

**Energy and US Economic Growth in the Next Thirty Years:
The Role of Information Technology and Technical Change**

**Report 3 for the research project "Energy and U.S. Economic Growth in the
Information Age"**

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0. Executive Summary

The U.S. economy has undergone a remarkable resurgence since the mid-1990s with accelerating growth in output, labor productivity, and total factor productivity. Many have attributed this to rapid diffusion of information technology (IT), due to the unprecedented decline in prices of IT equipment and software. At the same time energy use has grown more slowly than output. With these developments came the following questions. Are these high growth rates in IT and GDP sustainable? Will the rate of decline in energy intensity continue or has it reached a plateau? The substitution of capital for energy has long been noted; the new issue is whether the rapid decline in IT prices could lead to faster substitution of IT for energy. This would lead to an optimistic outlook for energy consumption. Alternatively, trends in IT and energy use may be only loosely connected, so that the outlook for reductions in energy intensity would be unaffected by the IT revolution.

This aim of the research project "Energy and U.S. Economic Growth in the Information Age" is to evaluate the prospects for future economic growth and energy use in the U.S., taking account of recent trends in IT prices and investment and changes in input mix and productivity. These issues are often considered at an aggregate level, as in the relationship between growth of GDP and total energy use. Our approach is to address these questions at a detailed industry level and to describe the trends at the economy-wide level by aggregating over the industry results.

Our first step in understanding industry performance was to construct a database covering the whole economy at the industry level. In the first report of this research project, *Energy Efficiency, Information Technology, and the Sources of Growth across U.S. Industries*, we used this database to analyze the sources of growth of industry output covering the period 1977-2000. This period includes the second oil shock and the onset of the Information Age. We estimated the contribution of IT capital, non-IT capital, labor, energy intermediates, non-energy intermediates, and total factor productivity (TFP) to output growth in each industry. The difference in the growth of energy and non-energy intermediates was also compared for each industry. We then calculated the contribution of each industry to aggregate GDP growth, TFP growth, and energy use.

The second step in constructing scenarios for likely future energy utilization is to identify the factors that have led to the past reductions in energy intensity. The reduction in the aggregate energy:GDP ratio is due to two distinct trends, one is the reduction in energy:output ratios at the industry level, and second is the changing composition of aggregate output. Energy economists point to four major factors determining energy use at the industry level: (i) the substitution between energy and other inputs due to price effects, (ii) total factor productivity growth, i.e. improvements in technology that give higher output for the same inputs, (iii) “biases” in technical change that change input mix, even when prices of inputs are not changing, (iv) changes in composition of output within each industry.

In order to quantify the first three factors we estimate industry-level production functions. In the second report of this research project *U.S. Production Technology at the Industry level: Technical Change and Substitution among detailed Inputs* we estimate producer models for each industry, using the database constructed in the first step. Using data from the period 1958-2000 covering the oil shocks in the 1970s and the fall in oil prices in the 1980s we estimated the following for each of 35 industries: (a) the elasticities of substitution among capital, labor, energy intermediates, and non-energy intermediates, (b) the trend rates of productivity growth, and (c) the “biases” of technical change. The fourth factor, changes in composition of sector output, is an issue for studies at a high level of aggregation, for example, manufacturing as a whole. Our division of the economy into 35 industries is aimed at minimizing this factor in our analysis.

In the two earlier reports we find the following. (1) The IT-producing sectors – Machinery and Electrical Equipment – had very high productivity growth rates that are likely to be sustained. (2) Low or negative productivity growth is widespread, including industries which use information technology intensively. The simple average TFP growth over the 35 industries was 0.55% per year. (3) Sectors which use energy intensively had modest to good productivity growth (e.g. Primary Metals had TFP growth exceeding 1% per year), while those which produce energy had both positive and negative TFP growth. (4) The most common pattern of “biases” in technical change is capital-using and labor-saving, that is, productivity growth is retarded by high capital prices and promoted by high wage rates. Among the industries that use energy intensively all, but one, have

energy-using change, but there is no particular pattern among energy producers. (5) There is no strong link between energy-saving technical change and IT use, with the exception of Gas Utilities.

In this third report we project the growth and energy use in the U.S. economy over the next 25 years using a multi-sector model that incorporates the information about recent producer behavior in the above two reports. This model is a general equilibrium model where the prices of energy, prices of non-energy commodities, investment and growth are simultaneously determined for all years. We project that GDP growth will slow down to 2.6% per year from the 3.1% during 1977-2000. This is due to the opposing effects of the sharply slower growth of working age population and the high productivity growth that we expect to be carried forward from the IT boom. We expect to see a continuing fall in the price of investment goods and a rapid growth of investment. The big increase in the supply of capital will favor the capital intensive sectors.

We project good productivity growth in Electric Utilities, and combined with the falling cost of capital, leads to cheap electricity and a high rate of growth of use. In the oil and coal sectors we project a more modest fall in prices leading to a slower growth of fossil fuel use. The projected biases in technical change are quite varied and matters substantially for individual industries. That is, energy cost shares are projected to change substantially for many industries, in both negative and positive directions. However, at the aggregate level there is only a modest net effect. These biases are also not related to the rate of IT use and thus does not benefit from the growth in IT supply.

The net effect of these changes is that fossil energy use per dollar of GDP falls only at a 0.65% annual rate over the next 25 years compared to the 2.3% rate achieved during 1977-2000. The small size of the IT producing sectors gives their rapid TFP growth a tiny contribution to overall reduction in energy:GDP ratios. Electricity per dollar of GDP is expected to rise at a 0.97% annual rate compared to the small decline in the sample period. These trends mean that energy per person is projected to rise at 1.2% per year, compared to the small decline observed during 1977-2000, or the small increase during the boom period 1995-2000. Domestic oil output growth is limited and we project a high growth of oil imports at 3.0%.

Our projected growth rates are somewhat different from those made by the Energy Information Administration in the Annual Energy Outlook 2004. Our GDP growth for 2001-25 is 2.6% per year compared to 3.0% in AEO2004, this is due to our lower projection of labor supply and lower labor productivity growth. Our projected energy use, on the other hand is higher, energy intensity (energy:GDP) only falls at a 0.6% annual rate in our forecasts, whereas it is 1.5% in AEO2004. This is due to our higher productivity growth projection for the energy industries, in particular Electric Utilities. The growth of electricity use is 3.6% compared to 1.8% in AEO2004, while Oil & Gas use rises at 2.4% compared to 1.5%.

These projections show the key role played by changes in technology. Or, in other words, projections of future growth and energy use depend crucially on the assumptions about technical change. Our statistical procedure projects technical change based on the behavior during 1958-2000. Alternative assumptions about the rate and biases of technical progress will change our economic and energy use projections. Our framework allows these alternative assumptions to be easily analyzed.

We should also note that changes in factors that we do not explicitly consider may change things dramatically. This includes world crisis, large oil shocks or environmental regulation. The effects of these shocks may be considered as alternative scenarios using the same methodology that we have developed.

1. Introduction.

The aim of the research project "Energy and U.S. Economic Growth in the Information Age" is to evaluate the prospects for future economic growth and energy use in light of the rapid growth in the production and use of information technology (IT). The Information Age is identified with the resurgence in U.S. economic growth since the mid-1990s and the widespread consensus that this was due mainly to IT. The acceleration in economic growth from 2.4% per year during 1990-95 to 4.2% during 1995-2000 is described in detail in our first report "Energy Efficiency, Information Technology and the Sources of Growth across U.S. Industries" (Jorgenson, Ho and Stiroh 2003). We also noted that the growth of energy use was slower than the growth of Gross Domestic Product (GDP).

With the boom in IT investment and economic growth, and the coincident energy savings, came the following questions: Are these high growth rates in IT and GDP sustainable? Are energy use and IT use related? Will the rate of decline in energy intensity continue or has it reached a plateau? The trends in recent energy use and its prospects are of interest to those concerned with energy policy, and have been analyzed by Hakes (2000) and Romm (1999), among others. Many authors have written about a possible link between information and energy use, e.g. Spreng (1993) and Ruth (1995). Our approach is to address these questions at an industry level and, by carefully aggregating the industry results, analyze the trends at the aggregate level.

Two sets of factors contribute to changes in the aggregate energy:GDP ratio. One is the reduction in energy:output ratios at the industry level, and second is the changing composition of aggregate output. Energy economists point to four major factors determining energy use at the industry level: (i) the substitution between energy and other inputs due to price effects, (ii) total factor productivity growth, i.e. improvements in technology that give higher output for the same inputs, (iii) "biases" in technical change that change input mix even when prices of inputs are not changing, (iv) changes in composition of output within each industry.

Our analysis of economic growth and energy use over the next three decades considers all of these factors except for item (iv) – changes occurring below the industry level, which are excluded by definition. We use a model of the U.S. economy which

includes 35 business industries and 2 sectors for households and government. The substitution between energy and other inputs, in particular IT inputs, is modeled explicitly and provides an important lever for understanding the effects of changes in future world oil prices, or the effects of a slowdown in the rapid decline of IT prices.

Earlier versions of this Intertemporal General Equilibrium Model (IGEM) have been used to study energy and environmental policies, as described by Jorgenson (1998)¹ and Jorgenson, Goettle, Wilcoxon and Ho (2000). The production and consumption functions, determining supplies and demands in this model, are based on detailed data on past industrial performance and household behavior.

Our first step in understanding past industrial performance is to construct an industry database that includes outputs and inputs at a detailed level (roughly 2-digit SIC). This database extends to year 2000 and is a considerable improvement over data used in our earlier analysis of U.S. energy trends. In the first report of this research project, Jorgenson, Ho and Stiroh (2003) used this data to analyze the sources of growth of output for all industries over the period 1977-2000, a period that includes the second oil shock and the onset of the Information Age. We estimated the contribution of IT capital, non-IT capital, labor, energy intermediates, non-energy intermediates, and total factor productivity (TFP) to output growth of each industry (a procedure often called growth accounting). As an example, we find that of the 2.17% annual growth in Electric Utilities during 1977-2000, capital, labor and intermediate inputs contributed 0.89, 0.08 and 0.88 percentage points respectively, while TFP growth contributed 0.34%.

