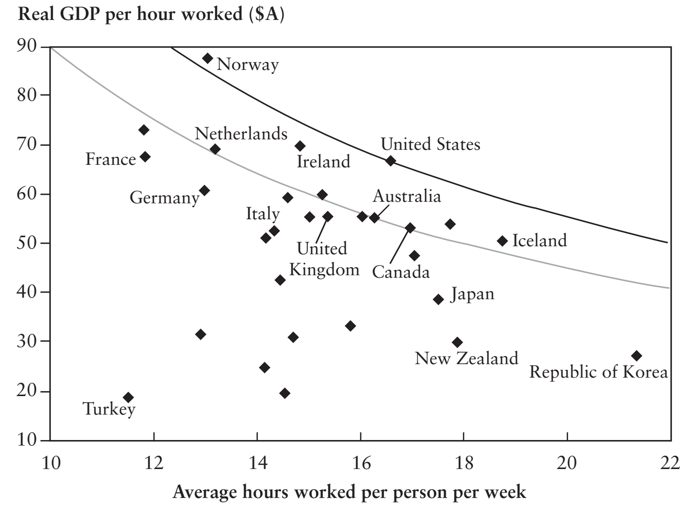

Figure 6.14
Labor Force Participation and Productivity: A Cross-Country Comparison
Source: Morgan Stanley Research; OECD Productivity Database, September 2006.
Note: Average hours worked per person are calculated across the whole population, not just the labor force. Thus, the horizontal axis combines the population and participation components of the 3Ps. Countries on the same contour line have the same GDP per head.

American workweek more clearly. This difference famously reflects cultural differences, but it also reflects labor market regulation. The policy message is that deregulation of labor markets abroad may reverberate in U.S. labor markets. Figure 6.16 shows how strong is the incentive to outsource in Asia and elsewhere based solely on wage differentials, although these data reflect the Bureau of Labor Statistics's definition of compensation on an hourly basis. U.S. compensation includes the fixed cost of employer-provided healthcare, so defining it on an hourly basis may not be entirely accurate, but this won't change the relative position here. The differences are still quite huge. Dale's paper offers a rich menu for future research. Below I identify two key areas for further study that flows from the analysis presented in this paper.

1. The need to assess the impact policy changes may have on labor force participation and aggregate U.S. output. We know from Munnell

