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GLOBAL ECONOMIC PROSPECTS: MEDIUM TERM PROJECTIONS AND STRUCTURAL CHANGE

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ABSTRACT

This paper explores prospects for the world economy to the year 2020 through a series of scenarios based on different assumptions about future changes in the structure of individual economies. It differs from most other medium term studies because we do not assume that each economy's variables (such as output, energy use, resource depletion or pollution) all grow in proportion to GDP. In fact, we argue that simple extrapolations derived by projecting GDP and assuming all variables grow in proportion would do a particularly poor job of explaining the historical record (and there is no reason to expect this approach to do better in the future). In our work we instead start with projections of future population growth and industry-level technical change based on a wide range of empirical studies. We use these projections in an empirically-based multi-sector general equilibrium model of the world economy to calculate GDP and other variables endogenously. We then explore the sensitivity of the aggregate outcomes across economies to the assumptions about sectoral productivity growth. In particular, we use as a metric the emissions of carbon dioxide from fossil fuel use in the global economy. Under each set of assumptions we calculate the size of a carbon tax sufficient to stabilize emissions in 2010 at 1990 levels. We show that this tax varies significantly depending on the assumptions made about productivity growth at the sectoral level.

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1 Introduction

Projecting the course of the world economy over the next few decades is a daunting task. One only need look at the history of the last half century to see precisely how difficult it is. How accurately, for example, would we have been able to predict the 1995 world economy in 1965? To take a single economy as an example, 1965 forecasts of the 1995 US economy would almost certainly have missed all of the following: the sharp decline of the US steel industry, the rapid increase in market share by Japanese automobile manufacturers, the explosion of the computer industry, the decline in manufacturing employment and the expansion in services, the sharp decrease in energy use per capita and per unit of GDP brought about by the oil price shocks, and the transition of the US from international creditor to net debtor. Moving from the US economy to the world as a whole adds countless more events which would probably not have been predicted in 1965, ranging from the extraordinary growth of Japan to the rapid increase in the volume of world trade.

History holds at least three lessons which are important to remember. The most obvious is simply that today's projections are unlikely to be right. The immediate consequence of this is that projections of the world economy should be used more to discover which variables are important than to develop point estimates of future GDP or other variables. The second lesson is that the most interesting and important events are likely to lie in the details of individual industries and countries. The third lesson, demonstrated vividly by the oil shocks of the 1970's, is that people respond to changes in prices. Together these lessons mean that projecting aggregate GDP is unlikely to be useful: it will almost certainly be wrong and it will fail to capture the most important events. To put this another way, the 1995 world economy is clearly not a simple scaling of the 1965 economy.[1]

To make this point more concrete, consider the effect of the 1973 and 1979 oil price shocks on the economies of the U.S. and Japan. Figure 1 shows GDP, energy use and carbon dioxide emissions for the United States from 1965 to 1990 (each series has been normalized to one in 1965).[2] Figure 2 shows the same series for Japan[3]. Before the 1973 increase, oil prices were low and energy use per unit of GDP was relatively constant. When prices rose, however, energy use per unit of GDP began to fall significantly. During that period, in other words, energy use was growing substantially more slowly than GDP. In economic terminology, American and Japanese energy users substituted away from energy when oil prices where high; in ordinary language, they conserved energy. From this example it is clear that economies can be highly responsive to changes in relative prices, even over fairly short periods of time.

The evidence in these graphs has been analyzed more formally in a number of papers using econometric techniques to quantify the responsiveness of energy demand to changes in relative prices. For example, using a model with moderate disaggregation, Ban (1991) estimates that the responsiveness of the Japanese economy to changes in energy prices has been high and much of the change in the energy/GNP ratio from the early 1970's to the late 1980's has been due to the response of households and firms to changes in relative prices of energy. A recent OECD study covering a range of countries also comes to the same conclusion. Hoeller and Coppel (1992) estimate price and income elasticities for carbon emissions using a cross-section of 20 OECD countries. After accounting for energy taxes in each economy, the authors found that for 1988 the income elasticity of carbon emissions was 0.95 and the price elasticity was -0.75. In other words these results imply that a 10 percent rise in the price of carbon emissions would potentially reduce carbon emissions by 7.5 percent. (Since this figure is based on a cross-section study it should be considered a long-run result.) Both the income elasticity and the price elasticity are somewhat larger than would be consistent with the results we present below. Comparing this to the historical record suggests that a 1960 projection of current carbon emissions based on output growth alone would miss nearly half of the actual movements in carbon emissions for OECD countries.

Thus, future projections for carbon emissions depend not just on GDP growth projections but also importantly on changes in relative energy prices as well as a range of other economic factors. This suggests that an exercise of this kind requires the use of a global general equilibrium model that embodies the empirical relationships we have observed during the recent decades.

In this paper we use a multi-sector, multi-region world economic growth model called G-Cubed to explore the roles of population growth and differential rates of productivity growth across countries and sectors in determining the future course of the world economy. G-Cubed is a neoclassical growth model in the spirt of Cass-Koopmans and Ramsey. The behavior of households and firms in the model is based on econometric evidence from the postwar period. As a result, G-Cubed will be able to capture the demonstrated ability of economies to respond to changes in relative prices. In addition, the model also accounts for physical capital accumulation, perhaps the single most important determinant of economic growth. We base our forecasts of future population on projections produced by the World Bank; our productivity figures are taken from various papers in the productivity literature.

Implications for Stabilizing Carbon Emissions

In addition to presenting projections of the world economy through the year 2020, we also consider how the composition of GDP growth contributes to industrial emissions of carbon dioxide, an important greenhouse gas[4] that has received the attention of policy makers concerned about global warming.[5] In particular, we calculate how large a carbon tax[6] would have to be to hold year 2010 emissions to 1990 levels. We chose this particular policy because it is similar to proposals now being considered under the auspices of the United Nations Framework Convention on Climate Change (which we will refer to from now on as the Framework Convention). The Framework Convention was one of the centerpieces of the United Nations Conference on Environment and Development, held in Rio de Janeiro in June 1992. It was signed by more than 150 countries and became legally binding in March 1994.

Among other things, the Framework Convention requires each developed country to try to hold its year 2000 greenhouse gas emissions to the levels prevailing in 1990. Some of these countries were required to submit a "National Action Plan" specifying targets for future greenhouse gas emissions and describing the policies to be used to make sure these targets are achieved. These national action plans were to be reviewed by the supreme body of the Framework Convention, the "Conference of the Parties". After the Conference of the Parties review, the Convention requires countries to move toward adopting specific, binding targets for greenhouse emissions.

The first meeting of the conference of the Parties was held in Berlin in late March 1995. At this meeting the “Berlin Mandate” was adopted. The Berlin Mandate acknowledged that the commitment of developed countries to take measures aimed at returning their greenhouse gas emissions to 1990 levels by the year 2000 was not adequate to achieve the Convention's objective. To allow for this slippage in commitment by developed economies, the meeting established a process that would enable the Parties to take appropriate action for the period beyond 2000 up to the year 2020. The meeting did not introduce any new commitments for developing countries. The outcome of the conference suggests that developed economies are not undertaking any serious attempts to mitigate greenhouse gas emissions in the foreseeable future. Nonetheless we will assume that all countries attempt to stabilize emissions at 1990 levels by 2010 in order to explore how stabilization taxes vary with assumptions about sectoral productivity growth.

An Outline of the Rest of the Paper

In the following section we present a general discussion of the sources of economic growth. In subsequent sections we: present G-Cubed, the model we use to assess the effects of population and productivity growth; discuss world population forecasts and the economic literature on productivity growth; present simulation results for different assumptions about future productivity growth; present results for a carbon tax to stabilize emissions; and draw conclusions.

2 The Sources of Economic Growth

At an abstract level there are four sources of growth within an individual economy: (1) increases in the supply of labor, capital and other inputs; (2) increases in the quality of these inputs, (3) improvements in the way inputs are used (technical change); and (4) improvements in the way that inputs are allocated across industries. For the world economy as a whole, a fifth source of growth is reallocation of inputs among countries. The first three effects can be illustrated with a simple model. Suppose an industry can be represented by the following Cobb-Douglas production function:

$$Y_t = A_t(F_tK_t)^{\beta}(G_tL_t)^{\gamma}(H_tM_t)^{(1-\beta-\gamma)}$$

where: Y_t is output at time t; K_t, L_t and M_t are inputs of capital, labor and materials; β and γ are parameters; A_t is a coefficient reflecting the overall level of productivity; and F_t, G_t, and H_t coefficients capturing the quality of each input.[7] This expression can be transformed into a relationship between growth rates by differentiating with respect to time and dividing through by Y_t. The result is shown below, where lower case variables represent the rates of growth of the corresponding upper case variables:

$$y = a + \beta(f+k)+\gamma(g+l)+(1-\beta-\gamma)(h+m)$$

Output growth will thus be a weighted sum of overall productivity growth (a), increases in the quantity of factors (k, l ,and m), and increases in factor quality (f, g, and h). The weights in the sum are parameters of the production function.[8]

A more general expression can be obtained by relaxing the assumption that the production function is Cobb-Douglas. Suppose the production process may be represented by a constant returns to scale function Q which depends on the level of technology, A, and quality-adjusted inputs of capital, labor and materials:

$$Y_t = Q(A_t \, , \, F_t K_t \, , \, G_t L_t \, , \, H_t M_t)$$

If firms minimize costs taking prices as given it is straightforward to show that the rate of output growth will be given by:

$$y = \left(\frac{1}{Q} \frac{\partial Q}{\partial A} \right) a \; + \; S_K (f+k) \; + \; S_L (g+l) \; + \; S_M (h+m)$$

where the first term on the right hand side is called the rate of total factor productivity (TFP) growth, and S_K, S_L and S_M are the shares of capital, labor and materials in total costs. This expression is similar to the Cobb-Douglas case except that the weights in the sum are now cost shares instead of production function parameters. In fact, the Cobb-Douglas function is a special case in which the cost share of each input can be shown to be equal to the corresponding parameter. The main difference between the two expressions is that the general case is nonparametric: decomposition of the growth rate does not depend on estimates of production function parameters. Moreover, observations of the rates of growth of inputs and outputs cannot be used to estimate parameters of the production function since no parameters are identified. For the purposes of analyzing growth, however, this is not a liability.[9]

As an empirical matter, decomposing output growth into its constituent pieces is a difficult task. For many industries, measuring the rate of output growth y is fairly straightforward: the quantity produced in one year is compared to the quantity produced the previous year. However, determining the source of the growth requires very careful accounting to measure the quality-adjusted rates of growth of factor inputs. Any errors in measuring inputs will cause the rate of total factor productivity growth to be misstated.

It is worth emphasizing the last point: studies of the sources of growth use the equation above to determine total factor productivity growth (*tfp*) *as a residual* after accounting for other factors:

$$tfp = \left(\frac{1}{Q} \frac{\partial Q}{\partial A} \right) a = y - S_K(f+k) - S_L(g+l) - S_M(h+m)$$

Any error in the measurement of input growth rates will cause *tfp* to be measured incorrectly. Denison (1962), Christensen and Jorgenson (1969), and others have emphasized that careful accounting for quality adjusted growth of inputs leaves little residual growth to be attributed to improvements in total factor productivity.

Jorgenson (1988) has shown that for the economy as a whole there is also another potential source of growth: reallocation of resources between industries. To see this consider an economy with two sectors, *X* and *Y*. If the overall productivity of labor in sector *X* is higher than it is in sector *Y* (say because of prior technical change), a shift in final demand from *Y* to *X* shifts primary factors from *Y* to *X* and will result in growth of total output. This occurs even if there is no concurrent productivity growth in the individual sectors. The effect is even more pronounced if the composition of demand shifts toward sectors which have productivity growth rates that are higher than average.

Thus, in order to project the world economy over the next few decades we would need underlying projections of each country's labor force, capital stock, materials inputs, changes in factor quality and changes in product demand patterns. Many of these will lead to changes in relative prices and thus change the structure of each region's economy. Moreover, the evolution of each country's capital stock will be an endogenous result of domestic and foreign investment decisions. In order to combine all of these projections, capture the effects of relative price changes, and project the future path of the capital stock we have developed a disaggregated intertemporal general equilibrium model called G-Cubed. In the next section we describe the key features of G-Cubed. In section 4 we survey empirical estimates of productivity growth rates and discuss the estimates used in G-Cubed to generate projections of the world economy over the next few decades.

3 An Overview of The G-Cubed Model

We now present a brief overview of the features of our model, G-Cubed, that are important for this study. A more complete description is contained in McKibbin and Wilcoxen (1995a) or McKibbin and Wilcoxen (1994).

G-Cubed has several features which together distinguish it from other models in the literature. It uses econometric estimates of parameters describing preferences and production technology; it integrates macroeconomic adjustment with the sectoral adjustment to changes in exogenous variables; it captures the link between flows of goods and flows of assets between economies; and it endogenously determines financial prices such as interest rates and exchange rates which play a crucial role in the adjustment of the global economy to alternative projections and policies.

G-Cubed disaggregates the world economy into the eight economic regions listed in Table 1. Each region is further decomposed into a household sector, a government sector, a financial sector, the twelve industries shown in Table 2, and a capital-goods producing sector. This disaggregation enables us to capture regional and sectoral differences in the impact of alternative environmental policies.

In the remainder of this section we present an overview of the theoretical structure of the model. To keep notation as simple as possible we have not subscripted variables by country except where needed for clarity. The complete model, however, consists of eight of these submodels linked by international trade and asset flows.