We also compared the differences in the growth of energy and non-energy intermediates for each industry, as well as the difference in growth rates over time. We then calculated the contribution of each industry to aggregate GDP growth, including the contribution of each industry's TFP to aggregate TFP. We found that there were several industries with negative TFP growth. Of the weighted TFP growth of 0.16% per year, the tiny Computer & Office Equipment industry contributed 0.16, the entire amount, while the large Construction industry contributed -0.12. Among the energy sectors Electric

¹ The first chapter of Jorgenson (1998) is Jorgenson and Wilcoxon (1998) which surveys the issue of energy and the environment. Other chapters that describe the model include Jorgenson and Wilcoxon (1993), and Ho (1989).

Utilities contributed 0.01 percentage points and Oil & Gas Mining –0.10. The diversity of industry performance highlights the importance of disaggregating the aggregate numbers.

In the second report, Jorgenson, Ho, Jin and Samuels (2004) estimated the industry production models for incorporation into IGEM, using the updated database covering 35 industries. We estimate parameters that describe the evolution of technology and price-induced substitution among all the inputs, both primary and intermediate inputs. The technology components of the model facilitate a more sophisticated projection of the various industries, where they may evolve at different rates consistent with recent history (e.g. high productivity growth in Electric Equipment versus negative growth in Construction). These components also allow the rate of technical change to be affected by prices. The elasticities of substitution are crucial for estimating the effects of policies that change energy prices. This approach to production makes IGEM an unusually flexible and precise economic model, compared to other multi-sector models, and provides a tight integration among data, parameters and producer sub-models.

Since the data cover the period 1958-2000 we are able to consider the behavior of producers after the oil shocks of the 1970s and during the much-noted productivity revival of the mid-1990s. We found the following: (1) The IT-producing sectors – Machinery and Electric Equipment – had very high productivity growth rates that are likely to be sustained for some time. (2) Low or negative productivity growth is widespread, including some industries that use information technology intensively. The average TFP growth over the 35 industries was 0.55% per year². (3) Sectors which used energy intensively had modest to good productivity growth (e.g. Primary Metals had TFP growth exceeding 1% per year), while those which produce energy had both positive and negative TFP growth. (4) The most common pattern of “biases” of technical change is capital-using and labor-saving, so that productivity growth is retarded by high capital prices and promoted by high labor prices. Among the industries that use energy intensively, all but one has energy-using change, but there is no particular pattern among energy producers. (5) There is no strong link between energy-saving technical change and IT use except for Gas Utilities.

² These are econometrically estimated TFP growth rates under assumed functional forms that are distinct from rates estimated by the growth accounting methods in the first report.

In this third report we incorporate the models of producer behavior estimated in the previous reports into IGEM and simulate the growth of the economy, the change in industrial composition, and the change in energy intensity. We show how the growth in our base case slows down from 3.1% during 1977-2000 to 2.6% for 2001-2025 as labor supply growth slows dramatically but the high TFP growth of the boom period is maintained. The next 25 years is projected to see a continuing fall in the price of investment goods, especially IT goods, and thus a rapid accumulation of capital. This leads to a rapid fall in the cost of capital and a boon to the capital-intensive sectors.

We project a decent productivity growth in the Electric Utilities sector and combined with this falling cost of capital leads to cheap electricity and a high rate of growth of use. In the oil and coal sectors we project a more modest fall in prices leading to a slower growth of fossil fuel use. The projected biases in technical change are quite varied and matters substantially for individual industries. That is, energy cost shares are projected to change substantially for many industries, in both negative and positive directions. However, at the aggregate level there is only a modest net effect.

The net effect of these changes is that fossil energy use per dollar of GDP falls only at a 0.65% annual rate over the next 25 years compared to the 2.3% rate achieved during 1977-2000. Electricity per dollar of GDP is expected to rise compared to the small decline in the sample period. These trends mean that energy per person is projected to rise at 1.2% per year, compared to the small decline observed during 1977-2000, or the small increase during the boom period 1995-2000.

The model projects quite a change in industry structure with rapid output growth in the IT sectors and low growth in the productivity laggards such as Construction. Domestic oil output growth is limited and the projected growth in demand for oil leads to high expected growth of oil and gas imports. Growth in demand for coal, on the other hand, is much slower due to the high productivity growth projected for Electric Utilities, i.e. increasing efficiency in electricity generation reducing unit coal use.

These projections show the key role played by changes in technology. That is, projections of future growth and energy use depend crucially on the forecasts about technical change. Forecasts using formal statistical methods like ours, or forecasts of the type made by EIA (2004), involve uncertainty that increases the further out we go. What

we have here is a framework that can take alternative assumptions about technical change explicitly into account and give a sense of the uncertainty.

In the next section we describe our projection methodology, and in section 3 we review the historical trends in energy use and technical change. Our projections are reported in section 4 which includes a comparison with the Energy Information Administration's projections. Section 5 concludes.

2. Methodology for projecting economic growth, energy use and IT investment.

Our methodology is based on industry-level observations of productivity change, energy substitution and use of Information Technology (IT). This enables us to provide far more detail than previous studies of energy consumption. On the demand side, our projection model incorporates information on demographic and income changes and tracks the changes in household energy demands. This model is an extension and revision of the one used in Jorgenson and Wilcoxon (1993), and Ho and Jorgenson (1994) to analyze environment and trade policies.

In this section we shall give a brief description of the essential features of the projection model; the complete details are presented in Appendix A1. We shall focus on the projection of production behavior including a description of the construction of indices of energy and IT inputs in sections 2.2 and 2.3.

2.1 The Intertemporal General Equilibrium Model (IGEM)

The Intertemporal General Equilibrium Model (IGEM) is a dynamic model of the U.S. economy which describes growth due to capital accumulation, technical change and population change. It is a multi-sector model that tracks changes in the composition of industry output, as well as changes in input mix. It also depicts changes in consumption patterns due to demographic changes, price and income effects.

Capital accumulation in this Cass-Koopmans-type model arises from savings of a household that is modeled as an economic actor with "perfect foresight." Aggregate household consumption and savings are chosen to maximize a utility function that is a discounted sum of the stream of future consumption. Shocks to the economy that are anticipated in the future will affect household decisions today.

Within each period the household chooses between consumption and leisure. The demand for leisure and the time endowment generate the supply of labor services. Total goods and services consumption is allocated to the separate commodities by a detailed sub-model of household demand that includes demographic characteristics and income effects (Jorgenson and Slesnick 1987). This constitutes the main element of the demand side of IGEM. The other elements of demand – investment, government and exports – are also considered, albeit in a less elaborate fashion as household demand.

The production – or supply – side of the model is represented by 35 industries, of which 21 are manufacturing and 5 are energy related. These are listed in Table 1. Each industry produces output using capital, labor, energy and non-energy intermediate inputs and the technology evolves over time. Coal and refined oil and gas are separately identified inputs. We follow the official input-output tables in distinguishing between industries and commodities. Each industry produces a primary commodity and many produce secondary commodities. For example, the Petroleum Refining industry produces mainly refined petroleum products; however, it also has outputs classified as chemicals. The domestically produced commodities are supplemented by imports from the rest of the world, which are treated as imperfect substitutes.

The production side of the model generates demand for capital and labor services. These services are supplied by the household, where capital is the result of past investment. Labor supply is the flip side of leisure demand and is keyed to population growth and demographic change. We assume that capital and labor are mobile, that is, they can be moved costlessly from one sector to another within any period. While this is insufficiently realistic for short-term projections, it is a very useful simplifying assumption for intermediate- and long-term projections. Finally, all the markets for goods and factors are assumed to be competitive. Prices adjust to equate the supply from domestic and foreign producers to the demand from households, investors, government and exports in each period. Prices also adjust to clear the factor markets, that is, we do not model unemployment.

The flows in this model are based on a system of national accounts developed by Jorgenson (1980) that integrates the capital accounts with the National Income Accounts. These capital accounts include the calculation of capital stock from investment flows, and

the calculation of the rental price for the use of capital from income and tax data. There is an equation linking the price of investment goods to the stream of future rental flows, a link that is essential to modeling the dynamics of growth.

This model is implemented econometrically, so that the parameters governing the behavior of producers and consumers are statistically estimated over the time series dataset described in the first report, Jorgenson, Ho and Stiroh (2003). This is in sharp contrast to multi-sector models that are calibrated to the economy of a particular year. The U.S. economy has experienced major shifts, even in the short span of the last half century; these changes that are not captured by movements in prices that are the focus of most economic models.³ The shifts are expected to continue and our projections include an endogenous rate and bias of technical change for each sector that capture the most important non-price effects.

We find it useful to classify our 35 industries by their roles in the production and utilization of energy and IT in Table 2, reproduced from our second report. Five of the industries are labeled as energy producers – Coal Mining (industry 3), Petroleum and Gas Mining (4), Petroleum Refining (16), Electric Utilities (30) and Gas Utilities (31). Seven are classified as energy-using industries; these are industries with value share of energy inputs in total output exceeding 4% in 1995, the beginning of accelerated economic growth. The remaining industries are referred to as “other industries”. We should note that our Electric Utilities industry does not distinguish among fossil fuel, nuclear, and hydroelectric plants.

We also group the industries by their role in IT production and use, as explained in Jorgenson, Ho and Stiroh (2004). The two IT producers are Machinery (22) and Electrical Machinery (23), while 8 industries where the IT capital input exceeds 13% of total capital input in 1995 are classified as IT-using. The remaining 25 industries are labeled as non-IT.

2.2 Production functions and technical change

The response of firms to changes in prices determines the ability of the producers to substitute other inputs to an important degree, including Information Technology (IT) inputs, for energy. Changes in technology have also drastically altered the input mix. The

³ These issues are discussed in Ho and Jorgenson (1998).

exact specification and parameterization of producer behavior and technical change is thus essential for an analysis of future energy trends and responses to energy and environmental policies.