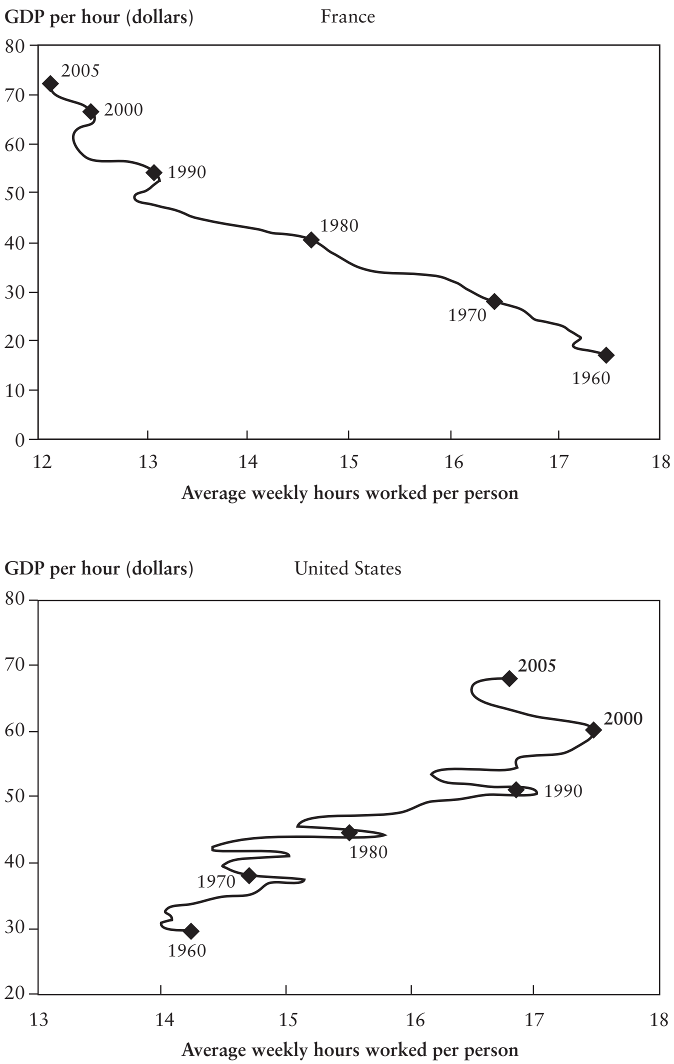

Figure 6.15
Productivity Differences Between the French and American Workweeks, 1960–2005
Source: Australian Federal Budget, 2007–2008, Statement No. 4, http://www.budget.gov.au/2007-08/bp1/download/bp1_bst4.pdf; Groningen Growth and Development Centre, Total Economy Database, January 2007; Morgan Stanley Research.

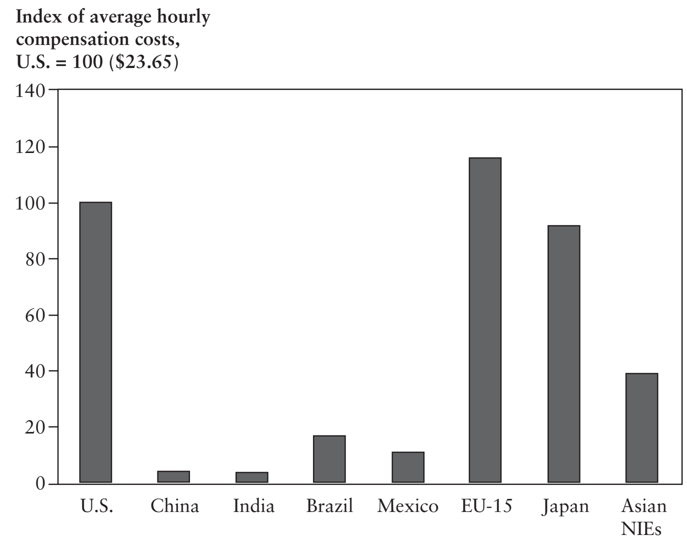

Figure 6.16
Global Wage Differentials for Manufacturing Workers, 2005
Source: Morgan Stanley Research, U.S. Bureau of Labor Statistics.
Note: Asian NIEs (newly industrialized economies) include Hong Kong, Korea, Singapore, and Taiwan. Numbers for China and India are estimates.

and Sass's paper and from Gene Steuerle's work that changes in Social Security retirement ages and benefits, as well as the start of Medicare, induced important shifts in retirement decisions and in labor force participation among older workers. Will changes in the financing of healthcare, such as proposals to tax employer-provided health benefits or proposals among the 2008 presidential candidates to finance U.S. healthcare outside of the workplace, induce significant changes in U.S. labor force participation? Dale tells me that he is doing some work for the Department of Health and Human Services' Centers for Medicare and Medicaid Services along this line, which I applaud. Immigration and tax policies are also worth analyzing.

2. The globalization of product and labor markets has been disinflationary for much of the last 10–15 years. I suspect that this situation will reverse, and changing demographics abroad, as well as the emergence of giants like China and India, may play a role in that reversal. Over time, if these demographic transitions occur abroad, the disinfla-

tionary effect may reverse, and so an analysis of changing demographics abroad may play a role in that analysis.

To conclude, I have a story that knits together thoughts about labor supply, incentives, cultural differences, and the risks of going global. It's especially appropriate that a guy from Wall Street tells this anecdote.

An American investment banker was at the pier of a small coastal Greek village when a small boat with just one fisherman docked. Inside the small boat were several large yellow fin tuna. The American complimented the fisherman on the quality of his fish and asked, "How long does it take to catch them?" The fisherman replied: "Only a little while." The American then asked why didn't he stay out longer and catch more fish? The Greek said he had enough to support his family's immediate needs. The American then asked, "But what do you do with the rest of your time?" The Greek fisherman said, "I sleep late, fish a little, play with my children, take siesta with my wife, Maria, stroll into the village each evening where I sip wine and play cards with my friends, I have a full and busy life." The American scoffed, "I am a Harvard M.B.A. and I could help you. You should spend more time fishing and with the proceeds, buy a bigger boat. With the proceeds from the bigger boat you could buy several boats, and eventually you would have a fleet of fishing boats. Instead of selling your catch to a middleman you would sell directly to the processor, eventually opening your own cannery. You would control the product, processing, and distribution. You would need to leave this small coastal fishing village and move to Athens, then London, and eventually New York where you will run your expanding enterprise." The Greek fisherman asked, "But, how long will this all take?" To which the American replied, "15–25 years." "But what then?" The American laughed and said that's the best part. "When the time is right you would announce an initial public offering, sell your company stock to the public, and become very rich—you would make millions." "Millions ... then what?" The American said, "Then you would retire. Move to a small coastal fishing village where you would sleep late, fish a little, play with your kids, take a siesta with your wife, stroll to the village in the evenings where you could sip wine and play cards with your friends."