Producer Behavior

Each producing sector is represented by a single firm which chooses it inputs and its level of investment in order to maximize its stock market value subject to a multiple-input production function and a vector of prices it takes to be exogenous. We assume that output can be represented by a constant elasticity of substitution (CES) function of inputs of capital (K), labor (L), energy (E) and materials (M). Omitting industry and country subscripts the production has the following form:

$$Q = A_O \left(\sum_{j=K,L,E,M} \delta_j^{1/\sigma_O} X_j^{(\sigma_O - 1)/\sigma_O} \right)^{\frac{\sigma_O}{(\sigma_O - 1)}}$$

where Q is the industry's output, X_j is the quantity of input j, and A_O, δ_j and σ_O are estimated parameters which vary across industries. In addition, the A_O and δ parameters vary across countries. Without loss of generality we constrain the δ's to sum to one. We introduce technical change by specifying that X_L , the effective input of labor in each industry, is equal to hours of work multiplied by a country- and industry-specific labor quality adjustment factor. This specification has the effect of making stationary the ratio of prices to wages per effective labor unit (Harrod neutrality), which is convenient when solving the model.

Energy and materials, in turn, are CES aggregates of inputs of intermediate goods. The form of the function is the same as for the output tier but the inputs and estimated parameters are different. For energy:

$$X_E = A_E \left(\sum_{j=1}^{5} \delta_j^{1/\sigma_E} X_j^{(\sigma_E - 1)/\sigma_E} \right)^{\frac{\sigma_E}{(\sigma_E - 1)}}$$

where X_E is the industry's input of energy, X_j is the quantity of input j, and A_E, δ_j and σ_E are estimated parameters which vary across industries. As before, A_E and the δ parameters also vary across countries. The materials aggregation is defined in a similar manner.

In order to estimate the parameters in these equations we constructed a time-series data set on prices, industry outputs, value-added, and commodity inputs to industries for the United States. The following is a sketch of the approach we followed; complete details are contained in McKibbin and Wilcoxen (1995a).

We began with the benchmark input-output transactions tables produced by the Bureau of Economic Analysis (BEA) for years 1958, 1963, 1967, 1972, 1977 and 1982.[10] The conventions used by the BEA have changed over time, so the raw tables are not completely comparable. We transformed the tables to make them consistent and aggregated them to twelve sectors. We then shifted consumer durables out of final consumption and into fixed investment.[11] We also increased the capital services element of final consumption to account for imputed service flows from durables and owner-occupied housing. Finally, we used a data set constructed by Dale Jorgenson and his colleagues to decompose the value added rows of the tables,[12] and a data set produced by the Office of Employment Projections at the Bureau of Labor Statistics to provide product prices. We use this data to estimate the elasticities of substitution in production at different levels of the nest.

To parameterize the other regions we impose the restriction that substitution elasticities are equal throughout the world. In other words, we assume that each industry has the same energy, materials and KLEM substitution elasticities no matter where it is located. This is consistent with the econometric evidence of Kim and Lau in a number of papers (see for example Kim and Lau (1994)). However, the share parameters for other regions corresponding to individual countries (Japan, Australia, China, and approximately the Eastern Europe and Former Soviet Union region) are derived from input-output data for those regions and are not set equal to their U.S. counterparts. The share parameters for the remaining regions, which are aggregates of individual countries, are calculated by adjusting U.S. share parameters to account for actual final demand components from the aggregate national accounts data for each of the regions. In effect, we are assuming that all regions share production methods that differ in first-order properties but have identical second-order characteristics. This is intermediate between the extremes of assuming that the regions share common technologies and of allowing the technologies to differ across regions in arbitrary ways. Finally, the regions also differ in their endowments of primary factors and patterns of final demands. The main limitation of this approach is that there are very few benchmark input-output tables so our data set contains few observations. The problem is severe outside OECD countries.

Maximizing the firm's short run profit subject to its capital stock and the production functions above gives the firm's factor demand equations. At this point we add two further levels of detail: we assume that domestic and imported inputs of a given commodity are imperfect substitutes, and that imported products from different countries are imperfect substitutes for each other. Thus, the final decision the firm must make is the fraction of each of its inputs to buy from each region in the model (including the firm's home country). We represent this decision using a two-tier CES function, although in this version of the model data limitations have forced us to impose unitary substitution elasticities. We assume that all agents in the economy have identical preferences over foreign and domestic varieties of each particular commodity.[13] We parameterize this decision using trade shares based on aggregations of the 4-digit level of the United Nations SITC data for 1987. The result is a system of demand equations for domestic output and imports from each other region.

In addition to buying inputs and producing output, each sector must also choose its level of investment. We assume that capital is specific to each sector, that investment is subject to adjustment costs, and that firms choose their investment paths in order to maximize their market value. The capital stock changes by the amount of gross investment less depreciation of existing capital.

Following the cost of adjustment models of Lucas (1967), Treadway (1969) and Uzawa (1969) we assume that the investment process is subject to rising marginal costs of installation. To formalize this we adopt Uzawa's approach by assuming that in order to install J units of capital the firm must buy a larger quantity that is quadratic in the rate of investment.

Setting up and solving the firm's investment problem yields an equation for investment that depends on taxes, the size of the existing capital stock and marginal q (the ratio of the marginal value of a unit of capital to its purchase price).

Following Hayashi (1979), the investment function is modified to improve its empirical properties by writing investment as a linear function of optimal investment and current capital income. This improves the empirical behavior of the specification and is consistent with the existence of firms that are unable to borrow and therefore invest purely out of retained earnings.

In addition to the twelve industries discussed above, the model also includes a special sector that produces capital goods. This sector supplies the new investment goods demanded by other industries. Like other industries, the investment sector demands labor and capital services as well as intermediate inputs. We represent its behavior using a nested CES production function with the same structure as that used for the other sectors. However, we estimate the parameters of this function from price and quantity data for the final demand column for investment.

Households

Households consume goods and services in every period and also demand labor and capital services. Household capital services consist of the service flows of consumer durables plus residential housing. Households receive income by providing labor services to firms and the government, and from holding financial assets. In addition, they also may receive transfers from their region's government.

Within each region we assume household behavior can be modeled by a representative agent with an intertemporal utility function of the form:

$$U(t) = \int_t^{\infty} (\ln C(s) + \ln G(s)) e^{-\theta(s-t)} ds$$

where C(s) is the household's aggregate consumption of goods at time s, G(s) is government consumption, which we take to be a measure of public goods supply, and θ is the rate of time preference.[14] The household maximizes its utility subject to the constraint that the present value of consumption be equal to human wealth plus initial financial assets. Human wealth (H) is the present value of the future stream of after-tax labor income and transfer payments received by households. Financial wealth (F) is the sum of real money balances, real government bonds in the hands of the public (Ricardian neutrality does not hold in this model because some consumers are liquidity-constrained; more on this below), net holdings of claims against foreign residents and the value of capital in each sector. Under this specification, the value of each period's consumption is equal to the product of the time preference rate and household wealth.

Based on the evidence cited by Campbell and Mankiw (1987) and Hayashi (1982), however, we assume that only a portion of consumption is determined by these intertemporally-optimizing consumers and that the remainder is determined by after-tax current income. This can be interpreted as liquidity-constrained behavior or as permanent income behavior when household expectations are backward-looking. Either way we assume that total consumption is a weighted average of the forward looking consumption and backward-looking consumption.

Within each period the household allocates expenditure among goods and services in order to maximize C(s), its intratemporal utility index. In this version of the model we assume that C(s) may be represented by a Cobb-Douglas function of goods and services.[15]

The supply of household capital services is determined by consumers themselves who invest in household capital in order to generate a desired flow of capital services. We assume that capital services are proportional to the household capital stock. As in the industry investment model, we assume that investment in household capital is subject to adjustment costs.

Government

We take each region's real government spending on goods and services to be exogenous and assume that it is allocated among final goods, services and labor in fixed proportions, which we set to 1987 values. Total government spending includes purchases of goods and services plus interest payments on government debt, investment tax credits and transfers to households. Government revenue comes from sales taxes, corporate taxes, personal income taxes, and from issuing government debt. In addition, there can be taxes on externalities such as carbon dioxide emissions.

We assume that agents will not hold government bonds unless they expect the bonds to be serviced, and accordingly impose a transversality condition on the accumulation of public debt that has the effect of causing the stock of debt at each point in time to be equal to the present value of all future budget surpluses from that time forward. This condition alone, however, is insufficient to determine the time path of future surpluses: the government could pay off the debt by briefly raising taxes a lot; it could permanently raise taxes a small amount; or it could use some other policy. We assume that the government levies a lump sum tax equal to the value of interest payments on the outstanding debt. In effect, therefore, any increase in government debt is financed by consols and future taxes are raised enough to accommodate the increased interest costs. Thus, any increase in the debt will be matched by an equal present value increase in future budget surpluses. Other fiscal closure rules are possible such as always returning to the original ratio of government debt to GDP. These closures have interesting implications but are beyond the scope of this paper (see Bryant and Long (1994)).

International Trade and Asset Flows

The eight regions in the model are linked by flows of goods and assets. Flows of goods are determined by the bilateral import demands described above. These demands are summarized in a set of bilateral trade matrices which give the flows of each good between exporting and importing countries. There is one 8 by 8 trade matrix for each of the twelve sectors for each country.

Trade imbalances are financed by flows of assets between countries. We assume asset markets are perfectly integrated across the OECD regions. With free mobility of capital, expected returns on loans denominated in the currencies of the various regions must be equalized period to period according to a set of interest arbitrage relations. In generating the baseline of the model we allow for risk premia on the assets of alternative currencies although during simulations we assume these risk premia are constant and unaffected by the shocks under study. For the non-OECD countries we also make the assumption that exchange rates are free to float at an annual frequency. We also assume that capital is freely mobile within the regions and between the regions and the rest of the world. This may seem simplistic since many developing countries have restrictions on short term flows of financial capital. Many of these countries nonetheless have significant flows of direct foreign investment responding to changes in expected rates of return. In the model, capital flows capture both of these effects because they include foreign direct investment as well as short term financial capital. Future work will focus more on modeling financial markets in the developing regions of the model. Finally, we assume that OPEC chooses its foreign lending in order to maintain a desired ratio of income to wealth subject to a fixed exchange rate with the U.S. dollar.

Labor Markets

We assume that labor is perfectly mobile among sectors within each region but is immobile between regions. Thus, within each region wages will be equal across sectors. The nominal wage is assumed to adjust slowly according to an overlapping contracts model where nominal wages are set based on current and expected inflation and on labor demand relative to labor supply. In the long run labor supply is given by the exogenous rate of population growth, but in the short run the hours worked can fluctuate depending on the demand for labor. For a given nominal wage, the demand for labor will determine short-run unemployment.

Money Markets

Finally, we assume that money enters the model via a constraint on transactions. We use a money demand function in which the demand for real money balances is a function of GDP and short-term nominal interest rates. The supply of money is determined by the balance sheet of the central bank and is exogenous.

4. Projecting Labor Supply and Productivity Growth

The first step in using G-Cubed to project the future path of the world economy is to obtain appropriate estimates of the rates of labor force growth, total factor productivity growth, and factor augmentation for each country and industry in the model. For each of these we relied on the large literature of empirical studies of the post-war historical record.

This section discusses those studies and describes how we used them to construct parameters for G-Cubed.

Labor Supply

To compute long run labor supply growth we began by assuming that labor force participation rates remain constant. As a result, labor force growth will be exactly equal to population growth. To project population, we used figures from the World Bank.

Figure 3 shows population levels for G-Cubed regions for five periods beginning in 1970. As one would expect, the largest increases have been in China and the LDC region. Figure 3 provides an uncomfortable reminder of the scale of the population problem -- excluding China, the LDC region added more than a quarter of a billion people between 1985 and 1990. Figure 4 shows population growth rates, which are projected to decline. If population growth continues to slow, global population will eventually stabilize, albeit at a level considerably higher than today's.

Figure 4 is based on the World Bank's population projections under its "standard fertility decline" scenario. The Bank also constructs two other scenarios based on different fertility assumptions. The three scenarios are summarized in the table below which shows projected world population in 2100 under each alternative:

Fertility	Population at 2100

Slow Decline	12.219 billion
Standard Decline	10.958 billion
Rapid Decline	9.380 billion

Source: World Bank (1994)

Two sets of assumptions underlie these projection. First, life expectancy at birth is expected rise from its 1990 value of 63.9 years to a global average of 84.7 by 2100. Second, global fertility is projected to fall to the replacement rate (an inference for which there is empirical evidence), but at varying rates in the different scenarios. Fertility rates in countries currently at or near the replacement level are assumed to remain there indefinitely in all scenarios, while fertility in countries in a transition phase are assumed to continue approaching the replacement level at an empirically derived rate. The scenarios differ in the rate at which countries which have yet to begin the transition are assumed to start moving to the replacement level. The slow transition is projected to take twice as long as the standard transition while the fast transition is projected to take half the time.

There is considerable uncertainty in these forecasts. For example, recent changes in projected life expectancy increased the projected population at 2100 by 1 billion people under the standard scenario. On the other hand, the more rapid than expected fertility decline in China and India decreased the population projection by a smaller but still significant amount.

Productivity Growth

The empirical literature on productivity growth is enormous. However, many of the studies reach contradictory conclusions and none have been done with exactly the right specification for use with G-Cubed. In this section we begin by describing exactly what productivity estimates are required by G-Cubed. We then discuss how estimates done for other purposes could be mapped into G-Cubed's parameters. Finally, we present a short survey of the most relevant part of the productivity literature.