We specify a production sub-model for each of the 35 industries listed in Table 1. This sub-model is a set of nested functions and gives demands for the inputs of capital, labor, 35 intermediate commodities and one non-competing import. At the top tier of this nested structure, the output of industry j at time t is a function of capital, labor, energy and non-energy materials,

$$Q_{jt} = f(K_j, L_j, E_j, M_j, t).$$

Energy, E , and materials, M , are aggregates of the 35+1 intermediate commodities. We find it more convenient to work with the dual cost function instead of the direct production function and write the unit output price as a function of the input prices and technology,

$$P_{Qj} = p(P_{Kj}, P_{Lj}, P_{Ej}, P_{Mj}, t).$$

We choose the translog form for this cost function, as explained in Appendix A1.2.2, and write this function as:

$$(1) \quad \ln P_{Qj} = \alpha_0 + \sum_{i=1}^n \alpha_i \ln P_{it} + \frac{1}{2} \sum_{i,k} \beta_{ik} \ln P_{it} \ln P_{kt} + \sum_{i=1}^n \ln P_{it} f_{it} + f_{pt}$$

$$i,k=\{K,L,E,M\}$$

where α_0, α_i and β_{ik} are parameters that are separately estimated for each industry. Of the remaining variables, the f_{it} 's are state variables representing biases in technical change, and f_{pt} is the state variable for the level of technology. We refer to f_{pt} as the price technology term⁴.

The state variables are unknown functions of time and we express them as a vector auto-regression (VAR). The price technology term is non-stationary but the difference, $\Delta f_{pt} = f_{pt} - f_{pt-1}$, is stationary. Let $\mathbf{F} = (f_k, f_l, f_e, f_m, \Delta f_p)'$ denote the entire vector of stationary state variables. The transition equations are assumed to be governed by:

⁴ This specification using the unobserved state variables is a major change from the deterministic trends used in the earlier version of IGEM described in Jorgenson (1998).

$$(2) \quad \mathbf{F}_t = \mathbf{\Phi} \mathbf{F}_{t-1} + \mathbf{u}_t$$

where \mathbf{u}_t is a random variable with mean zero and $\mathbf{\Phi}$ is a matrix of estimated coefficients of the VAR.

As explained in Appendix equation (A1.6), the demand for inputs derived from the translog cost function is a share equation that is a linear function of the bias term f_{it} . As an example, the share equation for capital input ($i=K$) is:

$$(3) \quad v_{Kt} = \frac{P_K K}{P_Q Q} = \alpha_K + \sum_k \beta_{Kk} \ln P_{kt} + f_{Kt}$$

The parameters β_{ik} are the share elasticities giving the substitution between input- i and input- k ; when $\beta_{ik} = 0$ then the production function has the Cobb-Douglas form with an elasticity of substitution equal to one. The estimation of these parameters is reported in Jorgenson, Ho, Jin and Samuels (2004), our second report. The f_{it} biases capture the non-price shifts in input mix, and most of the industries show a labor-saving and energy-using bias⁵. This implies an increase in the price of energy slows down productivity growth.

Productivity growth translates into a fall in the output price, given input prices. The productivity change between $t-1$ and t is given by:

$$(4) \quad \Delta T_t = - \sum_{i=1}^n \ln P_{it} (f_{it} - f_{i,t-1}) - \Delta f_{pt}$$

where Δf_{pt} captures productivity change. The projection of future levels of technology is given by eq. (2), that is, the cost function for $T+1$ is given by the observed values for the last year of our sample, $T=2000$, and updated by the estimated $\mathbf{\Phi}$ matrix in eq. (2), and so on for all future t , using the Kalman filter.

As we have emphasized in our first two reports, the rate of productivity growth for the IT producing sectors is very high, and accelerated substantially during the 1995-2000 period. This high TFP growth rate is projected by equation (2) for a substantial number of years, since the estimated value of the $\mathbf{\Phi}$ matrix extrapolates the productivity growth rate forward. This leads to a rapid fall in the prices of IT equipment and software,

⁵ These are given in Table 7,8,9 of Jorgenson, Ho, Jin and Samuels (2004).

relative to all the other commodities, as we show below in Section 4. The detailed specifications for the production models are given in the appendix A1.2.3.

2.3 Energy and Information Technology Inputs

In order to generate a tractable model of producer behavior we wrote our production function as

$$Q_{jt} = f(K_j, L_j, E_j, M_j, t)$$

at the top tier, where E_j represents an index of total energy inputs. This illustrates an important issue that many authors have discussed – what is the appropriate method to construct an index representing coal, oil, gas and electricity inputs?

In many analyses, including the U.S. Department of Energy’s *Annual Energy Review*, the simple sum of BTUs is reported, that is, the sum of energy embodied in the primary fuels - coal, oil, gas, nuclear and renewables (*AER* 2002, Table 1.5 for example). The inability of this simple sum to track the changing composition of fuels has been long noted and indices using price weights have been constructed, for example, by Berndt (1990) and Stern (1993). Our measure of energy is given in equation A1.13 in the appendix; the index in the sample period is calculated as a translog aggregate of commodities from Coal Mining, Petroleum and Gas Mining, Petroleum Refining, Electric Utilities, and Gas Utilities⁶:

$$(5) \quad \ln \frac{E_{jt}}{E_{j,t-1}} = \sum_{i=2,3,16,30,31} \bar{v}_{i,j} \ln \frac{X_{ijt}}{X_{ij,t-1}}$$

$$\bar{v}_{i,j} = \frac{1}{2} \left(\frac{P_{it}^X X_{ijt}}{\sum_i P_{it}^X X_{ijt}} + \frac{P_{i,t-1}^X X_{ij,t-1}}{\sum_i P_{i,t-1}^X X_{ij,t-1}} \right); \quad i=2,3,16,30,31$$

This translog index gives greater weight to the more valuable BTUs, so that a BTU of electricity gets a bigger weight than a BTU from coal. The effect of this is that during a period of rising oil prices the fall in the quantity of oil will receive a larger weight and the energy index will fall faster than an unweighted sum of BTUs.

We distinguish between IT as capital goods and IT as intermediate goods. In the production function, K denotes capital input which is an aggregate of 60 different types

⁶ This is given in eq. (2.3) in our first report Jorgenson, Ho and Stiroh (2003), together with the details of the data construction.

of assets; these include the three types that we classify as IT assets – computers and peripheral equipment, software, and communications equipment. These IT assets are the basis of the classification used in Table 2 for dividing the industries into IT-using versus non-IT. Commodities such as semiconductors and other components that go into these IT capital goods as intermediate inputs are counted in the M index in the production function.

The industries that produce IT assets are Machinery, Electronic & Electric Equipment and Services. However, these industries produce many products and they are not all classified as IT goods, in particular, software is a very small fraction of the Services industry (number 34). Semiconductors are produced by the Electronic and Electric Equipment industry, and a substantial portion of this industry output goes as intermediate input into the Machinery industry. Finally, some studies classify workers as IT workers and non-IT workers. We do not make such a distinction, since our labor input index is derived from data that classify workers by educational attainment and age, not by occupation. Including such labor input could change the classification in Table 2, although this is highly unlikely, given the close relation between the share of IT capital and the share of IT labor.

3. Summary of recent trends in energy use and productivity change

The production functions used to make our projections are estimated over the period 1958-2000 for the top tier and 1977-2000 for the lower tiers. We now review the trends in economic activity, energy use and productivity change for these past 25 years, trends that we may then compare with our projections for the next 25 years in section 4 below.

Aggregate indicators

In Table 3 we tabulate the indicators of US economic and energy performance over this period, including the growth rates of aggregate GDP, fuel use of various types, total primary energy in BTUs, total energy consumption using our aggregation index (5), and population. Both the official GDP and our expanded definition are included to show

how the growth rates are similar even though the level estimates are different. The energy data are taken from *Annual Energy Review 2002*⁷.

For the 1977-2000 period GDP grew at 3.08% per year while the population was growing at 1.08%. Of the 3.08% growth in GDP, capital contributed 1.74 percentage points, labor contributed 1.19, and productivity growth only 0.14⁸. The quality of the labor force, the effect of changing composition by educational attainment and experience, was rising at a rapid 0.41% per year in this period. This labor composition change, however, has slowed in recent years. On the other hand, capital quality has been rising at a rapid 1.79% per year for the whole period, and accelerated to 2.33% during the boom period. This capital quality index captures the effect of a rising share of short-lived assets which have high marginal productivities. This reflects the rapid growth of IT capital input, which grew at 16% per year.

All forms of primary energy consumption grew at rates substantially below the GDP growth rate with the exception of nuclear power. Total energy use per dollar of GDP fell at a 2.06% rate, this trend is also plotted in Figure 1. Total electricity use grew 2.67% per year, only slightly slower than GDP growth. This is primary energy from nuclear and hydro, plus secondary energy from fossil fuel plants and grew at very different rates from primary energy.

How did the growth change during the IT boom period 1995-2000? The higher investments in IT capital and much faster TFP growth boosted GDP growth to 4.20% per year. The reduction in energy intensity (BTU per dollar of GDP) accelerated modestly with more rapid growth of output, falling at 2.33% per year compared to 2.06%. These rates of improvement in energy intensity are very similar, but mask two opposing trends. The high rate of growth of nuclear and renewables in the 1977-95 period declined substantially after 1995, while the rate of growth of oil use rose significantly by comparison with the earlier oil crisis period. The IT boom was accompanied by continued

⁷ The BTU and electricity totals are from Tables 1.1, 1.3, 1.5, 8.1, 8.2 of *Annual Energy Review 2002*. This may be obtained from www.eia.doe.gov/emeu/aer/overview.html. Population data are from the Bureau of the Census website, data pre1980 in <http://eire.census.gov/popest/archives/pre1980/popclockest.txt>, data for 1980-90 in *U.S. Population Estimates by Age, Sex, Race, and Hispanic Origin: 1980 to 1999*, and data 1990+ in <http://eire.census.gov/popest/data/national/tables/intercensal/intercensal.php>. These population data are constantly revised to match the latest censuses (e.g. 1981 data is revised to be consistent with the 1990 Census), the latest series may not have been used in the AER Tables 1.5 and D1.

⁸ These are taken from Table 1 of the first report, Jorgenson, Ho and Stiroh (2003).

high growth in the use of electricity, about 2.7% per year in both sub-periods. However, high GDP growth meant that the reduction in electricity per dollar of GDP accelerated to -1.30% per year during 1995-00 from -0.42% for the entire period 1977-2000.