Comments on "U.S. Labor Supply and Demand in the Long Run" by Dale W. Jorgenson et al.

Erik Brynjolfsson

It's been said that productivity isn't everything, but in the long run, it's almost everything. And there are few people, if any, who have made a greater contribution to our understanding of productivity growth than Dale Jorgenson, so it's nice to have a few minutes of fame sharing the podium with him.

It's fascinating to discuss U.S. labor supply and demand in the long run. We get to look way out into the future and speculate on what might be, which is always fun. Unlike Bob Hall's business cycle weather predictions, no one can really know for sure whether or not these estimates by Dale and his co-authors are going to come true for quite some time. But with that opening disclaimer, let me try to add some value to the discussion of the issues surrounding future labor supply and demand.

Briefly, here's a summary of some of the key takeaways from Dale and his co-authors' work in this paper, and elsewhere, a lot of which is methodological. The Inter-temporal General Equilibrium Model (IGEM) that he has developed is very impressive, with its inclusion of thirty-five industrial sectors in its number of inputs. As Dale mentioned, in the long run economic growth is really driven by demographics and technological change, his projections of which over the 2004–2030 period are being examined here. Quite a lot of effort went into that model and long-run projection, and he has harnessed an enormous amount of data that isn't really very visible in the particular paper here at hand. You have to dive into a number of his other papers to see the enormous effort and technical detail that went into this model by Dale and a whole host of co-authors and other researchers, including related papers with Hui Jin and Kevin Stiroh. I think that soon there will have to be a separate sector added to the U.S. economy to account for all the output from Dale's research team.

In this paper, Dale goes ahead and estimates long-run U.S. labor demand and supply, using data he's constructed based on the National Income and Production Accounts (NIPA), and calibrates these relationships between the different sectors and the inputs, particularly on the price side. Dale then makes his projections based on certain exogenous variables, some of which we can pin down pretty well, like what will be happening to population growth and time endowment over time. Those variables are pretty much baked in already. But the projections also need to make some assumptions about what's going to happen to the federal government deficit (I'm glad to see that Dale thinks it is going to decline and go away), the current account deficit, and some of the other most important macroeconomic variables moving forward. Dale's collective research has really made a lot of contributions to predicting what will be happening with education, which really translates into labor quality and capital quality. When Dale gets his Nobel citation, I'm sure it's going to prominently mention the contributions he has made to our understanding that it is not just the quantity of capital and labor that matters, but it is the quality of these inputs that counts, which thanks to Dale are now important factors in everyone's model of the aggregate economy.

Dale then projects the evolution to the economy that these technology changes enable going forward. Again, you need to go to another paper of his to really understand and appreciate some of the novelty of what's gone into this model and its projections. Dale just summarizes this research in a few sentences in this conference paper, but there is a tremendous amount of work that went into this model. His IGEM is a really dramatic extension of Bob Solow's work—as Dale mentioned, 50 years ago Bob developed the basic model of technological change that has really become the workhorse model of growth for economists. But if you want to understand input substitution in the various relationships between labor and capital, you can't just have unbiased technical change in the way Bob Solow's model includes it. You have to look at the bias of technical change for each of the different sectors, and that's what Dale's contribution has done. His IGEM is a very important innovation, and is

really going to be valuable for helping to address these questions about future labor supply and demand in the long run.