The production functions used in G-Cubed allow for industry-level labor augmenting technical change or improvements in labor quality. Since we cannot distinguish between the two in the context of the model we will refer to both as improvements in labor quality. The model determines materials use and the evolution of capital stocks endogenously, which means that we are imposing the condition below on the rates of growth of industry inputs and output:

$$y = S_K k + S_L(\hat{g}+l) + S_M m$$

In other words, in terms of the discussion in Section 2 we are imposing that the rates of total factor productivity growth (*tfp*), capital augmentation (*f*) and materials augmentation (*h*) be zero. To be consistent with historical data each industry's rate of labor augmentation must be chosen to satisfy the following equation:

$$\hat{g} = g + \frac{tfp + S_K f + S_M h}{S_L}$$

where g is the true rate of labor augmentation in the more general model. This expression gives the fundamental link between technical change in G-Cubed and a more general specification.

Following Solow (1957), much of the literature on sources of growth has been done at the level of entire economies using aggregate production functions. A number of studies are available which report productivity estimates for OECD countries, and some are also available for broad groups of developing economies. Table 3 presents a summary of GDP growth rates and the contribution of capital ($S_k\dot{k}$) for a number of major countries and regions. The studies reported are discussed briefly below.

Maddison (1989) extends his own earlier work on OECD countries (Maddison 1987) to examine growth in the global economy from 1900 to the 1980's. He analyses a sample of thirty-two countries in Latin America, Asia, the OECD area, and the U.S.S.R. A selection of these results are reported in Table 3.

Bosworth, Collins and Chen (1995) combine data from the Penn World Tables, the World Bank, and the International Labor Organization with additional information on human and physical capital to determine the extent to which growth outside the industrialized regions comes from factor accumulation rather than technical change. They conclude that in most cases factor accumulation is the dominant source of growth.

Chenery, Robinson and Syrquin (1986) use a general equilibrium model to examine the importance of various policy and institutional settings for the development process. In the course of constructing it they survey a number of studies to obtain parameters.

Gordon (1995) examines the tradeoff between productivity growth and unemployment in the G7 countries. He shows that participation rates as well as hours worked have been changing in those countries to the point where inferences on population productivity are completely reversed when hours worked and labor force are considered. To conduct his analysis he develops a consistent database of hours worked and uses it to look at growth in nine sectors.

Using data from the United Nations population survey and from the International Labor Organization's publication on labor force and hours worked we constructed labor augmentation rates appropriate for G-Cubed and equivalent to the results in Table 3. These are shown in Table 4. If G-Cubed used aggregate production functions to represent each region, these would be precisely the productivity growth rates needed to project the world economy.

G-Cubed, however, disaggregates each region's production into twelve sectors. Thus, we would ideally like to have productivity estimates by region and sector.[16] Such estimates are quite scarce. Table 5 summarizes the relevant empirical literature on productivity at the sectoral level. The studies use a variety of techniques and are not always directly comparable.

A key set of results reported in Table 5 is from Jorgenson, Gollop and Fraumeni (1987), a 51 sector study of the U.S. economy. They estimate productivity growth by fitting translog unit cost functions to industry-level datasets spanning the postwar period. A great deal of attention was devoted to calculating quality-adjusted measures of factor inputs following the approach of Christensen and Jorgenson (1969). The results show that productivity growth not only varies considerably across sectors but also that for most sectors improvements in the use of intermediate goods have been a significant source of growth. Because of the study's wide scope and attention to detail, we used it to construct a set of sectoral estimates of productivity growth for G-Cubed. These results are contained in Table 6.

5. Alternative Future Scenarios for the World Economy from 1990 to 2020

In this section we describe the results of using the model to project a range of variables. Because agents in the model have foresight, in order to predict future endogenous variables such as GDP and industry output we must first project the model's exogenous variables far into the future. The most important of these variables are shown in Table 7. To create these projections we begin with the World Bank population projections discussed above. We then use two alternative sets of projections for changes in labor quality. These two alternatives are referred to as scenario 1 and scenario 2. In scenario 1 we project aggregate technical change based on the studies of aggregate productivity growth discussed above and then apply the aggregate projection equally to each sector within an economy. Thus for example referring to Table 8, we assume the aggregate growth in labor quality in the United States is 1.4% per year and this aggregate growth is applied equally to all sectors within the US economy.

Scenario 2 is based on projections of differential labor quality change by sector within each economy. The purpose of scenario 2 is not to necessarily make the most likely projection of labor quality change, but to show how sensitive future projections of energy use, carbon emissions and aggregate GDP are to assumptions of differential labor quality changes (or labor augmenting technical change) across sectors of an economy. The growth rates of each sector are based on the studies of sectoral growth outlined above. The projections of labor quality change or labor augmenting technical change are contained in Table 10. We assume that there is no labor quality change in the energy sectors and several of the non energy sectors. Positive labor quality change is projected in Agriculture, Non-durable Manufacturing, Transportation and Services. For comparability with scenario 1 we scale up the sectoral productivity numbers in Table 10 for each country individually so that aggregate labor quality change, calculated as the output weighted shares of labor quality change in each sector (using 1990 weights), is equal to aggregate labor quality change for each country from scenario 1. By normalizing to the same aggregate labor quality change in each country we have a clear comparison of the importance of differential productivity growth across sectors for the projections.

The other main assumptions for scenario 1 are also shown in table 8. These include assumptions about energy efficiency improvements, tax rates, fiscal spending, monetary policy assumptions and the real price of oil. The real price of oil is assumed to be determined by the OPEC region in the model. This last assumption is fairly important: Jorgenson and Wilcoxen (1992) have argued, and we have illustrated above, that the oil price shocks of the 1970's reduced U.S. energy demand enough to hold carbon dioxide emissions essentially constant from 1972 through 1985. Several comments should also be made about the assumptions above in relation to other studies. Biases in technical change have been a significant source of controversy in the literature. Engineering studies sometimes suggest that there have been substantial improvements in energy efficiency over the last few decades beyond what would arise from price-induced substitution. Manne and Richels included this effect in their model “Global 2100" and referred to it as the rate of "autonomous energy efficiency improvements" or AEEI. Their value for AEEI ranges from 0 to 1 percent annually and varies over time and across regions. An AEEI of 1 implies that annual energy requirements per unit of output drop by one percent per year. The true value for AEEI is still a subject of debate. Econometric analysis by Hogan and Jorgenson (1991) suggests that the biases of technical change vary across industries and that for many industries technical change is actually energy-using, which would imply that AEEI should really be negative. In any case AEEI plays a very important role: Manne and Richels have shown that high values of AEEI lead to very slow growth of baseline carbon emissions and hence to low carbon taxes for any given target while low values of AEEI lead to rapid growth in baseline emissions and high carbon taxes. By the year 2100, according to Manne and Richels, the level of baseline emissions under a pessimistic view of AEEI is several hundred percent higher than under a more optimistic view. In our study we assume a zero value for AEEI and let the model determine endogenously the relationship between GDP and energy use.

Given these assumptions, we solve for the model's perfect-foresight equilibrium growth path over the period 1990-2050 using software developed by McKibbin (1994) for solving large models with rational expectations on a personal computer.

Scenario 1: Sectoral Productivity Growth the Same Across Sectors

For the purposes of this paper, the most important results for Scenario 1 are the future paths of GDP (shown in figure 5), the energy intensity of each economy (figure 6), and future paths of carbon dioxide emissions (shown in Figure 7). Figure 5 illustrates that the different population growth rates and labor productivity growth rate as well as different rates of private capital accumulation lead to different paths for real GDP in each economy. Figure 6 shows an index of the energy use per unit of GDP. A fall in this index indicates that energy use is falling per unit of GDP produced. For China and other developing countries the energy intensity rises initially before gradually falling over time. For industrial economies, the index falls over time although after 2000 there is some gradual rise in the energy intensity because falling energy intensity in developing economies reduces the relative price of energy for industrial economies. Energy intensity in the Eastern Europe an Former Soviet Union region moves around far more reflecting the large structural changes taking place in these economies. Frankly, however, this part of the model is largely based on speculation. Little reliable data exists.

Figure 7 shows the emission of carbon in millions of metric tons from 1990 to 2020 by country or region. In Scenario 1, global emissions rise from 5,388 million metric tons of carbon in 1990 to 15,378 million tons in 2020. The change in carbon emissions in individual countries and regions between 1990 and 2020 (in million of metric tons) are: United States (1,339 to 2,251); Japan (316 to 680); Australia (76 to 176); Rest of the OECD (1,025 to 2,228); China (608 to 2,310); other non-oil developing countries (1,015 to 4,663); and the Eastern Europe and former Soviet Union (1,010 to 2,544). Emissions growth in China and the other developing country region is particularly high because economic growth is projected to be highest in those regions.

Regional shares in total emissions and their projected evolution are shown in Table 9. The share of emissions from China and other developing countries rises over the next 30 years. At the same time, the share of carbon emissions from currently industrialized economies in the OECD falls (although in absolute terms emissions continue to increase). This clearly illustrates the policy dilemma with greenhouse gas emission reduction: a large part of future emissions are likely to be produced by developing economies who can least afford to bear the burden of future emissions reductions.

Scenario 2: Differential Sectoral Productivity Growth

The same calculations as for scenario 1 are undertaken for scenario 2 with differential rates of sectoral productivity growth. The path of GDP for each country is shown in figure 8. These results are similar to those for figure 5 except the growth rates are lower. Given that average labor productivity and population growth are the same, the difference in trends is due to differential capital accumulation across sectors in the two scenarios. Strong growth in the non-energy sectors leads to a rise in the demand for energy. This raises the relative price of energy which draws resources into the energy sectors and leads to substitution away from energy inputs in production. With this reallocation of inputs the aggregate GDP growth path is reduced.

Energy intensity in each region is shown in figure 9. Here we see a difference in the results compared to figure 6. Differential productivity growth across sectors has led to large changes in energy intensity despite similar paths for overall GDP in each economy. If one were to look only at GDP and energy use, this would appear to be "autonomous energy efficiency improvement" because energy intensity is declining even though prices are constant. These results show that even if energy efficiency appears to improve at the aggregate level it should not be interpreted, as it commonly is, to result from technical change in energy production. In this case, differential productivity growth across sectors changes relative prices and thus the pattern of energy demand. The results look more like the historical experience that scenario 1 because we have imposed differential sectoral growth more similar to historical experience than the assumptions behind scenario 1.

The path of carbon emissions are shown in figure 10. It is clear comparing this to figure 7 that the emission paths for carbon are quite different, as one might expect given the different energy intensities under the two scenarios. Even over a 30 year period we see a significant difference between the two scenarios despite similar aggregate assumptions. In Scenario 2, global emissions rise from 5,388 million metric tons of carbon in 1990 to 9,818 million tons in 2020. That is almost 5,500 million tons less than under scenario 1! The change in carbon emissions in individual countries and regions between 1990 and 2020 (in million of metric tons) are: United States (1,339 to 1,738); Japan (316 to 488); Australia (76 to 146); Rest of the OECD (1,025 to 1,648); China (608 to 1,020); other non-oil developing countries (1,015 to 2,523); and the Eastern Europe and former Soviet Union (1,010 to 1,831).

The share of each region in global carbon emissions are shown in Table 11. A broadly similar story to scenario 1 holds for the pattern of emission shares over the next 30 years for scenario 2. The share of emissions from developing countries is expected to rise while the share for industrialized economies is expected to decline. However, the size of the shift is quite different under the two scenarios. In scenario 2 the rise in emissions is projected to be much less and therefore the change in shares is less dramatic . This is clearly seen in figure 10. The faster rise in emissions when overall productivity growth is the same is not surprising. In scenario 2 the relative prices of non-energy goods fall faster than the prices of energy goods. This raises the relative price of energy causing consumers and firms to substitute away from it. (Another way to think of this is that without rising labor productivity in the energy sectors, energy becomes relatively scarce which reduces the growth of downstream industries.) The growth in energy supply in scenario 1 is dominated by the assumed growth in productivity whereas in scenario 2 , the growth in energy supply is dominated by capital accumulation in the energy sectors in response to market forces changing relative prices. Hence emissions of carbon dioxide rise with growth in GDP but at a slower rate in scenario 2 than is scenario 1.

The Implications for Emission Stabilization

As we discussed above, the UN Framework Convention on Climate Change requires countries to take action to limit rising emissions of carbon dioxide. To show the effect on this policy of assumptions about baseline conditions we calculate the carbon taxes needed to stabilize emissions in each region by the year 2010 at the level of 1990, given that the revenue is used to reduce fiscal deficits in each country by the amount of revenue raised by that country. We have shown elsewhere (McKibbin and Wilcoxen (1994)) that the assumption about how the revenue is recycled has important macroeconomic and sectoral impacts on the results. Here we will stay with a deficit reduction assumption for both scenarios.

Several important assumptions make the results we report here different from other studies of this issue, and from our own previous work using G-Cubed. First, we begin the simulation in 1990, but since 1990 has actually passed, we phase the carbon tax in gradually starting in 1995. In other words, the simulations are conducted as though the tax were announced in 1990 to start in 1995. (As a result, asset prices adjust somewhat before 1995.) The tax is set so that emissions gradually fall to the 1990 target by the year 2010 rather than stabilizing emission in every year up to 2010. This is done to minimize the output loss over the adjustment path since, in this model, announcing credible tax changes in advance leads to changes in capital accumulation in advance of the policy. Investment is channeled away from sectors hurt by the shock (in this case the coal industry in each country) towards other sectors of production. The results would be quantitatively different had we stabilized each year at 1990 levels.

With the tax in place in both scenario 1 and scenario 2, emissions are gradually reduced to 1990 levels by the year 2010 (in all regions) but begin rising after that because the tax is held constant. This is an important aspect of the problem of taxing carbon emissions. Because the future path of emissions is projected to rise continually in both scenarios, targeting emissions at 1990 levels after the year 2010 will require a continually rising tax. In the experiments report here we assume that the tax is held constant after the year 2010 so emissions continue to rise after 2010 but from a lower level.