Expressed in per capita terms, the small change in energy intensity improvement combined with the acceleration of GDP growth, meant that the IT boom symbolized the end of falling energy use *per person*. For the entire 1977-2000 period, total energy per capita fell by 0.05% per year, while it rose at a 0.47% rate during the 1995-2000 boom. The trend for the whole period, as shown in Figure 1, consisted of a sharp fall during the oil shock followed by an slow upward trend since the mid-80s.

The pattern for total energy use is the consequence of different trends in the components as shown in Figure 2. Electricity use per person rose at an annual rate of 1.49% during the boom period, very similar to the rate in the prior sub-period. This rise pulled coal use along with it throughout the 1977-00 period. Oil – an item not usually associated with information technology – continued its rise in per capita terms after the sharp fall due to the oil price shocks of the 70s. On average, oil use per capita fell at a 0.93% rate during 1977-2000 but rose at 0.96% during the boom period. This saw-toothed trend is even more marked for natural gas; since bottoming out in 1986, gas use per person has been rising at a 1.4% annual rate.

The final notable feature of the pattern of energy use is the dramatically rising share of imported energy. Energy imports in BTUs, most of which is petroleum, grew at 1.62% per year during 1977-2000, compared to total energy consumption growth of 1.03%. In the IT boom period domestic oil production continued to fall rapidly and energy imports rose at a 5.3% rate, even faster than the booming GDP.

To conclude the summary description of the aggregate economy, we give a snapshot of the economy in year 2000 in Table 4. On the income side, 53.5% of total value added went to labor and the remainder to capital. On the expenditure side investment was 24.3% of GDP, while imports were 13.8%. The energy-producing industries constitute only a small fraction of the modern U.S. economy, of the total value added of \$10651 billion only \$306 billion went to the energy sector. The energy commodity share in terms of gross output is a bit higher, 4.1% of the total \$17.6 trillion. Of the total energy consumption of 98.942 quadrillion BTUs, oil contributed 38.8% while

natural gas contributed 24.2%. Imports were 29.3% of total energy use, measured in terms of BTUs. Since oil constitutes most of the imports and is much more valuable per BTU, the import share of total energy bought is much higher in value terms.

Industry indicators

In our previous two reports we have described the performance of the 35 industries in detail – productivity growth, energy use, IT use, and the change in performance after 1995. We reproduce the highlights of the first report in Table 5, giving the output growth rate, productivity growth, energy use and IT capital use. The dominance of the Computers and Electronic Components sectors in the IT age is given by the high output and TFP growth rates, while the importance of IT inputs is shown by the high growth of IT use in all sectors. The energy-producing sectors showed mixed performance with positive TFP growth in Coal Mining and Electricity, but negative growth in Oil Mining, Petroleum Refining, and Gas Utilities. Similarly, the big energy users show a wide range from the satisfactory TFP growth in Primary Metals to the negative growth in Chemicals.

In the second report we estimated the biases of technical change and found that technical change is “capital-using” and “labor-saving” in a majority of cases, so productivity growth is impeded by high capital costs but enhanced by high labor costs. Among the industries that use energy intensively all, but one, are energy-using, so that productivity growth is hampered by higher energy prices. Among energy producers the biases of technical change go in both directions, energy-saving and energy-using. Looking from the IT dimension, IT producers are energy-using but only in a trivial way. IT-users are modestly energy-saving, with the exception of Gas Utilities with a high rate of energy-saving technical change. We concluded, therefore, that there is little link between IT use and energy performance.

4. Projections of energy use and economic growth

The main determinants of growth in this model are population growth, capital accumulation and total factor productivity (TFP) growth. The sample period of our data is 1977-2000, and we simulate the growth model forward from 2001. We focus our

discussion on growth projections over a 25-year horizon, that is, the change in the economy over the 2001-2025 period.

4.1 Projections of exogenous variables

The exogenous variables driving the economy are described in detail in the Appendix section A2. The key variables are population and working age population, labor quality, government deficits, and trade deficits. Growth rates are summarized in the top portion of Table 6 and compared with growth during the sample period. The first thing to note is the fall in population growth in the next 25 years, and the very sharp decline in growth of the working age population, from 1.18% per year to 0.56%. If capital and technology growth were unchanging this factor alone would reduce the growth rate of GDP per capita. Compounding the slowdown is the severe fall-off in the growth of labor quality from 0.41% to 0.06%. Education attainment and experience were rising rapidly in the sample period with the surge in college enrollments, but this is expected to slow dramatically. Effective labor input growth is thus much slower; the “time endowment” is projected to grow at only 1.07% per year compared to 1.60% in the sample period.⁹

The projected productivity growth and biases in technical change at the industry level are given in Tables 7 and 8. As explained in Appendix A2, the parameters estimated over the sample period are used to project TFP growth. These parameters consist of two components, the rate and biases of technical change. The first column of Table 7 gives the rate of technical change over the period 2001-2025. The IT-producing sectors are expected to continue their high rates of productivity growth; Electronic & Electric Equipment is projected to enjoy a TFP growth rate of almost 5% per year while Industrial Machinery has a 1.5% rate of growth. Among energy producers Electric Utilities and Gas Utilities have very high projected TFP growth rates, exceeding 1.6% per year. Construction, on the other hand, has negative growth continuing at a dismal -0.79% per year.

In the first column of Table 8 we give the projections of the energy biases. This is the change in the f_{et} term (eq. 1) between 2001 and 2025, where a negative value

denotes a falling share of energy costs in total costs. The magnitudes of these changes should be compared to the simulated shares in 2001. For example, in Primary Metals the econometrically estimated change over the next 25 years is 0.0131 and the simulated energy cost share is 0.0544 (5.44% of total costs). However, other things will also change in this period, such as the price of capital, and the final rise in energy shares is only 0.0076. Among energy producers Petroleum & Gas Mining and Petroleum Refining have negative projected energy biases, while Coal Mining, Electric and Gas Utilities have positive biases.

4.2 Projections of output and energy use

Using the projections of exogenous trends, the model solves for the steady state and calculates a transition path. The endogenous variables are calculated for each period so that markets clear and conditions for inter-temporal equilibrium hold. The results for 2001-2025 are given in the bottom of Table 6, and in Tables 7 and 8. GDP is projected to grow at an average of 2.61% per year over the 25-year horizon. This results from the very modest growth in the working age population and a rapid accumulation of capital. The contribution of capital is 1.66 percentage points, while labor only contributes 0.29 and TFP growth 0.66. The share of GDP going to investment is projected to be higher than in the sample period and this leads to a high rate of capital stock growth. The high TFP growth projected for the IT sectors continues to generate a contribution of TFP much like the boom period, considerably higher than the contribution in the period 1977-2000.

The rapid growth of TFP and capital accumulation leads to a substantial rise in real wages. This would have tended to reduce the demand for leisure and raise labor supply, but the effect of growth in per capita income and the demographic changes predominate. Over the period 2001-2025 leisure per capita rises at 0.51% per year.¹⁰

How did rapid growth of GDP and TFP affect energy use? There are a number of forces acting in different directions: (i) Modest TFP growth in the energy-mining sectors mean that fuel prices are rising relative to other inputs and demand is diminished. (ii)

⁹ We construct an index of the time available to the whole population by aggregating over all adults using wages as weights. Each adult may allocate his hours between work and leisure. This aggregate index is referred to as the “time endowment” of the economy.

¹⁰ As was explained in the previous footnote the aggregate index uses wages as weights, the older workers who retire are still given weight in the time endowment calculation, albeit a smaller weight compared to the high wage prime-aged workers. The retirement effect alone raises the leisure share substantially.

Strong TFP growth in Electric Utilities and Gas Utilities leads to a fall in prices and higher demand for these secondary energy sources. This leads, in turn, to higher demand for primary fuels. (iii) The energy-using industries have a mixed set of TFP projections, from -0.09% in Transportation to 0.75% in Stone, Clay & Glass. This means that their output prices go in different directions and the net effect on energy demand is not very sizable.

The net effect is that fossil fuel energy per dollar of GDP is falling at a slow rate of 0.65% per year, compared to the 2.3% rate during 1977-2000. Total fossil energy consumption grows at 1.96% per year, compared to the 2.61% for GDP. The growth paths of GDP and energy use are plotted in Figure 3. Oil and gas consumption grows faster than the use of coal, since the poor TFP performance in Coal Mining generates higher relative coal prices. Since our model has only one Electric Utilities sector, we cannot project the use of nuclear and hydroelectric power separately. These non-fossil sources constituted about 14% of total primary energy in the U.S. in 2000, as noted in Table 4.

Petroleum imports grew very rapidly during the boom of 1995-00 and this continues into the projection period, due to our assumptions of limited capital input for the Oil Mining industry and stable world oil prices. Petroleum import growth is projected at 3.0% compared to the 1.6% rate during the past 25 years.

The electrification of the economy continues apace with the electricity:GDP ratio rising at 0.97% per year. This may seem surprising, but can be attributed primarily to healthy TFP growth in Electric Utilities and the rapid accumulation of capital. The rise in capital supply leads to a rapid fall in the cost of capital; since Electric Utilities is a capital intensive sector, it is able to reduce the electricity price quickly, encouraging electricity consumption. In terms of per capita consumption, electricity is rising at a much faster rate than during the sample period, 2.83% per year versus 1.59%.

We next take a closer look at the projected performance of the individual industries, as a consequence of changes in supplies and demands for the various commodities. Relative supplies are driven in substantial part by the TFP growth in the first column of Table 7. We see large outward shifts in supply for Electric Equipment,

Instruments, Electric Utilities, Gas Utilities and Agriculture due to this effect. On the other hand, Coal Mining, Services and Construction see negative shifts in supply.

The change in input prices – P_K, P_L, P_E, P_M – is the next important determinant of changes in supply. The relatively flat labor supply and rapidly rising stocks of capital affect relative costs to the extent that labor:output and capital:output ratios differ. Capital-intensive sectors, such as most of the manufacturing industries, benefit most from the fall in the cost of capital and see the biggest reductions in unit costs. The rise in the cost of energy input is indicated by the relatively small decline in the prices of Coal and crude petroleum and natural gas. This indicates a modest decline relative to the price of labor, a big rise relative to the price of capital, and an increase relative to the price of non-energy materials. This has large negative effects on supply from the energy-using sectors – Chemicals, Stone-Clay-Glass, Primary Metals, and Transportation.