The key result, as Dale mentioned, is that we are going to have a significant growth slowdown in a lot of the key input factors. Population growth, labor force participation, and educational attainment are all slowing down. It's hard to argue with any of these projections—you can quibble here and there on the margin, but the broad picture seems largely set in stone. Dale also sees a dramatic decline in investment growth and significant multifactor productivity slowdowns. We can argue about whether that's significant or not, as in an early version of this paper he did not project much of a change. In this more recent version, the numbers have shown more of a decline, so maybe some of the text needs to match up with the numbers a little bit more on that score. But I think that the overall picture and the big takeaway is much slower growth is in the future for the U.S. economy. If you put all three together, slower labor supply growth, dramatically less investment, and significantly lower multifactor productivity growth, you see that overall growth is less than half of what it was in the past, and that's a function of all three of those factors, labor, capital, and productivity growth, interacting in his model. I'll call this "the Great Slowdown," as depicted in Figure 6.8 in Dale's paper.

So that's the summary and background; now for some comments. I'd like to be somewhat of an optimist, like Dale used to be in some of his earlier papers. So in thinking about what's going forward, I'll try to raise some questions that challenge these projections. Of course, it is much easier to be the critic on these sorts of things.

Stability of the Parameters

One question I'll raise is about the stability of the parameters used in the IGEM. Every forward-looking projection has to be estimated from the data we actually have in hand now. Since we do not have data on future years, we need to extrapolate from the historical data to project the future. This a natural thing to sort of do; for instance, to get future consumption patterns, you need to look at what people consumed in the past and are consuming now in order to predict what people like my sons will be buying in the year 2030, when they will be the prime-age consumers. What my sons are consuming now—iPods, Xboxes, cell phones, and lots and lots of hours of instant text messaging—pretty much accounts for all of their disposable income and all of their disposable time, as far as I can tell. It's an interesting market basket, because none of those items existed 25 years ago. The point is that right now I cannot predict exactly what my sons are going to be consuming in the year 2030—obviously some of it will be housing and food, and maybe some of the discretionary consumer goods will be in keeping with the electronic technologies they are consuming today, but one would suspect that there is going to be a different consumption pattern and set of relationships. Now if you aggregate these predictions enough, maybe you can lump them all into some broad categories, but it is not so obvious that all these fine-grained parameters are going to stay the same, and we need to remember this. While it is important to try and predict the future in order to make better policy choices today, we have to also recognize that to some degree this is an exercise in uncertainty. Who would have predicted the radio in 1900, television in 1925, video cassette recorders in 1965, or iPods in 1985? Later this week, I'm going out to Cisco Systems to see this new product they call TelePresence, a virtual "in-person" communications system that they think is going to revolutionize the world. A TelePresence unit costs $300,000 and enables people to have meetings across great distances, which cuts down on travel and saves time. While it costs $300,000 now, you can be pretty sure that in the next 10 or 20 years it is going to cost a small fraction of that and will have similar or better capabilities. Is a TelePresence unit going to be a big part of the consumption bundle in the future, much like cell phones or personal computers are today? I would bet it may be a standard part of the consumer market basket in 20 years, even though it's not today, and it could substitute for or complement other things today.

Even aside from the uncertaintly about the future substitution relationships among specific components, the unfortunate reality is that the key variables moved around quite a bit in the past. Take productivity growth, which has bounced around quite a bit over the last couple decades. Dale referred to the pessimism people have with the latest downturn, but over

periods of 10 or 20 years we have seen a doubling or a tripling of key productivity numbers. Surprisingly, in some cases the numbers change even for the exact same year. That happens because of revisions to earlier data. In one of his previous papers, Dale pointed out that for the year 1996, the data were revised to show that productivity growth moved from 0.8 to 2.7 percent. So you've got to take these past numbers with some pretty broad confidence bounds, and some of them with a grain of salt. But again, I'm being the critic here, which is a very easy task. Yet it is very difficult to come up with an alternative approach to the one Dale offers here, as you need to work with the data you have in hand. But I think that bearing in mind how these numbers can change just makes you want to be a little cautious about how precise you are about the predictions made going forward.