The taxes required to stabilize emissions are shown in Table 12. For clarity, three representative years are shown although the model is actually solved on an annual basis. By 2010 the stabilizing tax in the United States is $44.80 (1990 $US) per ton of carbon in scenario 1 and $22.40 per ton of carbon under scenario 2. It is clear from this table that the different assumptions about the sectoral composition of growth has a dramatic effect on the size of the taxes necessary to stabilize carbon emissions in each region. This is not surprising because we saw above that the path of carbon emissions is quite different under the two scenarios given the change in energy intensity cause by changes in relative prices in the global economy.

4 Conclusion

In this paper we have focussed on the importance of the sectoral composition of economic growth for calculating future paths of the world economy. The common practice of using aggregate projections of trend GDP growth in different countries to derive projections of energy use, carbon emissions and other variables can be misleading. Using a global economic model that accounts for (1) general equilibrium interactions, (2) expectations of future events and (3) that is based on historically estimated substitution possibilities, we have illustrated that the composition of future growth is crucial for the relationship between a range of variables of importance.

We found that the energy composition of GDP can change significantly over a 30 year period because of changes in the composition of output as well as a changes in the use of inputs in production. These changes occur through changes in relative prices reflecting substitution decisions by households and firms. These have been observed historically and the model suggests that under plausible assumptions may be important in the future.

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Footnotes

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1.In spite of this, simple projections of GDP growth have been widely used. For example, such projections form the basis of much of the material used in the scenarios prepared for the Intergovernmental Panel on Climate Change (IPCC). Moreover, almost all studies of global warming that have very simple stories about GDP growth and the relationship between growth and a range of variables.

2.This point has been emphasized by Jorgenson and Wilcoxen (1991b), who point out that over the period 1973-85, U.S. energy consumption and carbon emissions remained essentially constant.

3. Similar graphs for Japan can be found in Ban (1991) and Yamazawa, Nakayama and Kitamura (1995).

4.Gases which contribute to the greenhouse effect include carbon dioxide, methane, nitrous oxide, chloroflurocarbons and others.

5.For an overview of the economics of global warming see Cline (1992), Nordhaus (1991a) or Schelling (1992). See Hoeller, Dean and Nicolaisen (1990), Nordhaus (1991b), or Energy Modeling Forum (1992) for surveys of estimates of the cost of reducing greenhouse gas emissions.

6.A carbon tax would be applied to fossil fuels in proportion to the carbon dioxide they produce when burned. Nordhaus (1979) proposed this as means of taxing the externality (global warming) produced by users of fossil fuels.

7.Coefficients F, G and H could also be interpreted as biases in the pattern of technical change. A more general specification would allow for both improvements in factor quality and biases in technical change. Empirically, it would be difficult to distinguish the two effects. One approach would be to form a panel data set from time series data for a large number of industries and then estimate productivity growth rates imposing the restriction that biases be industry specific and improvements in factor quality be the same across industries.

8.This is a generalization of Solow (1957). For a survey of recent papers which use less restrictive production or cost functions, see Dewiert (1992). Maddison (1987) presents a broad survey of the productivity literature.

9.This approach is due to the pioneering work of Denison and is sometimes called "growth accounting". See Denison (1974, 1979, 1985) for much more refined examples of this style of analysis.

10.A benchmark table also exists for 1947 but it has inadequate final demand detail for our purposes.

11.The National Income and Product Accounts (and the benchmark input-output tables as well) treat purchases of consumer durables as consumption rather than investment.

12.This data set is the work of several people over many years. In addition to Dale Jorgenson, some of the contributors were Lau Christiansen, Barbara Fraumeni, Mun Sing Ho and Dae Keun Park. The original source of data is the Fourteen Components of Income Tape produced by the Bureau of Economic Analysis. See Ho (1989) for more information.

13.Anything else would require time-series data on imports of products from each country of origin to each industry, which is not only unavailable but difficult to imagine collecting.

14.This specification imposes the restriction that household decisions on the allocations of expenditure among different goods at different points in time be separable.

15.This specification has the undesirable effect of imposing unitary income and price elasticities. There is abundant empirical evidence against this assumption and we intend to relax it in future work.

16.In fact, Jorgenson (1988) has argued that productivity analysis at an aggregate level is an uninformative exercise because it leads to a single number which can completely miss varying trends in the underlying processes. He notes that over a long period of time there is little tendency of various sectors to grow at the same rate or even in the same direction.

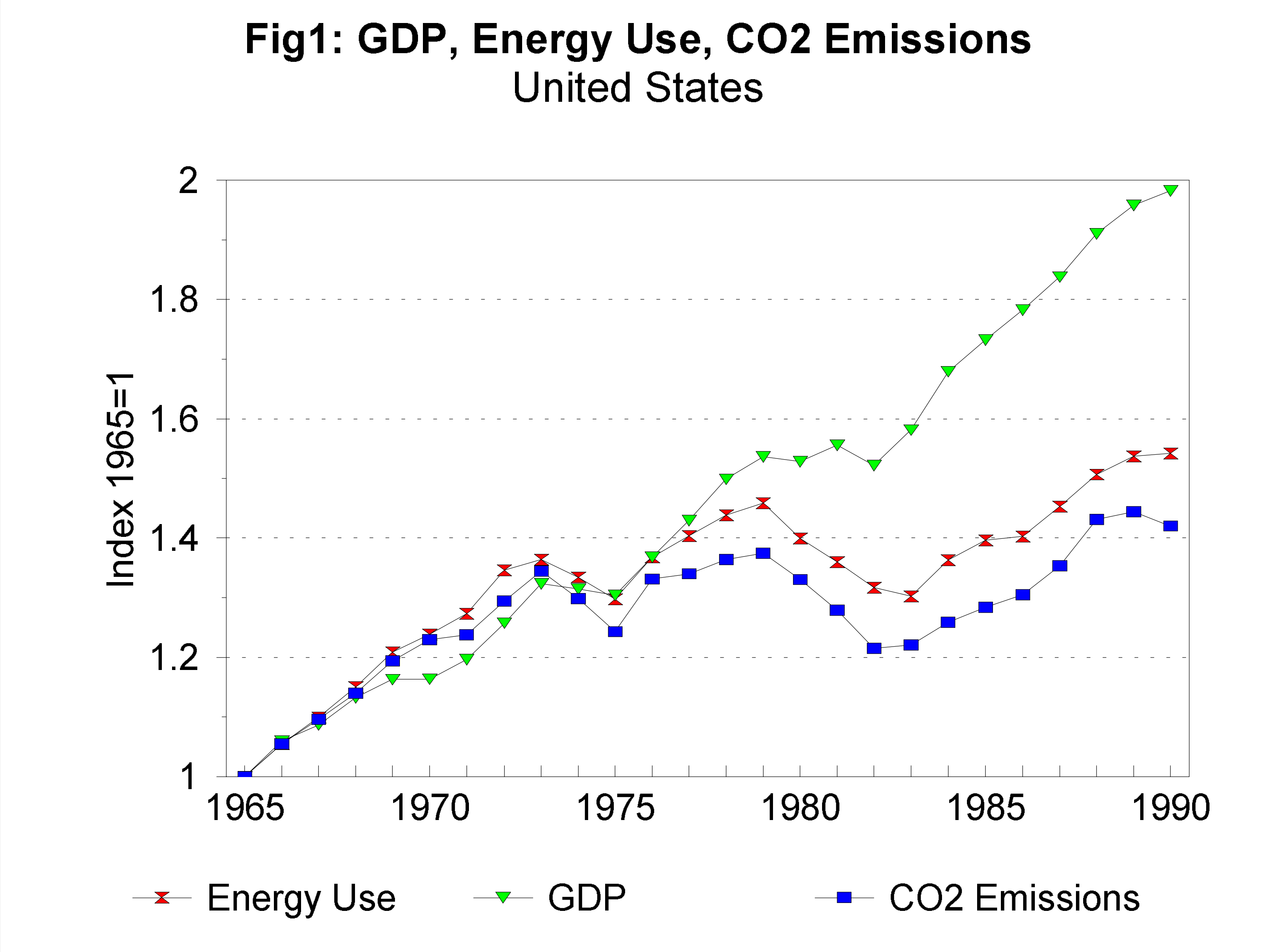


Fig1: GDP, Energy Use, CO2 Emissions
United States
Index 1965=1
2
1.8
1.6
1.4
1.2
1
1965
1970
1975
1980
1985
1990
Energy Use
GDP
CO2 Emissions

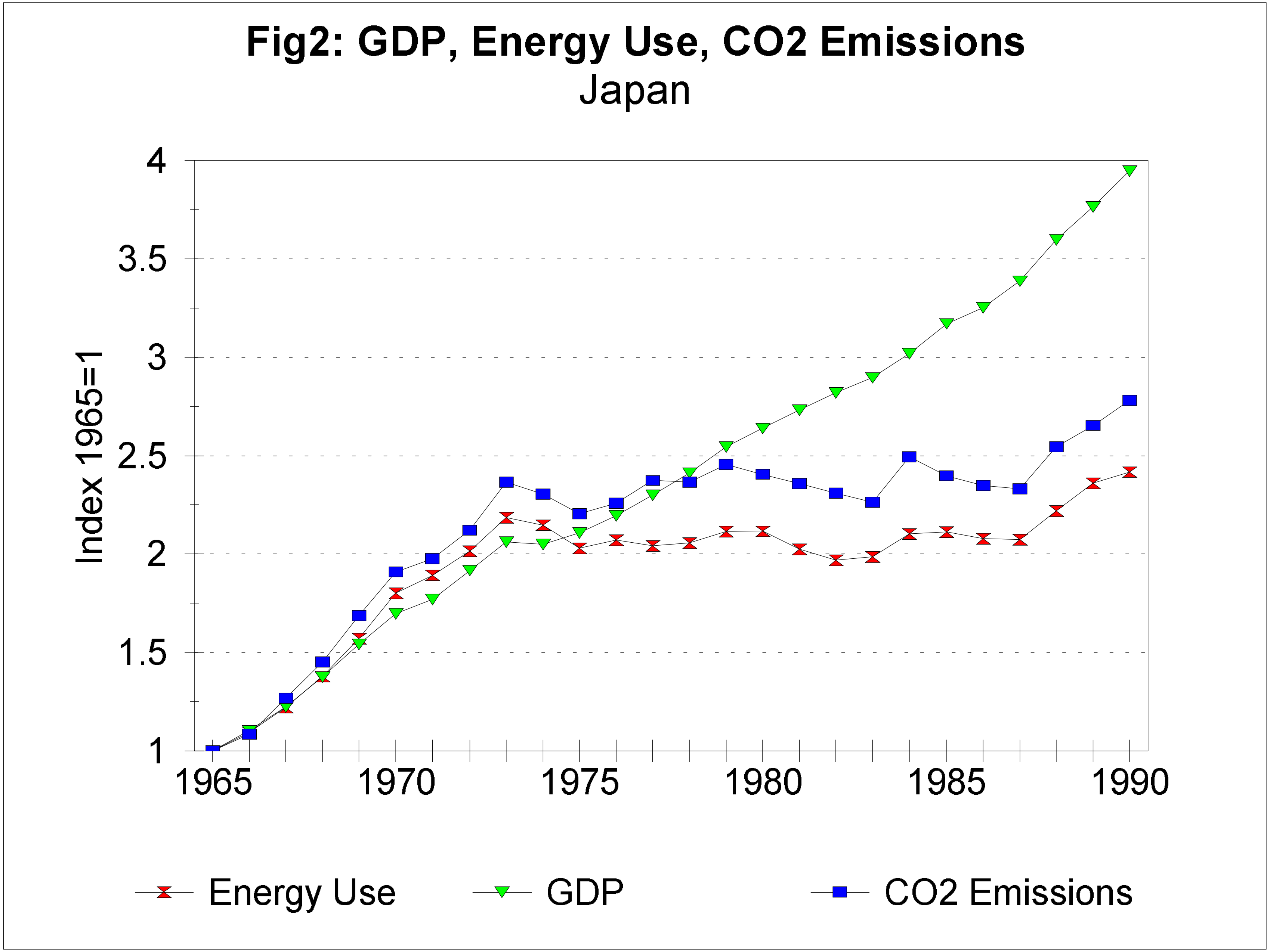


Fig2: GDP, Energy Use, CO2 Emissions
Japan
Index 1965=1
4
3.5
3
2.5
2
1.5
1
1965
1970
1975
1980
1985
1990
Energy Use
GDP
CO2 Emissions