Turning to the demand curves, these shift at rates that differ from GDP growth to the extent that the final demand patterns change. As described in section 2, the household demands are allowed to have income elasticities different from one; as incomes rise the share of total expenditure going to food falls and the share for services rises. The other components of domestic final demand – investment and government – are assumed to have unit income elasticities. These shifts are small in comparison to the shifts in the supply curves with the exception of Food. The demand for food is inelastic and this means a very slow growth in the Food industry despite positive TFP growth and a decline in price.

The net effect of these shifts in supply and demand curves are the price and quantity changes given in Table 7. In the second column is the average annual growth (% per year) in industry output prices between the first year and 25th year, all prices are relative to the numeraire, the price of labor, which is 1.0 in all periods. All the industry output prices fall relative to the labor price; however, the largest declines are in the industries with the most rapid TFP growth. The relation between price change and TFP change is also plotted in Figure 4. For most sectors there is a clear link between projected productivity growth and the output price decline. In other words, for most sectors the TFP effect dominates the effect of changing input prices or demand shocks.

The Electronic and Electric Equipment industry, which makes semiconductors, has the biggest TFP gain and price fall, and sees the largest gain in output, growing at 10.5% per year. This is followed by Instruments and Industrial Machinery, which makes computers, both growing at 5.5%. Gas Utilities benefit from both high TFP growth and a fall in Petroleum-Gas Mining prices, so that the price of delivered gas declines rapidly and gas deliveries grow at 5.9% per year.

Finally, we examine projected energy use for individual industries. The *level* of demand for energy by each particular industry is driven by the demand for the output of that industry. Here we discuss the *unit* energy use which is driven by input prices and technical change. In the first column of Table 8 we give the projected change in the energy bias term (f_{et} in the cost function in eqs. 1 and 3) as was described in section 4.1 above. In the second column we give the energy cost share in the first year of the simulation, this range from a tiny half percent in Communications to 80% in Petroleum Refining. In the third column we give the change in cost share between 2001 and 2025. In Figure 5 we plot this change in cost shares versus the change in the energy bias term.

While the energy cost share is affected by both prices and technical change, the strong relation between shares and energy biased technical change is apparent for many sectors. The industries with the largest projected change in the energy bias term -- Petroleum Refining, Coal Mining, and Electric Utilities -- have the largest changes in energy cost shares, positive or negative. Of course not all sectors have this pattern, Transportation has a rise in the energy bias term but a projected fall in the energy cost share.

Before we conclude this description of the projections we should review the features of our methodology that generates these high growth rates of energy use that may surprise some.

- Our industry classification at the 2-digit SIC level means that we cannot examine the electricity, transportation and other sectors at a level of detail found in other studies of energy use. We have a basket of capital with one price, and this price is an important determinant of the cost of producing a unit of electricity or a unit of transportation services. The malleability of capital assumption and the rapid accumulation that we project means that all users of capital pay a common price

that is falling over time. That is, we cannot account for the possibility that the capital price of a nuclear reactor, or the price of an airport, may behave differently from the average capital price. To the extent that these costs are underestimated we would have overestimated the demand for energy.

- The specification of technical change in equations (1) and (2) is fairly elaborate for the level of disaggregation used here. Our statistical method generates error bounds that naturally increase with the projection period. These uncertainties are in every forecasting method, they are formally defined in ours. If the rate of productivity growth in Electric Utilities turns out to be lower than our central projection, then the price would be falling slower, and the growth of electricity consumption slower.
- We have not included possible and likely changes in pollution control laws. Regulations to reduce mercury or carbon emissions will certainly mean higher prices and lower consumption (see e.g. Jorgenson (1998) chapter 3). Similarly, more intense efforts to improve traffic management will generate trends different from recent history that are not captured by our parameter estimates.

4.3 Comparison to other projections

The most important set of projections of energy patterns by the U.S. government is the *Annual Energy Outlook* (AEO) published by the Energy Information Administration. Other organizations provide forecasts of various aspects of energy but we shall focus our comparisons with the EIA (2004) projections here (comparisons of the EIA forecasts with the others are given in p. 107-116 of AEO 2004)¹¹.

The AEO projections are based on the National Energy Modeling System (NEMS) of the EIA which has separate modules for macroeconomic, household, industry and international projections, in addition to distinct modules for each major form of energy. It is not a general equilibrium system like IGEM where growth is endogenously determined, that is, the prices of commodities (say, price of energy and capital) are simultaneously determined with the rate of energy consumption, investment and growth.

¹¹ The information in this section is from AEO 2004 with further details from <http://www.eia.doe.gov/oiaf/aeo/index.html> , downloaded November 2004.

In NEMS the GDP growth is specified by the macroeconomic module and drives the other forecasts of energy prices and quantities; shocks in the energy modules do not feed back to affect aggregate GDP. In NEMS the energy industries are modeled in great detail, for example, electricity is generated with many different technologies explicitly projected. Such different approaches should be expected to generate different forecasts and one might gain a better understanding of the different methods by contrasting the projections.

The comparisons are given in Table 9. The first differences to note are the projections of the drivers of GDP growth. Up to 2025 we project that the combination of changes in working age population, labor force participation rates, work hours and labor quality would only increase effective labor supply by 0.6% per year. The growth rate of the working age population is 0.56%, markedly less than the 0.8% for total population. In contrast, NEMS has labor force growing faster than total population, at 0.9% per year (work hours are assumed to grow equally with the labor force in NEMS). Secondly, we project TFP growth (aggregated over the 35 industries) at 0.66%, and together with the endogenous capital accumulation generates a labor productivity growth rate of 2.0%. AEO 2004 projects a slightly higher 2.3% exogenous growth rate for labor productivity.¹² The net result is that we project GDP to grow at only 2.6% between 2001-2025, while AEO 2004 projects 3.1%.

Our model does not explicitly account for energy from non-fossil fuels (they are implicit in the Electricity sector) and we project fossil fuel use to grow at 1.96%, or a reduction in energy intensity (fossil fuel:GDP) of 0.65% per year. The AEO 2004 projects a much slower growth of energy consumption and has energy:GDP falling by 1.5% per year.¹³ Our projection of Oil & Gas use is 2.4% per year, about a half higher than the EIA's, this is most likely due to our projected productivity growth in mining and refining leading to a big fall in Oil & Gas price relative to the coal price, and a modest rise relative to the prices of non-energy intermediates. The projected consumption of electricity is double that of the EIA's, 3.6% versus 1.8%. Our high projection is due in

¹² Labor productivity growth is given by the sum of total factor productivity growth, capital deepening, intermediate input deepening, and labor quality growth. Setting this exogenously, as NEMS does, means ignoring the link between the investment generated by the macroeconomic module and this capital deepening.

large part to the high TFP growth and the cheap capital leading to cheap electricity. The counterpart of this high TFP growth is a modest growth in coal use, our projected coal consumption growth is only 0.9% per year compared to 1.6% in AEO2004. These very different rates of electricity output and coal use are the result of the parameter estimates of the production function in eq. (1) which show a good degree of substitubility among inputs. If the actual ability to substitute capital for energy materials turns out to be less than our estimates, then the electricity price would have been higher and output lower, and coal input higher. The detailed specification of the various electric generating technologies in NEMS gives a far more elaborate estimate of the substitution possibilities, however, we should note that their projections are also forecasts of costs quite distant into the future.

Our high rates of energy consumption arising from relatively cheap energy delivered by high productivity growth may appear very optimistic. These are based on the estimates of the productivity trends specified in equations (1) and (2), over the sample period 1958-2000. Should the future perform more poorly than indicated by past trends we would have slower output and consumption.

5. Conclusion

The last twenty-five years have seen substantial changes in energy consumption patterns in the U.S. with a rapidly falling energy:GDP ratio and a smaller, but still substantial, decline in energy per capita. The revolution in Information Technology gave rise to a boom in productivity and output after 1995. However, our earlier two reports found no simple relation between these two events. Industries with a large increase in IT input have not seen noticeably higher reductions in energy intensity. We do see that energy use rose during the IT boom, reversing the earlier fall in BTU per capita. However, this can be attributed to the changes in energy prices and incomes rather than any effect of IT investment.

Drawing on recent industry performance and consumption patterns we projected the growth of the U.S. economy, the change in industrial structure, and the utilization of energy. The slow growth of the working age population does imply more modest growth

¹³ The energy use projections are from AEO2004 Table A1 and A2.

in GDP, compared to the recent past, but the recent high rate of productivity growth is projected to continue and thus lead to higher per capita income. The strong projected growth of TFP in the IT sectors means a continuing fall in the cost of capital and rapid investment growth.

The effect of changes in TFP and the falling cost of capital imply that the cost of energy in general will fall at a moderate pace, relative to the cost of labor, and rise relative to the cost of non-energy materials. However, for electricity and gas in particular, the productivity effects are strong and prices are projected to fall substantially, leading to a rapid growth of energy utilization. We project a modest fall in the use of primary energy per dollar of GDP but rising electrification.

In projecting technical change we have allowed for the possibility that it may be input biased, that is, either energy-using or energy-saving. In the second report we found that there were strong biases in the sample period for many industries. These energy-using or saving trends are included in our projections and found to matter considerably. This points to the necessity of considering not only price changes, but also changes in technology, when making projections of the future.

It is clear that our projections of productivity change are crucial in determining the estimate of future growth. Or, in other words, projections of future growth and energy use depend crucially on the assumptions about technical change. Our statistical estimation procedure gives a projection based on behavior during 1958-2000. Alternative assumptions of technical change may be easily examined by our model of the U.S. economy. For example, some may be skeptical about continued negative growth of productivity in so many industries. Our approach can employ the alternative assumption of zero TFP growth, instead of negative, and examine the effects on the projections.

We should also note that changes in factors that we do not explicitly consider may change things to a greater or smaller extent. This includes world crisis, large oil shocks, or tighter environmental protection standards. The effects of these shocks may be considered as alternative scenarios using the same methodology that we have developed.