Price Identification

Another key issue is price identification, which is critical to this type of analysis. Estimating price effects at the intersection of supply and demand is the canonical example of problems introduced from simultaneity. It's a very tough question to sort out, rather like the chicken-and-the-egg issue of which factor really determines the outcome of the other one. Dale does a fantastic job of using instrumental variables to address these issues of simultaneity—he works out these details in some of the companion papers to the IGEM that he pointed me to. While his instruments pass all the statistical tests, I can't help but feel this nagging sense that I'm not fully understanding the model, because some of the correlations just seem a little unexpected. For instance, Dale mentions that increased price tends to be correlated with more technological change, such that this technology input is used more and more. That seems pretty counterintuitive to me—why would higher prices increase demand?—although that's what the data say. It seems plausible that instead there's some causality going the other direction, with higher demand leading to higher costs, as for instance when greater demand drives up wages in a technologically advancing sector. I'm not sure whether the technical change is leading to more demand for the input, which drives the price increases, but maybe there are some explanations that he can help us with. A related issue on prices is that demand and supply tend to be much more elastic in the long run than in the short run. This raises some questions about which numbers are being used and how these are projected into the future.

Adjustment Costs and Organizational Capital

Another issue is how you deal with adjustment costs and delays and the role of intangible capital. From my understanding of the model, it appears that the instant capital investments are made, these have effects on output and productivity, even before the capital is installed. Now it is difficult to reconcile this assumption with certain categories of intangible capital investment like software and information technology. I've done a lot of work looking at enterprise resource planning (ERP) systems. For instance, Scientific-Atlanta, which is part of Cisco Systems, purchased a large ERP system in late 1994, spent a lot of money and time, and didn't go live with it until 1997; even then, the firm really did not realize its full impact for several years after; see Figure 6.17. This kind of delay partly reflects the complementary of these unmeasured investments in

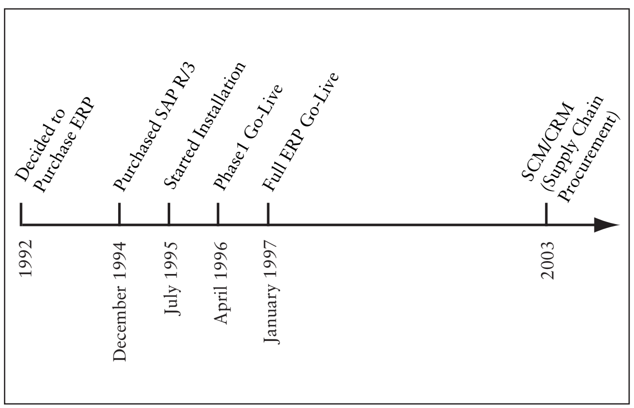

Figure 6.17
Scientific-Atlanta Enterprise Resource Planning (ERP) Timeline
Source: Aral, Sinan, Erik Brynjolfsson, and D. J. Wu. 2006. "Which Came First, IT or Productivity? The Virtuous Cycle of Investment and Use in Enterprise Systems." Working Paper. Cambridge, MA: MIT Center for Digital Business.

intangible capital, which I have become very convinced is a huge factor in the economy even though we don't measure this kind of intangible investment very well.

How do you measure things like organizational capital? I visited a Dell computer factory a few years ago which had doubled its output in response to increased demand. But the way they accomplished this was not by building a new factory next to the first one. Instead, Dell installed some software to redesign their business processes, and by establishing electronic links to their suppliers and their customers, eliminated some of the work-in-process inventory. This set of changes allowed them to produce twice the output with the same bricks and mortar. So had they really built a second factory? Actually, yes. Dell did build a second factory, but it was made out of software and business processes, not bricks and mortar. They installed the organizational capital that was producing real output in the form of physical computers, which resulted in real market value and real revenues. So in that sense, I think installing these new business processes constituted a real capital investment, but unfortunately this investment is not something that shows up in the conventional GDP

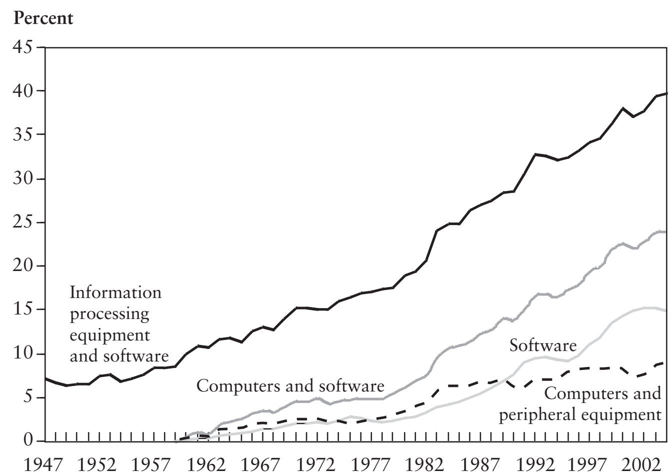

Figure 6.18
Investment Share of Information Technology (Percent of Private Nonresidential Fixed Investments)
Source: U.S. Bureau of Economic Analysis.