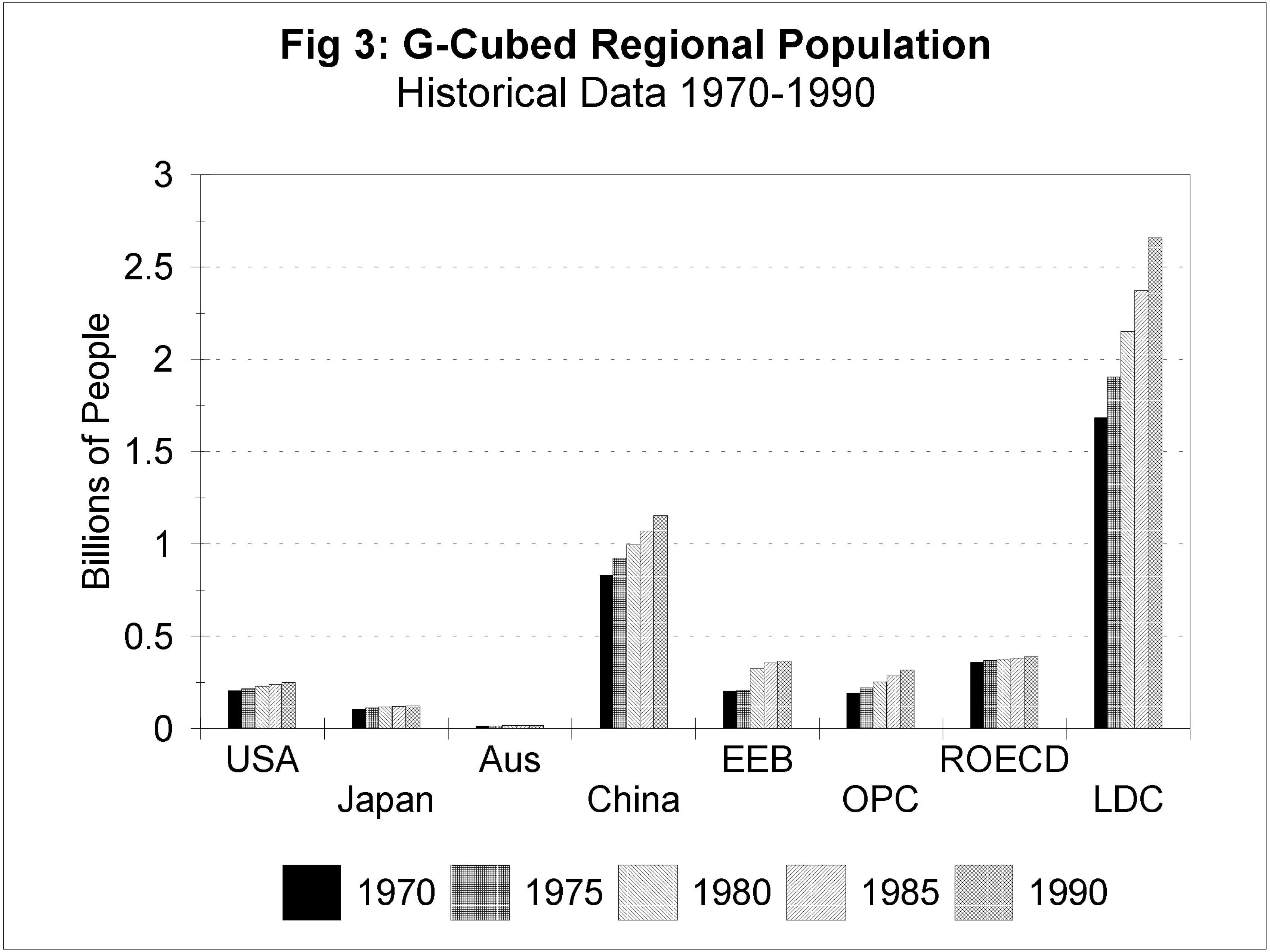


Fig 3: G-Cubed Regional Population
Historical Data 1970-1990
Billions of People
3
2.5
2
1.5
1
0.5
0
USA
Japan
Aus
China
EEB
OPC
ROECD
LDC
1970
1975
1980
1985
1990

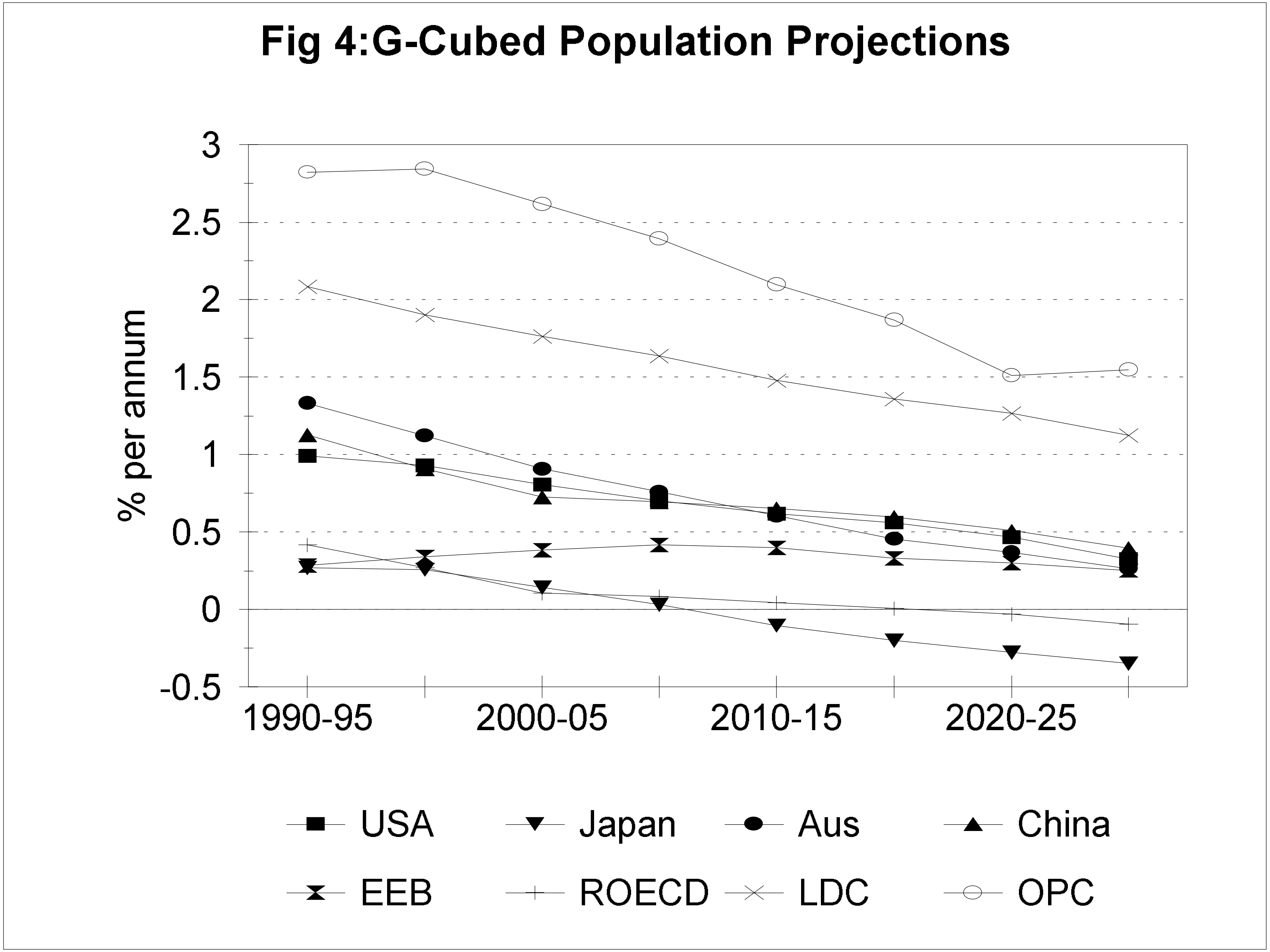


Fig 4:G-Cubed Population Projections
% per annum
3
2.5
2
1.5
1
0.5
0
-0.5
1990-95
2000-05
2010-15
2020-25
USA
Japan
Aus
China
EEB
ROECD
LDC
OPC

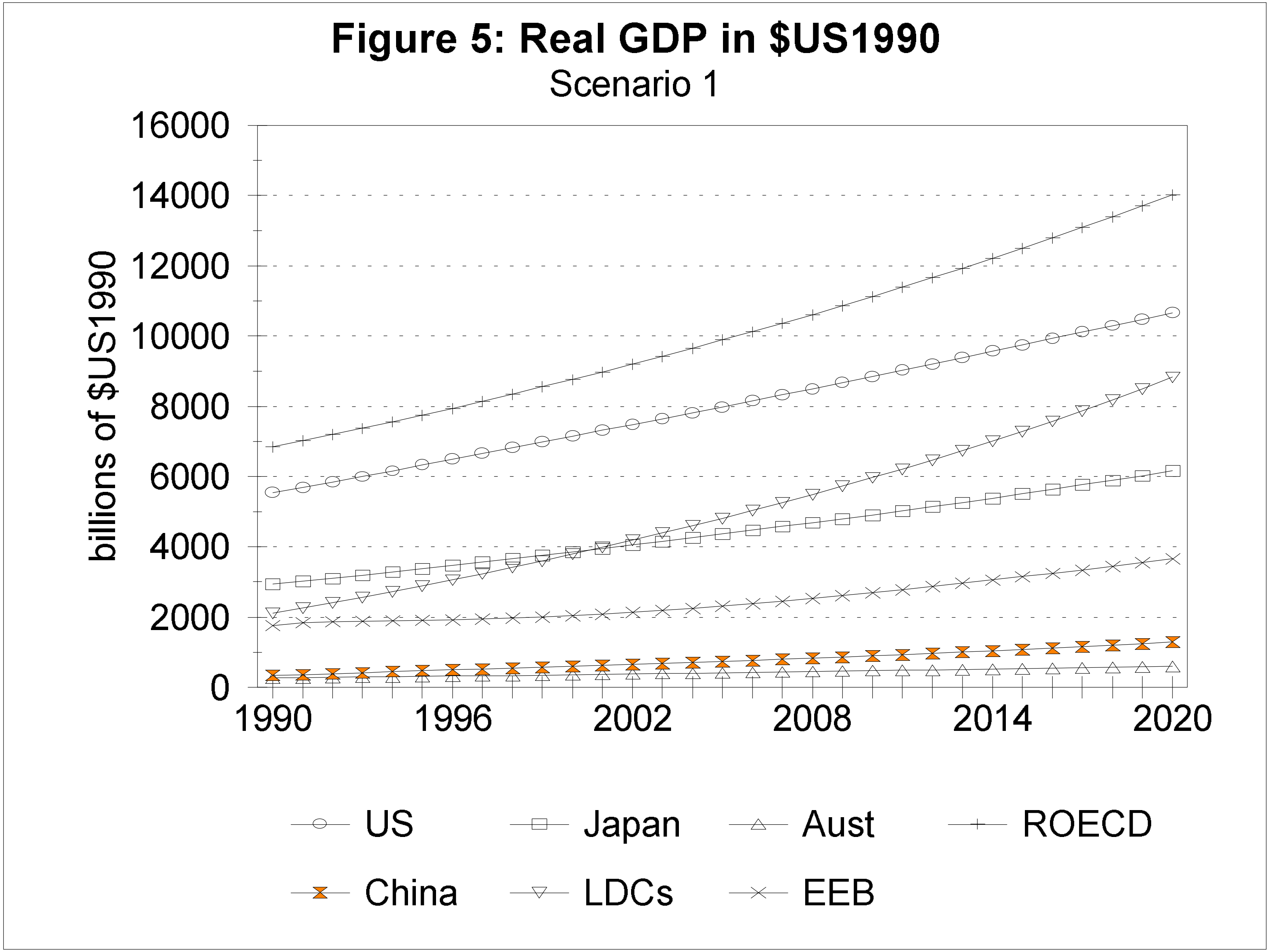


Figure 5: Real GDP in $US1990
Scenario 1
16000
14000
12000
10000
8000
6000
4000
2000
0
billions of $US1990
1990
1996
2002
2008
2014
2020
US
Japan
Aust
ROECD
China
LDCs
EEB