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Table 1: Classification of industries and Industry Characteristics, 2000

	Industry Name	Output	Value-Added	SIC
1	Agriculture	389.0	195.8	01-02, 07-09
2	Metal Mining	15.6	7.2	10
3	Coal Mining	23.1	14.2	11-12
4	Petroleum & Gas Mining	136.7	72.7	13
5	Nonmetallic Mining	18.9	10.6	14
6	Construction	995.3	419.2	15-17
7	Food Products	487.6	156.1	20
8	Tobacco Products	35.9	10.1	21
9	Textile Mill Products	61.6	21.8	22
10	Apparel and Textiles	84.3	32.9	23
11	Lumber and Wood	116.0	43.3	24
12	Furniture and Fixtures	88.0	39.6	25
13	Paper Products	176.0	72.9	26
14	Printing and Publishing	233.5	137.7	27
15	Chemical Products	422.7	183.4	28
16	Petroleum Refining	235.1	26.4	29
17	Rubber and Plastic	170.3	77.5	30
18	Leather Products	10.6	4.0	31
19	Stone, Clay, and Glass	111.0	53.5	32
20	Primary Metals	190.6	59.7	33
21	Fabricated Metals	279.5	125.5	34
22	Industrial Machinery and Equipment	472.3	193.6	35
23	Electronic and Electric Equipment	433.3	195.9	36
24	Motor Vehicles	427.7	83.1	371
25	Other Transportation Equipment	186.2	87.1	372-379
26	Instruments	183.3	104.4	38
27	Miscellaneous Manufacturing	52.7	21.9	39
28	Transport and Warehouse	553.5	263.3	40-47
29	Communications	430.3	231.0	48
30	Electric Utilities	245.9	166.6	491, %493
31	Gas Utilities	81.2	26.4	492, %493, 496
32	Trade	1965.7	1187.2	50-59
33	Finance, Insurance & Real Estate	2009.4	1240.0	60-67
34	Services	3455.3	2197.3	70-87, 494-495
35	Government Enterprises	256.3	167.7	
36	Private Households	1394.4	1394.4	88
38	General Government	1194.2	1194.2	

Notes: Figures in billions of current dollars. % indicates part of an SIC code.

Table 2. Classification of industries by the IT share of total capital input and energy share

	IT share of capital input	IT Classification	Energy share	Energy Classification
1 Agriculture	0.012	non-IT	0.022	
2 Metal Mining	0.056	non-IT	0.089	Using
3 Coal Mining	0.036	non-IT	0.134	Producer
4 Petroleum and Gas	0.029	non-IT	0.188	Producer
5 Nonmetallic Mining	0.031	non-IT	0.093	Using
6 Construction	0.065	non-IT	0.015	
7 Food Products	0.044	non-IT	0.013	
8 Tobacco Products	0.047	non-IT	0.005	
9 Textile Mill Products	0.096	non-IT	0.029	
10 Apparel and Textiles	0.085	non-IT	0.012	
11 Lumber and Wood	0.036	non-IT	0.018	
12 Furniture and Fixtures	0.083	non-IT	0.013	
13 Paper Products	0.043	non-IT	0.035	
14 Printing and Publishing	0.265	IT-using	0.009	
15 Chemical Products	0.061	non-IT	0.047	Using
16 Petroleum Refining	0.030	non-IT	0.682	Producer
17 Rubber and Plastic	0.075	non-IT	0.022	
18 Leather Products	0.037	non-IT	0.013	
19 Stone, Clay, and Glass	0.053	non-IT	0.053	Using
20 Primary Metals	0.043	non-IT	0.051	Using
21 Fabricated Metals	0.070	non-IT	0.016	
22 Industrial Machinery	0.198	IT-producing	0.010	
23 Electronic & Electric Equipment	0.155	IT-producing	0.011	
24 Motor Vehicles	0.045	non-IT	0.007	
25 Other Transportation Equipment	0.183	IT-using	0.009	
26 Instruments	0.453	IT-using	0.008	
27 Miscellaneous Manufacturing	0.069	non-IT	0.013	
28 Transport and Warehouse	0.126	non-IT	0.055	Using
29 Communications	0.561	IT-using	0.005	
30 Electric Utilities	0.062	non-IT	0.145	Producer
31 Gas Utilities	0.191	IT-using	0.554	Producer
32 Trade	0.222	IT-using	0.023	
33 Finance, Insurance & Real Estate	0.136	IT-using	0.009	
34 Services	0.172	IT-using	0.011	
35 Government Enterprises	0.112	non-IT	0.048	Using

Shares are calculated for 1995.

Table 3. U.S. economic and energy performance during 1977-2000 (growth rate, % per year).

	1977-2000	1995-2000
GDP (official)	3.09	3.95
GDP (ours)	3.08	4.20
Capital input contribution	1.74	2.27
Labor input contribution	1.19	1.30
Total factor productivity	0.14	0.63
Capital stock	2.64	2.87
Capital quality	1.79	2.33
IT capital input	16.22	19.28
Population, total	1.08	1.16
Population, aged 18-64	1.18	1.38
Labor quality	0.41	0.33
Time endowment	1.60	1.57
Energy consumption (BTUs)	1.03	1.62
Energy consumption index	1.66	3.24
Coal use	2.10	2.34
Oil use	0.15	2.11
Natural Gas use	0.80	1.00
Nuclear	4.64	2.11
Renewables	1.61	-1.59
Electricity use	2.67	2.65
Energy use per \$GDP	-2.06	-2.33
Oil per \$GDP	-2.95	-1.84
Electricity per \$GDP	-0.42	-1.30
Energy use per capita	-0.05	0.47
Coal per capita	1.02	1.18
Oil per capita	-0.93	0.96
Electricity per capita	1.59	1.49
Energy imports (BTUs)	1.62	5.27

Table 4. The economy in year 2000

		2000	Share (%)
GDP (ours)	(bil \$)	10651	100.0
Capital input		4532	42.5
Labor input		5693	53.5
Indirect taxes		426	4.0
Consumption		6687	62.8
Investment		2587	24.3
Government		1741	16.3
Exports		1103	10.4
Imports		1467	13.8
Value added of energy producers		306	2.9
Gross domestic output	(bil \$)	17623	100.0
Gross output of energy producers		722	4.1
Population	(million)	282.4	100.0
Aged 65+		35.1	12.4
Total energy consumption	(trillion BTU)	98942	100.0
Coal		22645	22.9
Oil		38404	38.8
Natural Gas		23953	24.2
Nuclear		7862	7.9
Other primary		6079	6.1
Imported energy		29035	29.3
Electricity	(tr kWh)	3605	

Table 5. Industry performance 1977-2000 (% per year)

	Output growth	Productivity growth	Energy input growth	IT capital input growth
1 Agriculture	2.40	1.84	0.11	22.2
2 Metal Mining	1.97	1.35	0.47	19.5
3 Coal Mining	1.89	2.75	-0.01	27.5
4 Petroleum & Gas Mining	-0.32	-0.98	-2.51	20.1
5 Nonmetallic Mining	1.12	-0.17	-0.20	33.5
6 Construction	1.65	-1.28	0.88	24.2
7 Food Products	1.76	0.62	0.03	18.6
8 Tobacco Products	-0.37	-1.99	1.38	15.3
9 Textile Mill Products	1.03	1.63	-0.75	18.0
10 Apparel and Textiles	0.20	0.77	-1.39	16.6
11 Lumber and Wood	1.18	0.18	0.08	19.0
12 Furniture and Fixtures	3.45	0.65	2.75	19.8
13 Paper Products	1.64	0.26	0.38	16.6
14 Printing and Publishing	2.06	-0.45	1.81	22.6
15 Chemical Products	1.45	-0.01	0.73	21.8
16 Petroleum Refining	0.47	-0.46	1.61	10.8
17 Rubber and Plastic	3.61	1.30	1.47	18.8
18 Leather Products	-2.06	0.15	-1.09	12.5
19 Stone, Clay, and Glass	1.65	0.51	0.42	13.7
20 Primary Metals	0.22	0.70	-1.51	14.1
21 Fabricated Metals	1.98	0.43	1.36	20.3
22 Industrial Machinery and Equipmen	7.22	3.42	1.49	16.6
23 Electronic and Electric Equipment	8.82	4.48	2.10	15.9
24 Motor Vehicles	2.60	-0.26	0.43	18.6
25 Other Transportation Equipment	2.32	0.17	2.01	20.9
26 Instruments	4.14	1.28	1.41	24.0
27 Miscellaneous Manufacturing	1.12	-0.26	0.43	17.1
28 Transport and Warehouse	2.76	0.18	1.88	17.3
29 Communications	4.48	0.17	2.59	7.0
30 Electric Utilities	2.17	0.34	1.92	18.5
31 Gas Utilities	-1.87	-0.78	-2.48	25.9
32 Trade	3.38	0.56	1.11	24.9
33 Finance, Insurance & Real Estate	4.32	0.22	4.32	20.8
34 Services	4.05	-0.40	2.19	22.7
35 Government Enterprises	2.46	-0.12	2.43	16.1

Table 6. Projections of the U.S. economy compared to history

	1977-2000	2001-2025
Exogenous variables		
Population growth	1.08	0.75
Population aged 16-64	1.18	0.56
Labor quality growth	0.41	0.06
Time endowment	1.60	1.07
Model projections		
GDP	3.08	2.61
Capital input contribution	1.74	1.66
Labor input contribution	1.19	0.29
Total factor productivity	0.14	0.66
Capital stock	2.64	4.15
Leisure per capita	0.41	0.51
Total imports	5.85	3.79
Energy from fossil fuels	0.78	1.96
Coal use	2.10	0.88
Oil and gas use	0.39	2.39
Electricity use	2.67	3.58
Oil imports	1.62	2.98
Energy (fossil) per \$GDP	-2.30	-0.65
Electricity per \$GDP	-0.41	0.97
Energy (fossil) per capita	-0.30	1.21
Electricity per capita	1.59	2.83

Note: Entries are growth rates in % per year.