accounts as adding to the nation's capital stock. This is not just an isolated story—you can look at many different examples from different firms, and see a similar pattern where hardware is just the visible tip of the iceberg that involves much larger investments like process engineering and human capital investment. These intangible capital investments actually account for the bulk of this capital investment, which I estimate is on the order of $2 trillion of information technology-related and computer- related intangible assets that as a nation we have built up in recent years.

Pessimism on Productivity

In this paper, Dale and his team are very pessimistic on future U.S. productivity gains given some of the other numbers generated in his model's projections. I got the sense that the role of multifactor productivity is grinding to a stop in their model. They don't provide exact numbers for the year 2030, when the projections end, but over the 2004–2030 period productivity is slowing down markedly.

But has productivity growth in the United States has been slowing down historically? If anything, there has been an upsurge in the last decade or so, which in large part reflects gains from information technology. It may be that to calibrate their neoclassical model they need to make some kinds of steady-state assumptions that eliminate the role of exogenous productivity growth. But I'm not sure exactly how this works through their model, and that is something I would be interested in hearing more about in Dale's response. This model's predictions of declining future productivity growth are certainly much more pessimistic than the projections made by a lot of other people who have looked forward, albeit with less elaborate and less sophisticated models. If you look at the bottom line here, for a ten-year period going forward, one of Dale's earlier papers with Min Ho and Kevin Stiroh estimated multifactor productivity growth at about 0.91 percent, which is a bit more than double what it is in the current paper. To square it with the slowdown Dale now anticipates for the next 30 years, maybe all of the projected slowdown in the new paper happens *after* the next 10 years.

Similarly, the paper sees real wages as kind of hitting the ceiling, as you can see in Figure 6.7 of Dale's paper. Real wages rise, but at an ever-declining rate over the 2004–2030 period. Again, from the paper I get the sense this is because of the assumption that long-run capital growth has to equal output growth over time, so you're going to have this asymptote. But I think this prediction may depend on where that asymptote is located. Are we approaching this point in the twenty-first century or sometime in the thirty-first century? I'm not sure, and in my opinion that obviously is going to have a big effect on when we're going to start seeing this kind of tailing off.

To extrapolate these trends that drive the model, we need to speculate on what's going to happen going forward with information technology and labor demand. A big question is whether or not this trend of productivity gains from advances in information technology is going to continue for the next 25 years. Dale predicts that productivity growth in information technology equipment and software will be slower than it was historically over the 1960–2004 period, especially in the computer sector (which is called "non-electrical machinery," ironically). Understanding the "why" behind the trend, as Lisa Lynch mentioned the other day and like the work that David Autor presented yesterday, is especially important when applied to these potential future outcomes.

Today, we have more and more computer applications that are "intelligent," from computer chess grand masters to software agents recommending books to different kinds of robots. Interestingly, in many cases, these applications were made possible simply because of increases computational power. This is useful to know, because improvements in computer power, not just microprocessors and memory, but also in hard drives and other components, are highly predictable. Moore's Law, the doubling of processor power every 18 months, has held for nearly 40 years. Computer scientists and engineers are confident that it will continue for at least another decade, and most think longer than that.

If information technology does continue to post gains as seen in the past, we will start hitting some key thresholds. For example, a lot of the reason that today's computers can't do tasks like using vision to recognize objects as well as a two-year-old human is because our brains are simply much more powerful at the necessary raw computations than computers. The vision centers of our brains have billions of processors that are actually arranged in a very simple way. When engineers try to simulate