Figure 6: Energy Use per unit of GDP

Scenario 1

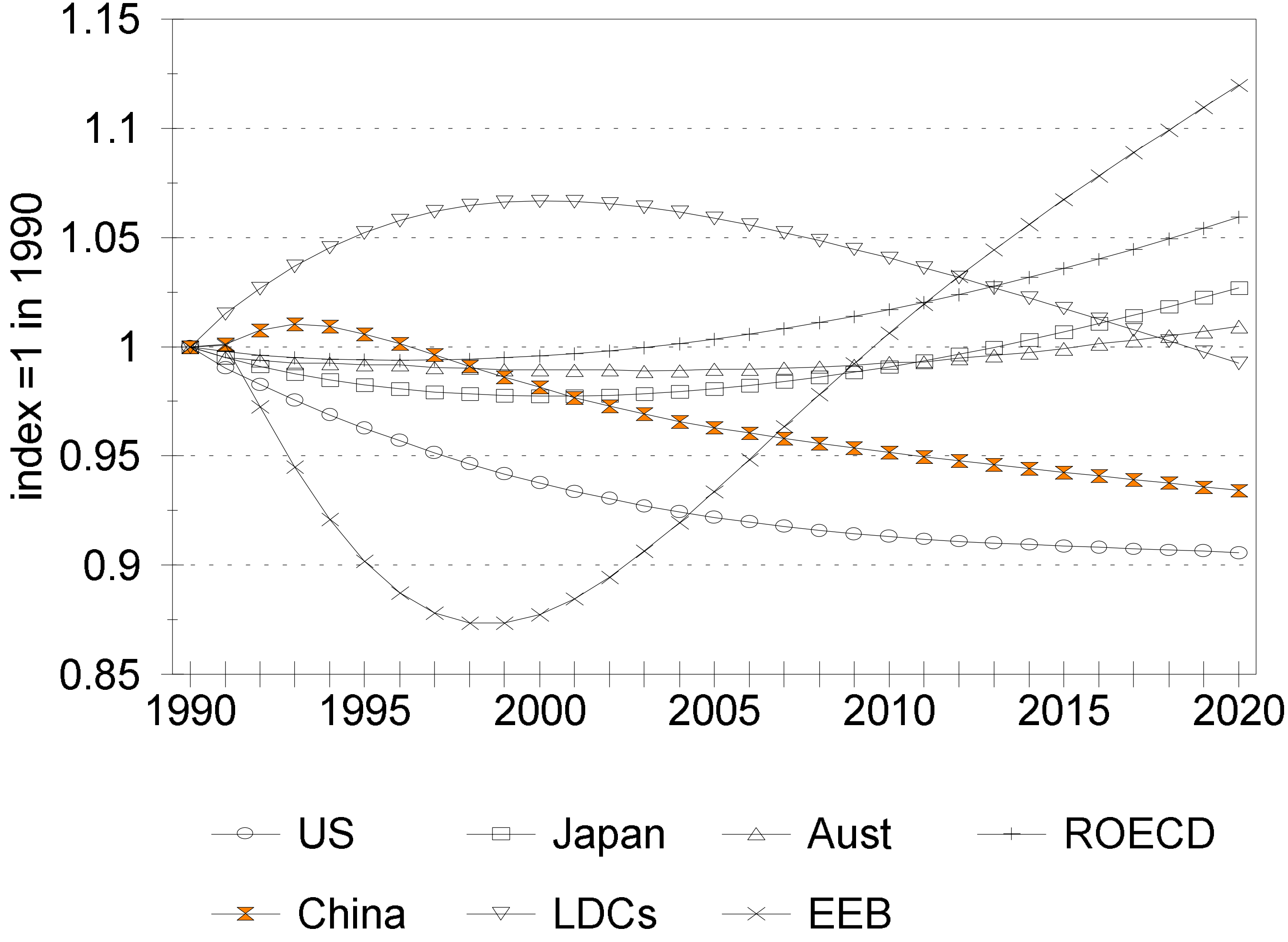
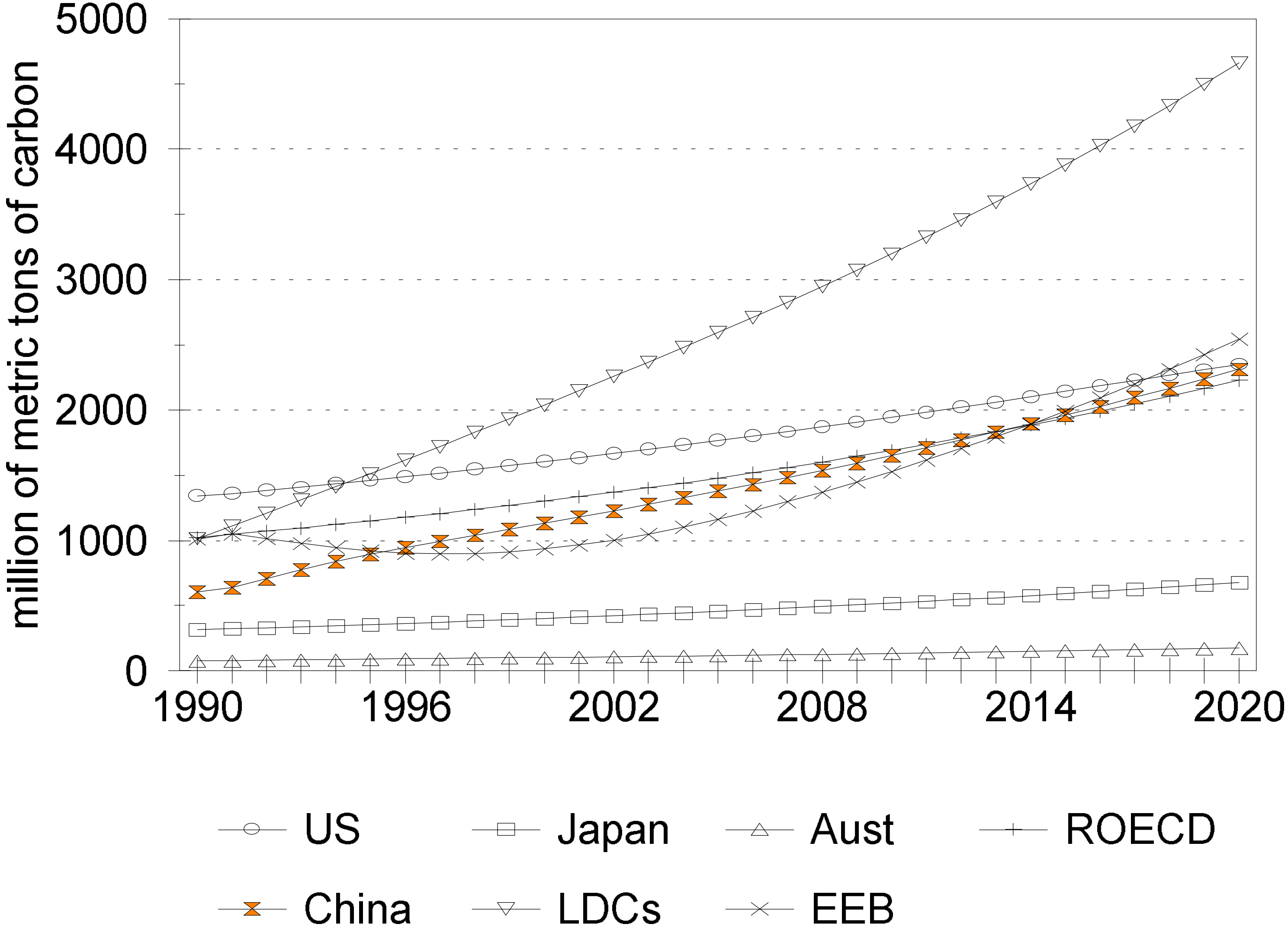


Figure 7: Carbon Emissions

Scenario 1



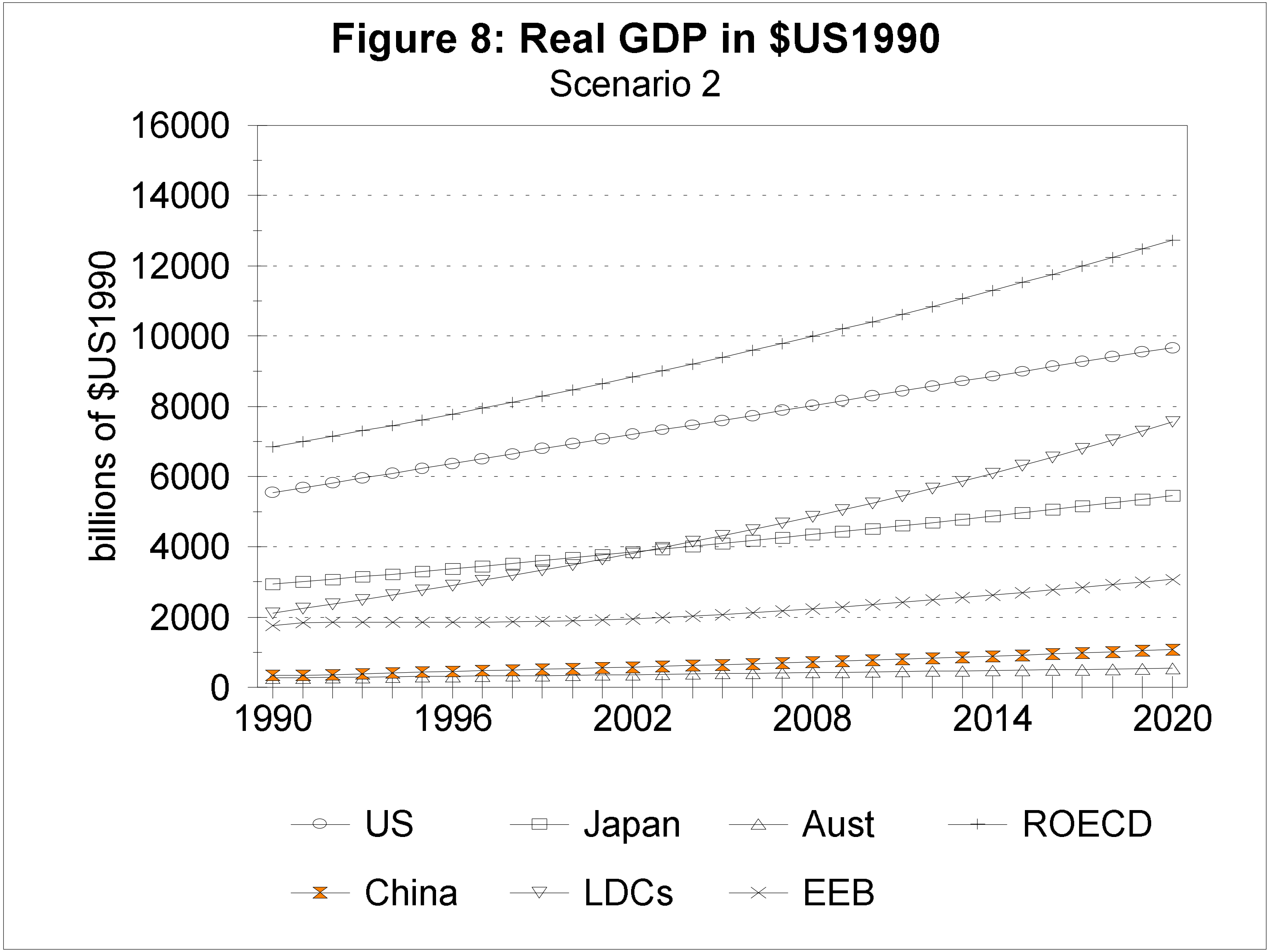


Figure 8: Real GDP in $US1990
Scenario 2
billions of $US1990
16000
14000
12000
10000
8000
6000
4000
2000
0
1990
1996
2002
2008
2014
2020
US
Japan
Aust
ROECD
China
LDCs
EEB