Table 7. Projected industry performance 2001-2025

	Exogenous Productivity growth (%pa)	Projected price change (%)	Projected Output growth (%pa)
1 Agriculture	1.57	-57.2	2.50
2 Metal Mining	-0.43	-24.2	0.54
3 Coal Mining	-1.35	-5.6	0.88
4 Petroleum & Gas Mining	0.74	-30.0	1.99
5 Nonmetallic Mining	-0.24	-28.8	-2.34
6 Construction	-0.79	-12.0	-0.21
7 Food Products	0.36	-45.7	0.60
8 Tobacco Products	-0.07	-40.6	0.79
9 Textile Mill Products	1.63	-58.3	4.12
10 Apparel and Textiles	0.80	-48.4	3.58
11 Lumber and Wood	0.11	-37.0	0.70
12 Furniture and Fixtures	0.89	-41.7	-3.23
13 Paper Products	0.72	-46.0	2.94
14 Printing and Publishing	-0.70	-8.3	0.86
15 Chemical Products	0.66	-48.9	3.24
16 Petroleum Refining	0.36	-43.6	3.56
17 Rubber and Plastic	0.82	-44.6	2.92
18 Leather Products	0.45	-37.4	2.54
19 Stone, Clay, and Glass	0.75	-43.5	1.90
20 Primary Metals	0.01	-35.1	0.10
21 Fabricated Metals	0.60	-40.5	-0.01
22 Industrial Machinery	1.49	-56.8	5.50
23 Electronic & Electric Equip	4.92	-85.0	10.49
24 Motor Vehicles	-0.49	-27.6	-1.14
25 Other Transportation Equip	0.42	-38.1	0.21
26 Instruments	2.76	-60.8	5.69
27 Miscellaneous Manufacturing	1.75	-58.5	4.78
28 Transport and Warehouse	-0.09	-21.6	1.64
29 Communications	1.53	-55.8	2.95
30 Electric Utilities	1.92	-61.5	3.57
31 Gas Utilities	1.68	-62.5	5.94
32 Trade	-0.13	-22.2	1.01
33 Finance, Insurance, Real Estate	0.34	-35.8	3.24
34 Services	-0.67	-5.5	1.09
35 Government Enterprises	1.21	-48.0	2.57

Table 8. Projected energy bias trends and energy use by industry 2001-2025

	Change in f(E,j) 2001-25	Energy share of total costs in 2001	Change in energy share 2001-25
1 Agriculture	-0.0010	0.0333	-0.0050
2 Metal Mining	-0.0074	0.0368	0.0094
3 Coal Mining	0.0208	0.1406	0.0769
4 Petroleum & Gas Mining	-0.0530	0.1899	-0.0768
5 Nonmetallic Mining	0.0074	0.3230	-0.0218
6 Construction	-0.0014	0.0254	-0.0007
7 Food Products	-0.0020	0.0164	-0.0001
8 Tobacco Products	0.0029	0.0067	0.0044
9 Textile Mill Products	0.0034	0.0348	0.0061
10 Apparel and Textiles	0.0016	0.0139	0.0045
11 Lumber and Wood	0.0001	0.0287	-0.0017
12 Furniture and Fixtures	-0.0001	0.0185	0.0057
13 Paper Products	0.0067	0.0466	-0.0008
14 Printing and Publishing	0.0006	0.0098	-0.0063
15 Chemical Products	0.0059	0.0574	0.0014
16 Petroleum Refining	-0.0092	0.7975	-0.0101
17 Rubber and Plastic	0.0018	0.0245	-0.0058
18 Leather Products	-0.0020	0.0201	-0.0003
19 Stone, Clay, and Glass	0.0001	0.0557	-0.0173
20 Primary Metals	0.0131	0.0544	0.0076
21 Fabricated Metals	-0.0008	0.0186	-0.0090
22 Industrial Machinery	0.0019	0.0101	-0.0038
23 Electronic & Electric Equip	0.0017	0.0136	-0.0026
24 Motor Vehicles	0.0019	0.0088	0.0013
25 Other Transportation Equip	-0.0003	0.0079	-0.0067
26 Instruments	0.0027	0.0081	0.0009
27 Miscellaneous Manufacturing	-0.0074	0.0160	-0.0086
28 Transport and Warehouse	0.0047	0.0427	-0.0153
29 Communications	0.0056	0.0054	0.0056
30 Electric Utilities	0.0275	0.1950	0.0496
31 Gas Utilities	0.0118	0.5917	0.0024
32 Trade	-0.0068	0.1416	-0.0198
33 Finance, Insurance, Real Estate	0.0013	0.0077	0.0032
34 Services	0.0022	0.0138	0.0052
35 Government Enterprises	-0.0150	0.0706	-0.0255

Table 9. Comparison with EIA's projections in Annual Energy Outlook 2004

	Ours (2001-25)	AEO2004 (2002-25)
Labor supply	0.6	0.9
TFP	0.7	
Labor productivity	2.0	2.3
GDP	2.6	3.1
Energy from fossil fuels	2.0	
Total primary energy		1.5
Coal use	0.9	1.6
Oil and gas use	2.4	
Oil use		1.6
Gas		1.4
Nuclear		0.2
Electricity use	3.6	1.8
Oil and Gas imports	3.0	
Oil imports		2.6
Gas imports		3.1
Energy (fossil) per \$GDP	-0.6	
Total energy per \$GDP		-1.5
Energy (fossil) per capita	-0.3	
Total energy per capita		0.7

Note: Entries are growth rates in % per year.

Fig 1. Energy (BTUs) per capita and per \$GDP (1977=1)

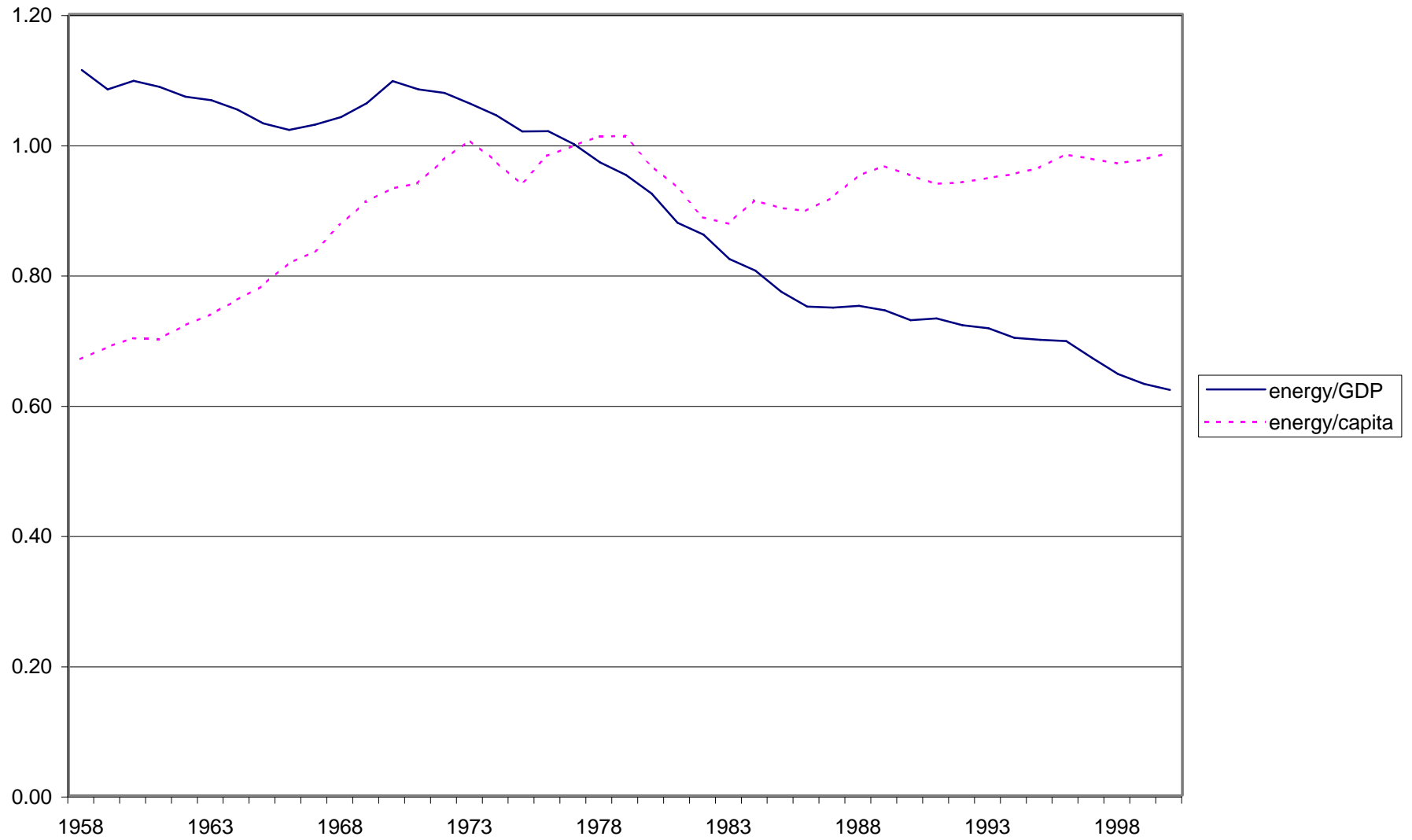


Fig. 2. Per capita consumption of various types of energy (1977=1)