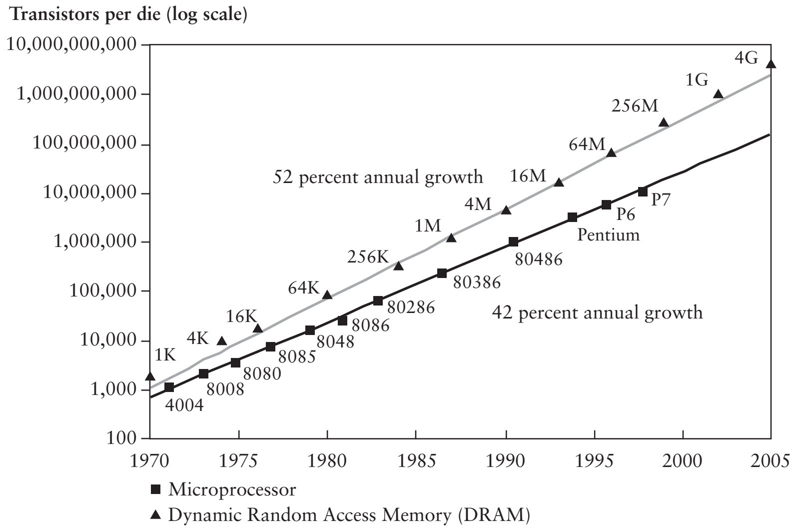

Figure 6.19
Moore's Law and Computer Investments, 1970–2005
Source: Grove, A. S. 1990. "The Future of the Computer Industry." *California Management Review* 33(1): 148–60, and company data. Trend lines are authors' estimates.
Note: P6 and P7 microprocessors and 256M, 1G, and 4G DRAMs are estimated by Intel and the Semiconductor Industry Association.

that ability in computers, it turns out that today's machines do not have the same level of computational power as the human brain. But that's not going to be true if these information technology trends continue for another decade or two. By then, we may actually have a level of computational power that by today's standard falls into the category of things that only humans can do. That will result in a fundamental change in the way the economy works.

Assuming that within the next three decades we will get to this point is a more optimistic scenario than the one Dale presented. In addition, it is quite possible not only that the underlying trends in productivity will continue, but also that the factor share of information technology will continue to grow. Historically, information technology *has* become a bigger and bigger share of the economy, despite the rapidly falling prices of this technology. If this sector continues to take up a bigger share of the economy, then we are going to have not only rapid productivity growth

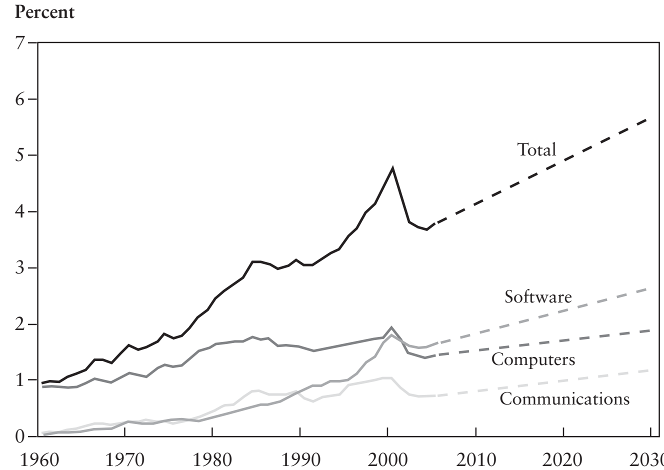

Figure 6.20
Value Added as a Nominal Percentage Share of GDP, 1960–2006, with Projection to 2030
Source: U.S. Bureau of Economic Analysis.

in the related sectors, but this productivity gain is going to have a bigger overall weighted average affect on the economy. This effect will tend to raise the average productivity growth of the economy as a whole, above even its current growth rate.

Let me just close with a comment made by Todd Thompson, the former chief financial officer of Citigroup. When I asked him about whether he was going to be able to cut his information technology budget because of rapidly falling prices, he said, "Oh, I hope not. I'm already spending billions of dollars on technology, and I want to spend more." And I said, why? You don't have to pay as much any more for your computers as you used to, doesn't that mean you can reduce their share of the budget? Thompson replied that Citigroup wants to try and get as much of the rest of the firm's labor force over onto the technology bandwagon, riding down the gains from Moore's law. I think there are a lot of other executives out there who are actively trying to be creative about shifting labor to areas where it can be augmented or replaced with computer power. If they succeed, then instead of winding down, we can expect to maintain or even increase the productivity growth rates we've seen historically.