Figure 9: Energy Use per unit of GDP

Scenario 2

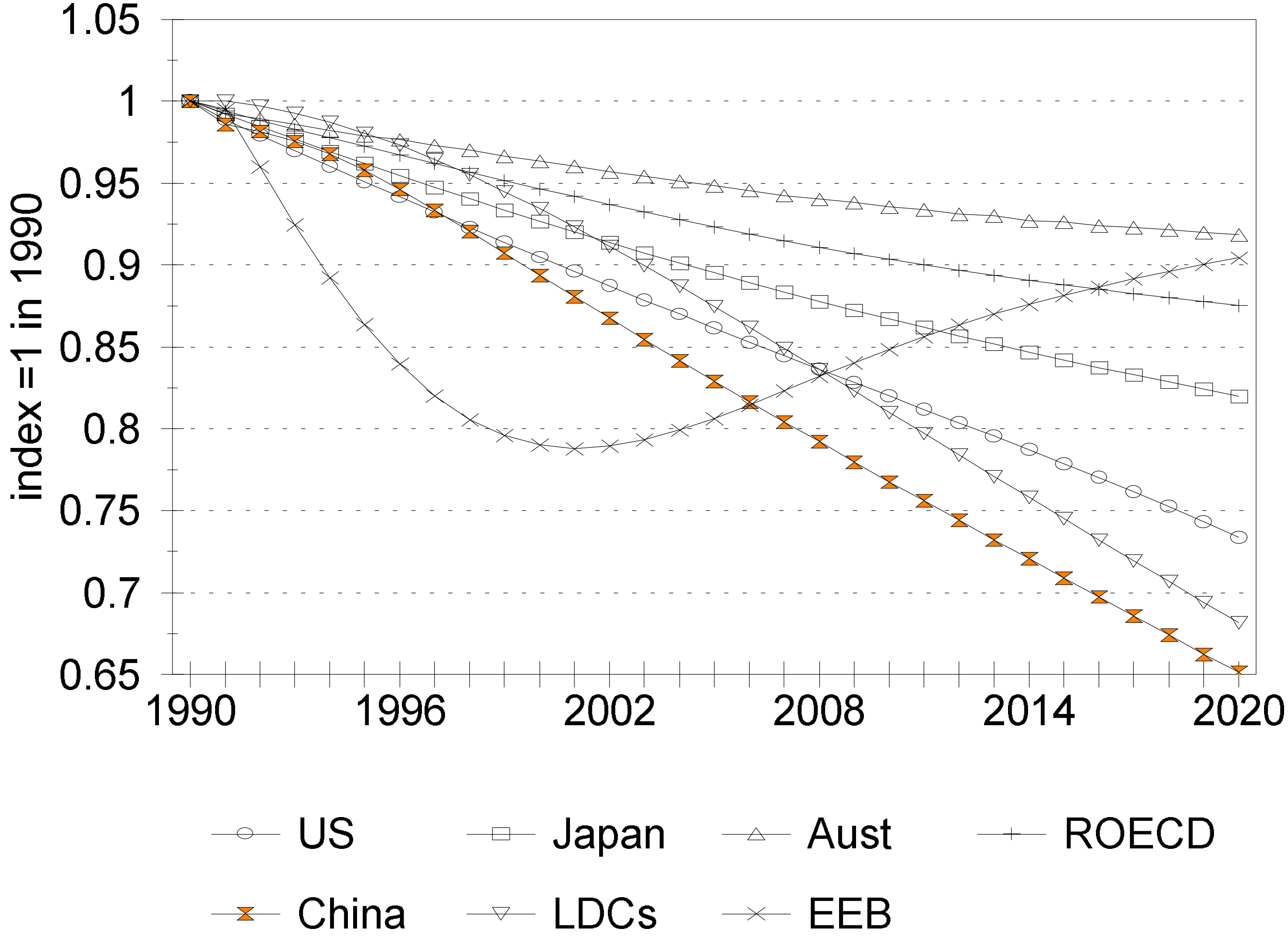


Figure 10: Carbon Emissions

Scenario 2

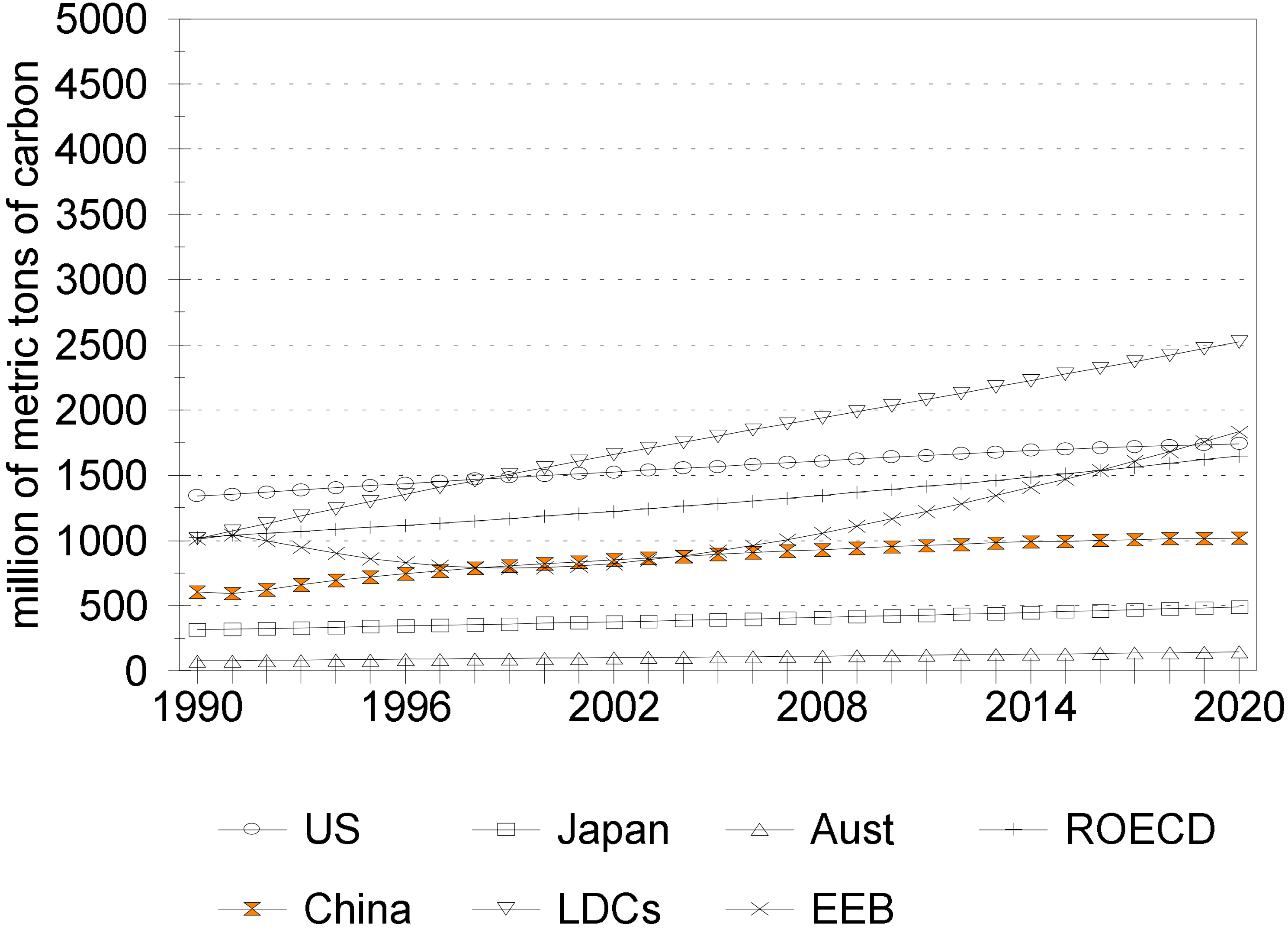


Table 1: List of Regions

United States
Japan
Australia
Other OECD (ROECD)
China
LDCs
Eastern Europe and the Former USSR (EEB)
Oil Exporting Developing Countries (OPEC)

Table 2: Industries in Each Region

1	Electric Utilities
2	Gas Utilities
3	Petroleum Refining
4	Coal Mining
5	Crude Oil and Gas Extraction
6	Other Mining
7	Agriculture, Fishing and Hunting
8	Forestry and Wood Products
9	Durable Manufacturing
10	Non-Durable Manufacturing
11	Transportation
12	Services

Table 3: Studies of Economy-Wide Growth in a Range of Countries

Maddison (1989)							**Gordon (1995) (a)**						**Bosworth/Collins/Chen (1995)**				
.Country	**Period**	**GDP Growth**	**TFP Growth**	**Cont. Capital**	**Cont. Labor**		**Period**	**Output Growth**	**TFP Growth**	**Cont. Capital**	**Cont. Labor**		**Period**	**GDP Growth**	**TFP Growth**	**Cont. Capital**	**Cont. Labor**
U.S.	1950-73	3.65	1.49	1.02	1.14	*	1960-73	3.12	1.35	0.95	0.82	*	1960-70	3.61	1.58	1.63	0.40
	1973-84	2.42	0.25	0.84	1.33	*	1973-79	2.69	-0.14	1.31	1.52	*	1970-80	2.96	1.67	1.99	-0.70
							1979-92	2.29	0.38	1.17	0.74	*	1980-86	2.71	0.78	1.43	0.50
													1986-92	2.24	0.77	1.27	0.20
Japan	1950-73	9.29	5.47	2.37	1.45	*	1960-73	7.72	---	---		*	1960-70	10.12	4.17	4.65	1.30
	1973-84	3.72	1.99	1.00	0.73	*	1973-79	3.29	1.29	1.86	0.14	*	1970-80	4.52	3.48	3.14	-2.10
							1979-92	3.98	1.63	1.83	0.52	*	1980-86	3.66	1.82	1.94	-0.10
													1986-92	4.07	2.04	2.33	-0.30
France	1950-73	5.13	3.69	1.07	0.37	*	1960-73	5.62	3.64	1.49	0.49	*	1960-70	5.64	2.62	2.62	0.40
	1973-84	2.32	1.47	1.20	-0.35	*	1973-79	3.84	2.39	1.52	-0.07	*	1970-80	3.66	2.36	2.10	-0.80
							1979-92	2.59	1.57	0.99	0.03	*	1980-86	2.42	1.59	1.34	-0.50
													1986-92	2.61	1.45	1.16	0.00
Germany	1950-73	5.92	4.14	1.59	0.19	*	1960-73	5.27	3.43	1.88	-0.04	*	1960-70	4.34	2.11	1.83	0.40
	1973-84	1.72	1.48	1.01	-0.77	*	1973-79	3.95	2.69	1.55	-0.29	*	1970-80	2.93	1.43	1.40	0.10
							1979-92	4.40	1.44	1.57	1.39	*	1980-86	2.11	1.01	1.20	-0.10
													1986-92	6.64	1.85	3.69	1.10
U.K.	1950-73	3.02	1.98	0.98	0.06	*	1960-73	3.36	2.32	1.15	-0.12	*	1960-70	2.82	1.57	1.65	-0.40
	1973-84	1.10	1.19	0.76	-0.85	*	1973-79	2.43	1.16	1.11	0.16	*	1970-80	2.21	1.75	1.36	-0.90
							1979-92	1.51	1.22	0.13	0.17	*	1980-86	3.41	1.21	1.19	1.00
													1986-92	1.30	1.19	1.01	-0.90
Canada							1960-73	3.02	2.30	0.72		*	1960-70	4.73	1.36	2.17	1.20
							1973-79	1.27	0.36	0.91		*	1970-80	4.70	2.16	2.74	-0.20
							1979-92	1.41	-0.04	1.45		*	1980-86	3.31	1.58	2.03	-0.30
													1986-92	2.02	1.60	2.02	-1.60
Italy							1960-73	6.71	5.56	1.15		*	1960-70	5.72	2.29	1.83	1.60
							1973-79	1.99	2.63	-0.64		*	1970-80	3.89	1.64	1.65	0.60
							1979-92	1.90	1.71	0.19		*	1980-86	2.31	1.37	1.34	-0.40
													1986-92	2.39	1.28	1.11	0.00
Australia													1960-70	5.14	2.47	2.67	0.00
													1970-80	3.64	1.48	2.26	-0.10
													1980-86	3.24	1.21	1.93	0.10
													1986-92	3.10	1.10	1.80	0.20
China	1950-73	5.84	0.49	2.74	2.61								1960-70	3.60	0.97	1.14	1.49
	1973-84	6.85	2.10	2.35	2.40								1970-80	4.91	2.91	2.93	-0.93
													1980-86	8.49	3.32	3.34	1.84
													1986-92	7.69	4.05	4.00	-0.35
Korea	1950-73	7.49	2.84	1.84	2.81	*							1960-70	6.83	4.92	4.54	-2.63
	1973-84	7.38	1.42	3.03	2.93	*							1970-80	7.64	5.52	5.54	-3.43
													1980-86	7.49	3.99	3.67	-0.17
													1986-92	7.59	4.90	4.49	-1.80
Taiwan	1950-73	9.32	3.51	2.32	3.49								1960-70	9.63	5.94	6.38	-2.69
	1973-84	7.63	1.23	2.83	3.57								1970-80	8.06	5.39	5.27	-2.60
													1980-86	4.50	*	*	*
													1986-92	5.90	*	*	*
India	1950-73	3.69	-0.05	1.84	1.90								1960-70	4.09	2.31	2.61	-0.83
	1973-84	4.29	0.50	1.37	2.42								1970-80	3.57	2.18	2.46	-1.07
													1980-86	5.35	2.04	2.39	0.91
													1986-92	5.35	2.32	2.63	0.41
Argentina	1950-73	3.78	1.38	1.05	1.35								1960-70	4.02	2.07	2.13	-0.18
	1973-84	0.69	-1.58	0.62	1.65								1970-80	3.35	2.29	2.49	-1.44
													1980-86	-0.59	0.42	0.65	-1.66
													1986-92	1.85	-0.13	0.05	1.92
Brazil	1950-73	6.75	2.13	2.15	2.47								1960-70	5.11	2.00	2.51	0.60
	1973-84	4.33	-1.97	2.90	3.40								1970-80	7.24	3.20	3.81	0.23
													1980-86	2.19	1.76	2.02	-1.58
													1986-92	-0.09	1.24	1.38	-2.72
Chile	1950-73	3.67	1.60	1.06	1.01								1960-70	4.16	1.67	1.93	0.56
	1973-84	1.24	-0.92	0.58	1.58								1970-80	1.67	0.57	0.74	0.36
													1980-86	-0.22	0.50	0.71	-1.43
													1986-92	6.75	1.79	1.99	2.96
Mexico	1950-73	6.38	1.91	2.06	2.41								1960-70	6.34	3.14	3.38	-0.19
	1973-84	4.55	-0.64	2.28	2.91								1970-80	4.93	2.55	3.30	-0.92
													1980-86	-0.07	2.04	1.98	-4.09
													1986-92	1.99	1.34	1.17	-0.52
USSR	1950-73	5.05	0.50	2.76	1.79	*											
	1973-84	2.16	-1.40	2.00	1.56	*											

Notes: CCJ: Christensen, Cummings and Jorgenson (1995),Ah: Aluwalia (1985), Y: Young (1994).
References for E: Elias (1978), El: Elias (1990), and D: Dougherty (1991) are found in Barro and Sala-i-Martin (1995)
(a) Gordon reports Nonfarm Private Business Sector. For Italy and Canada Output/Hour is reported.
* Labor is measured in hours worked
Growth in Labor Force is proxied by growth in population in Chenery/Robinson/Syrquin (1995) and Barro/Sala-i-Martin (1995) for non-OECD countries
In calculations for Chenery/Robinson/Syrquin (1995) and Barro/Sala-i-Martin (1995) a labor share of 0.7 was used for OECD economies and 0.6 for non-OECD economies..