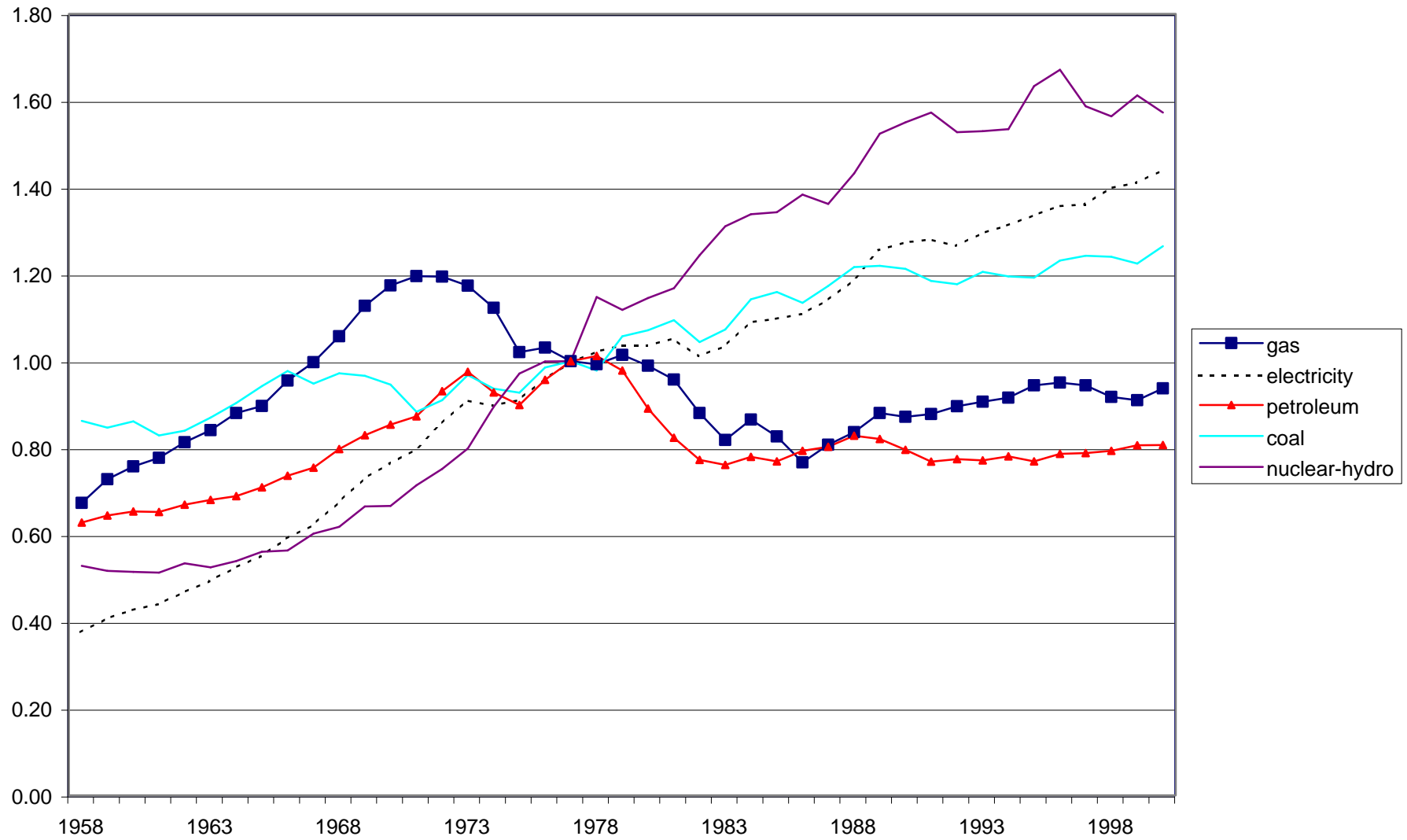


Fig. 3. Projected GDP, Energy and Electricity use

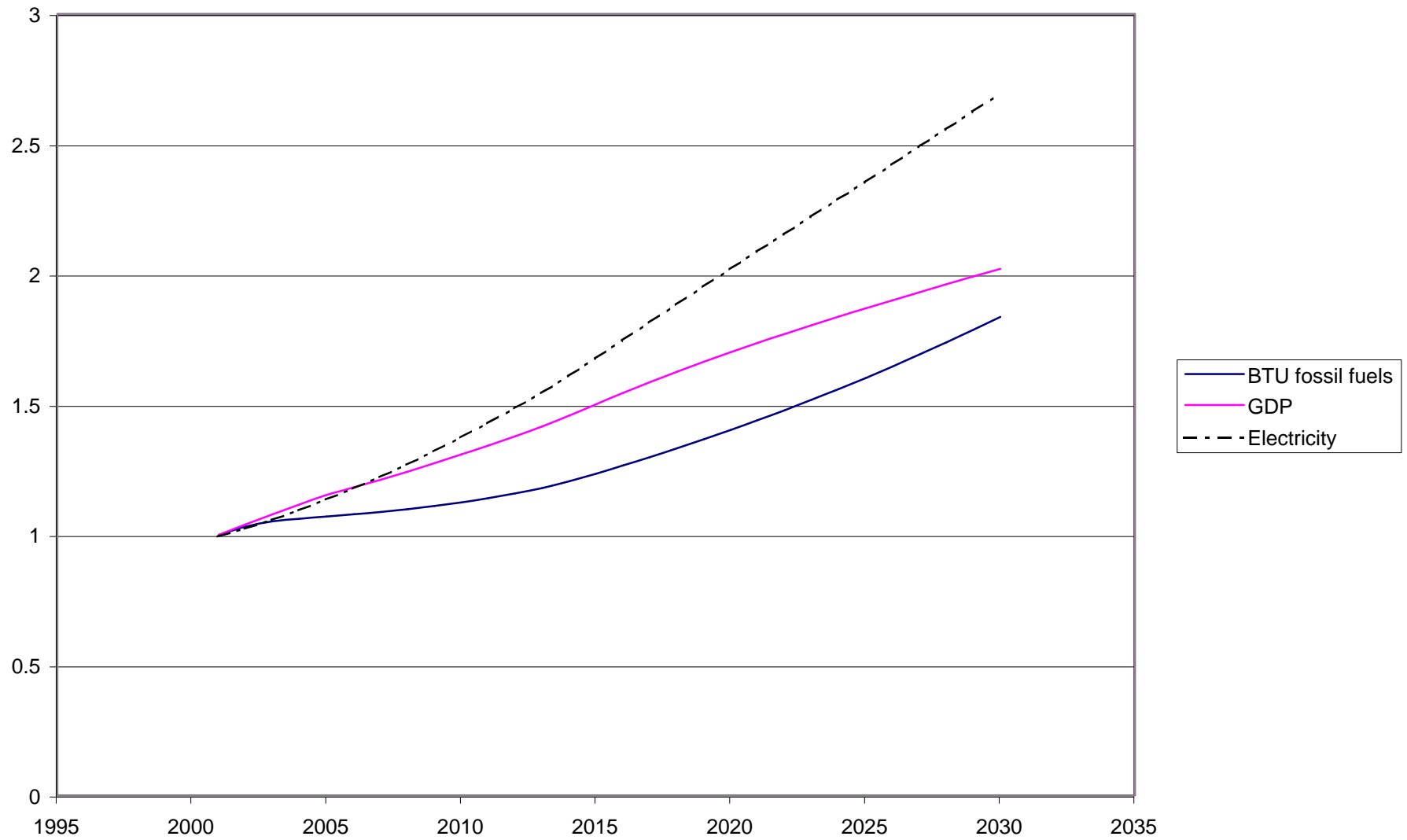


Fig 4. Projected TFP change and price change, 2001-25

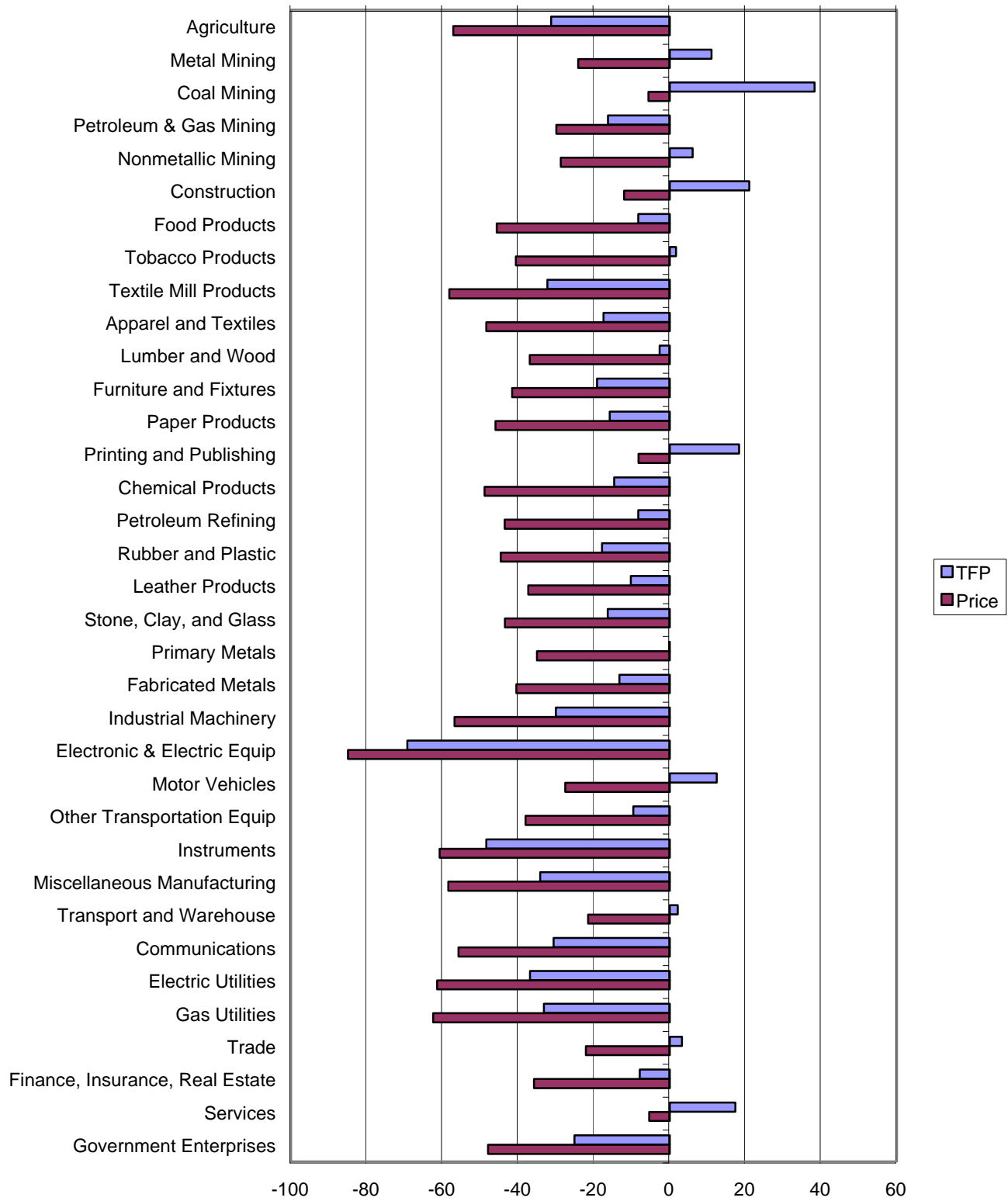


Fig 5. Energy bias coeff. & change in energy shares 2001-25