Table 3 (continued): Studies of Economy-Wide Growth in a Range of Countries

	Chenery/Robinson/Syrquin (1995)						**Barro/Sala-i-Martin (1995)**					
Country	**Period**	**GDP Growth**	**TFP Growth**	**Cont. Capital**	**Cont. Labor**		**Period**	**GDP Growth**	**TFP Growth**	**Cont. Capital**	**Cont. Labor**	
U.S.	1960-73	4.30	1.30	1.66	1.34	CCJ	1960-90	3.10	0.41	1.40	1.29	D
Japan	1960-73	10.90	4.50	4.77	1.63	CCJ	1960-90	6.81	1.96	3.87	0.98	D
France	1960-73	5.90	3.00	2.63	0.27	CCJ	1960-90	3.50	1.45	2.03	0.02	D
Germany	1960-73	5.40	3.00	2.81	-0.41	CCJ	1960-90	3.20	1.58	1.88	-0.26	D
U.K.	1960-73	3.80	2.10	1.78	-0.08	CCJ	1960-90	2.49	1.30	1.31	-0.12	D
Canada	1960-73	5.10	1.80	2.20	1.10	CCJ	1960-90	4.10	0.46	2.29	1.35	D
Italy	1960-73	4.80	3.10	2.07	-0.37	CCJ	1960-90	4.10	1.97	2.02	0.11	D
Australia												
China												
Korea	1960-73	9.70	4.10	2.42	3.18	CCJ	1966-90	10.32	1.20	4.77	4.35	Y
Taiwan	1955-60	5.24	3.12	1.07	1.05	Ch	1966-90	9.10	1.80	3.68	3.62	Y
India	1960-79	6.24	-0.18	2.50	3.92	Ah						
Argentina	1960-74	4.10	0.70		3.40	E	1940-80	3.60	1.10	1.55	0.95	El
Brazil	1960-74	7.30	1.60		5.70	E	1940-80	6.40	1.85	3.25	1.30	El
Chile	1960-74	4.40	1.20		3.20	E	1940-80	3.80	1.50	1.30	1.00	El
Mexico	1960-74	5.60	2.10		3.50	E	1940-80	6.30	2.30	2.55	1.45	El
USSR												

Table 4: Equivalent G-Cubed Labor Augmenting Technical Change (LATC) from a Range of Studies

Maddison (1989)			**Gordon (1995)**			**Bosworth/Collins/Chen (1995)**		
Country	**Period**	**Equivalent LATC**	**Country**	**Period**	**Equivalent LATC**	**Country**	**Period**	**Equivalent LATC**
U.S.	1950-73	3.81	U.S.	1960-73	1.99	U.S.	1960-70	1.22
	1973-84	2.26		1973-79	-0.21		1970-80	-1.18
				1979-92	0.56		1980-86	0.22
							1986-92	0.15
Japan	1950-73	11.29	Japan	1960-73		Japan	1960-70	6.59
	1973-84	4.76		1973-79	1.90		1970-80	1.05
				1979-92	2.40		1980-86	1.39
							1986-92	1.01
France	1950-73	6.57	France	1960-73	5.35	France	1960-70	3.58
	1973-84	1.68		1973-79	3.51		1970-80	1.36
				1979-92	2.31		1980-86	0.93
							1986-92	1.56
Germany	1950-73	7.01	Germany	1960-73	5.04	Germany	1960-70	3.55
	1973-84	1.23		1973-79	3.96		1970-80	1.76
				1979-92	2.12		1980-86	0.59
							1986-92	-0.63
U.K.	1950-73	3.21	U.K.	1960-73	3.41	U.K.	1960-70	1.45
	1973-84	0.68		1973-79	1.71		1970-80	0.71
				1979-92	1.79		1980-86	2.45
							1986-92	0.11
			Canada	1960-73	3.38	Canada	1960-70	1.12
				1973-79	0.53		1970-80	-0.40
				1979-92	-0.06		1980-86	0.22
							1986-92	-1.33
			Italy	1960-73	8.18	Italy	1960-70	5.93
				1973-79	3.87		1970-80	2.41
				1979-92	2.51		1980-86	0.48
				1979-92			1986-92	1.23
						Australia	1960-70	1.29
							1970-80	0.04
							1980-86	-0.16
							1986-92	-0.14
China	1950-73	2.16				China	1960-70	2.20
	1973-84	5.20					1970-80	1.60
							1980-86	7.20
							1986-92	4.67
Korea	1950-73	6.20				Korea	1960-70	2.09
	1973-84	5.11					1970-80	1.75
							1980-86	5.07
							1986-92	4.17
Taiwan	1950-73	7.37				Taiwan	1960-70	2.29
	1973-84	4.84					1970-80	2.68
							1980-86	7.50
							1986-92	9.83
India	1950-73	1.14				India	1960-70	0.77
	1973-84	2.74					1970-80	-0.42
							1980-86	2.78
							1986-92	2.48
Argentina	1950-73	3.14				Argentina	1960-70	1.93
	1973-84	-0.80					1970-80	-0.22
							1980-86	-3.47
							1986-92	1.75
Brazil	1950-73	4.38				Brazil	1960-70	2.33
	1973-84	-2.13					1970-80	3.39
							1980-86	-1.90
							1986-92	-4.27
Chile	1950-73	3.05				Chile	1960-70	2.15
	1973-84	-0.70					1970-80	-0.02
							1980-86	-3.23
							1986-92	6.28
Mexico	1950-73	4.32				Mexico	1960-70	2.79
	1973-84	-0.06					1970-80	-0.11
							1980-86	-5.54
							1986-92	-0.43
USSR	1950-73	2.12						
	1973-84	-0.82						

Table 4 (continued): Equivalent G-Cubed Labor Augmenting Technical Change (LATC) from a Range of Studies

Chenery/Robinson/Syrquin (1986)			**Barro/Sala-i-Martin (1995)**		
Country	**Period**	**Equivalent LATC**	**Country**	**Period**	**Equivalent LATC**
U.S.	1960-73	1.86	U.S.	1960-90	0.48
Japan	1960-73	7.47	Japan	1960-90	3.04
France	1960-73	3.91	France	1960-90	1.38
Germany	1960-73	3.41	Germany	1960-90	1.41
U.K.	1960-73	2.57	U.K.	1960-90	1.17
Canada	1960-73	1.30	Canada	1960-90	0.06
Italy	1960-73	4.24	Italy	1960-90	2.56
Korea	1960-73	9.81	Korea	1966-90	7.62
Taiwan	1955-60	6.95	Taiwan	1966-90	9.03
India	1960-79	6.21			
Argentina	1960-74	5.28	Argentina	1940-80	2.05
Brazil	1960-74	9.31	Brazil	1940-80	2.59
Chile	1960-74	5.16	Chile	1940-80	2.35
Mexico	1960-74	6.37	Mexico	1940-80	3.17

Table 5: Calculations of Total Factor Productivity for Gcubed Sectors From a Range of Studies

Source	Country	Period	Electric Utilities	Gas Utilities	Petroleum Refining	Coal Mining	Crude Oil & Gas Extraction	Mining	Agriculture	Forestry & Wood Prod	Durable Manuf.	Non-durable Manuf.	Transp.	Services
EM	**U.S.**	1970-83						-4.28	-0.38		1.49	1.16	1.65	0.37
JGF		1950-60	2.00	0.30	1.65	3.60	0.20	0.41	1.70		0.29	1.40	1.11	0.64
JGF		1960-70	2.40	0.80	1.90	1.90	1.30	0.21	2.10		0.98	0.92	0.55	0.05
JGF		1970-79	-1.70	-1.80	-8.50	-5.20	-7.90	-1.05	0.70		0.54	2.75	0.58	0.42
JK		1960-70	2.11	2.11	1.62			1.08	1.18		0.45	0.95	1.09	0.55
JK		1970-80	-1.47	-1.47	-4.56			-5.58	0.67		0.49	0.07	1.00	0.05
JK		1980-85	-1.67	-1.67	3.42			0.05	4.43		1.71	1.46	0.25	-0.39
BLS		1960-70									1.46	1.09		
BLS		1970-80									1.07	0.52		
BLS		1980-85									1.44	1.03		
G		1960-73	1.54	1.54				0.34	0.23		1.97	1.97	2.53	0.38
G		1973-79	0.21	0.21				-0.99	-1.10		0.64	0.64	1.20	-0.95
G		1979-92	0.72	0.72				-0.48	-0.59		1.15	1.15	1.71	-0.44
EM	**Japan**	1970-83						1.60	-0.74		2.62	0.66	1.15	0.55
JK		1960-70	3.22	3.22	-1.36			1.66	0.45		1.86	0.93	3.06	1.49
JK		1970-80	-2.99	-2.99	-3.89			1.72	-1.64		0.80	0.19	0.49	0.05
JK		1980-85	0.60	0.60	-1.29			0.30	-0.27		0.20	0.29	1.19	0.81
EM	**Germany**	1970-83						-2.43	3.08		1.60	0.62	0.52	1.37
EM	**France**	1970-83							1.97		0.89	2.06	0.85	0.85
EM	**U.K.**	1970-83						8.22	2.55		1.32	0.51	1.70	0.11
EM	**Italy**	1970-83							2.12		1.11	1.52	0.77	-0.13
EM	**Canada**	1970-83							0.17				1.77	
S		1957-79						-4.66						
RP		1967-80	0.94	0.94		-1.02		-0.04	-0.14	2.43	0.70	0.51	2.29	1.02
EM	**Belgium**	1970-83							2.50		0.51	3.27	-0.88	1.06
EM	**Denmark**	1970-83							3.26		0.83	2.68	-0.98	0.88
EM	**Finland**	1970-83						0.62	1.44				2.03	
EM	**Norway**	1970-83							2.68		1.17	-0.48	2.46	0.34
EM	**Sweden**	1970-83						-2.62	1.22		2.84	-1.58	1.76	1.09
EM	**Australia**	1970-83							2.95				2.52	
M	**China**	1980-85	-3.71			0.80	-0.82							
K		1961-85									7.00	7.00		
A	**India**	1960-85			-0.13						-0.12	-0.14		
E	**Brazil**	1950-80							2.55		2.25	2.25		
E		1960-80												
E	**Argentina**	1950-80							0.44		1.05	1.05		
E		1960-80												
E	**Mexico**	1950-80							1.84					
Z	**Africa**	1960-80							1.60					0.30

E: Elias (1992) M: McGuckin et. al. (1992) JGF: Jorgenson, Gollop and Fraumeni (1987)
RP: Rao and Preston (1984) A: Ahluwalia (1991) K: Kuan et. al. (1988)
JK: Jorgenson and Kuroda (1995) S: Stollery (1985) Z: Zind (1992)
EM: Englander & Mittlestadt (1987) G: Gordon (1995) BLS: Bureau of Labour Statistics Database

Table 6. Sources of Growth and Equivalent Labor Augmenting Technical Change (LATC) by G-(

Sector	Output Growth	Contribution of Capital	Contribution of Labor	Contribution of Interm. Input	TFP Growth
Electric Utilities	6.28	2.75	0.34	2.27	0.92
Gas Utilities	5.31	1.06	0.24	4.03	-0.01
Petroleum Refining	2.71	0.24	0.05	4.22	-1.79
Coal Mining	0.38	0.69	-1.16	1.12	-0.27
Crude Oil & Gas Extraction	2.13	1.04	0.31	2.91	-2.14
Mining	2.63	1.50	0.15	1.10	-0.14
Agriculture	2.20	0.42	-0.86	1.30	1.36
Forestry & Wood Products	2.88	0.45	-0.11	2.45	0.09
Durable Manufacturing	3.94	0.44	0.57	2.49	0.44
Non-durable Manufacturing	3.54	0.37	0.20	1.93	1.03
Transportation	2.93	0.52	0.07	1.39	0.94
Services	4.05	0.59	0.78	2.21	0.46

Source: Authors' calculations from data presented in Jorgenson, Gollop and Fraumeni (1987)

Table 7: Key Exogenous Variables

- population growth by region;
- productivity growth by sector by region;
- energy efficiency improvements by sector by region;
- tax rates by region;
- fiscal spending patterns on each sector's output by region;
- monetary policy by region
- real price of oil;
- other exogenous shifts in spending patterns..

Table 8: Regional Assumptions Used in Generating Scenario 1

	USA	Japan	Aust	ROECD	China	LDCs	EEB
Population growth:	see fig 4	see fig4	see fig 4	see fig 4	see fig 4	see fig 4	see fig 4
non-energy labor productivity growth	1.4%	2.5%	1.8%	2.0%	5.0%	5.0%	3.0%
energy sector labor productivity growth	1.4%	2.5%	1.8%	2.0%	5.0%	5.0%	3.0%
energy efficiency growth	0%	0%	0%	0%	0%	0%	0%
tax rates	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels
fiscal spending	1990 shares	1990 shares	1990 shares	1990 shares	1990 shares	1990 shares	1990 shares
monetary policy (fixed money growth rate)	2.9 %	1.25 %	1.64 %	3.98 %	12.84 %	6.48 %	23.81 %
real oil price	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels

Table 9: Share of Each Region in Global Carbon Emissions Scenario 1

	1990	2000	2010	2020
USA	23.0	20.2	17.5	15.3
Japan	5.4	5.1	4.7	4.4
Australia	1.3	1.3	1.2	1.2
Other OECD	17.6	16.4	15.2	14.5
China	10.5	14.3	14.9	15.0
LDCs	17.5	25.7	28.8	30.3
Eastern Europe and former Soviet Union (EEB)	17.4	11.8	13.8	16.6

Table 10: Annual Labor Productivity Growth Used in Generating Scenario 2

1	Electric Utilities	0
2	Gas Utilities	0
3	Petroleum Refining	0
4	Coal Mining	0
5	Crude Oil and Gas Extraction	0
6	Other Mining	0
7	Agriculture, Fishing and Hunting	3.89
8	Forestry and Wood Products	0
9	Durable Manufacturing	0
10	Non-Durable Manufacturing	5.28
11	Transportation	0.7
12	Services	0.63

Table 11: Share of Each Region in Global Carbon Emissions Scenario 2

	1990	2000	2010	2020
USA	23.0	22.4	20.1	17.7
Japan	5.4	5.4	5.2	5.0
Australia	1.3	1.4	1.5	1.5
Other OECD	17.6	17.6	17.1	16.8
China	10.5	12.2	11.7	10.4
LDCs	17.5	23.1	25.0	25.7
Eastern Europe and former Soviet Union (EEB)	17.4	11.7	14.3	18.7

Table 12: Emission Stabilization Taxes by the year 2010

1990 $US per metric ton of carbon

		1995	2000	2010
United States				
	scenario 1	2.80	16.80	44.80
	scenario 2	1.40	8.40	22.40
Japan				
	scenario 1	10.50	63.00	168.00
	scenario 2	5.50	33.00	88.00
Australia				
	scenario 1	3.80	22.80	60.80
	scenario 2	2.60	15.60	41.60
Other OECD				
	scenario 1	6.80	40.80	108.80
	scenario 2	3.70	22.20	59.20
China				
	scenario 1	1.15	6.90	18.40
	scenario 2	0.24	1.44	3.84
Developing Countries				
	scenario 1	2.60	15.60	41.60
	scenario 2	1.15	6.90	18.40
Eastern Europe and Former Soviet Union				
	scenario 1	1.15	6.90	18.40
	scenario 2	0.35	2.10	5.60