Growth Accounting in the Open Economy: International Comparisons

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September 2002

Abstract

This paper identifies, measures, and compares the main factors explaining nominal GDP growth in two dozen open economies. The analysis goes beyond the standard Solow approach by disaggregating outputs, by accounting for terms-of-trade changes, and by being based on a flexible representation of the aggregate technology, with special allowance for foreign trade. The results demonstrate the overwhelming importance of capital accumulation and technological change in explaining real growth. Movements in the terms of trade play a significant role in many countries as well. The contribution of labor is found to be negligible, or even negative, in most European countries.

JEL Classification: O4, C43, F11, D2 *Keywords*: Growth accounting, GDP function, index numbers, terms-of-trade effects, technological change

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1 Introduction

From 1967 to 1996, GDP growth averaged 48.8% in Turkey, but it barely reached 5.7% in Switzerland. How can such large differences be explained? Many reasons can be invoked. Besides the obvious fact that inflation has widely varied across nations, there are real factors too, such as uneven rates of technological change, differences in the rate of capital accumulation, differences in employment growth, and uneven terms-of-trade movements.

The purpose of this paper is to identify, to measure, and to compare the main factors explaining nominal GDP growth in a number of open economies. We will use an index-number decomposition that has a strong theoretical foundation, being based on the GNP/GDP function approach to modeling the production sector of an open economy.[1] This technique builds on the pioneering work of Diewert and Morrison (1986) who examined the welfare effects of technological change and terms-of-trade shifts.[2]

Much of the recent work on growth accounting has focused on the effects of technological change and increases in domestic factor endowments, especially the supply of capital; see Mankiw, Romer and Weil (1992), Young (1994a, 1994b), and Pack and Page (1994), for instance. A controversy has developed regarding the relative importance of these factors, with some authors stressing the role of technological change and productivity shocks, and others adopting a more conventional view by mostly crediting the process of investment and capital accumulation. It is likely, however, that in most cases both factors are simultaneously at work, and that any discussion as to the relative importance of these two forces can only progress on the basis of additional empirical evidence. In fact, it probably would be most useful to first refine the measurement of the various factors at work, and to ensure that all major growth determinants have indeed been taken into account. In this

[1]See Kohli (1978, 1991), and Woodland (1982). This approach recognizes the fact that the bulk in world trade is in raw materials and in intermediate goods, and that even most so-called "finished" products must still flow through the domestic production sector before reaching final demand. Similarly, exports are used as an input by the foreign technology, and they are thus not ready to meet final demand. As such, they are conceptually different from goods intended for domestic use that can therefore be viewed as nontraded goods.

[2]See Morrison and Diewert (1990), and Kohli (1990, 1991) for additional details.

regard, it strikes us that previous work has generally neglected the impact of terms-of-trade changes. This is all the more surprising that foreign trade has often been cited as a major factor explaining economic growth.[3] As noted by Diewert and Morrison (1986), an improvement in the terms of trade is similar to a technological progress since it makes it possible for a country to increase its net output for any given amount of domestic inputs. A deterioration, on the other hand, is equivalent to technological regress, and it reduces the net amount of goods that a country obtains for a given effort.

With a few exceptions, growth accounting is based on the method developed by Solow (1957).[4] That is, the technology is described by an aggregate production function. All outputs are aggregated, and two inputs — labor and capital — are considered. The functional form is Cobb-Douglas.[5] The model then decomposes growth into three parts: the contribution of labor, the contribution of capital, and an unexplained residual that is interpreted as the contribution of technological change. This calculation can easily be done, based on the knowledge of the data alone, and of the average share of labor and capital in total costs.

Solow's approach is clever, and it is based on a tight theoretical framework. It is both extremely simple and transparent. However, it suffers from a number of serious drawbacks, which, fortunately, can easily be remedied. First, by considering a single output, Solow's approach is excessively restrictive. Disaggregating outputs would be fairly straightforward, but it forces one to abandon the production function setting, or to assume that the technology is globally separable between inputs and outputs. Second, Solow's approach is not well suited to analyze open economies since it does not allow for imports and exports, and thus, it is incapable of assessing the contribution of terms-of-trade movements. Third, the use of a Cobb-Douglas functional form is unduly restrictive; it would be much preferable to use a flexible func-

[3]See Pack and Page (1994), for instance.

[4]See Christensen, Cummings, and Jorgenson (1980) for a decomposition based on the Translog production function.

[5]Thus, Mankiw, Romer and Weil (1992) explicitly use the Cobb-Douglas functional form, whereas Young (1994a, 1994b) measures total factor productivity growth by the difference between the growth rate of output per worker and a constant proportion of the growth rate of capital per worker.

tional form instead.[6] All three points are being addressed in what follows. Specifically, we will innovate by using a multiple-output GDP function instead of a production function, by using the Translog functional for rather than the Cobb-Douglas, and by explicitly modeling foreign trade, which will enable us to identify the terms-of-trade effect.

The shortcomings of the Solow approach are likely to affect the so-called Solow residuals that are traditionally interpreted as the contribution of technological change and the result of exogenous shocks. The assumption that the shares of labor and capital are fixed through time, for instance, or the neglect of the effects of changes in the terms of trade and changes in relative output prices are likely to lead to a number of biases. The residuals presented in this paper could advantageously be used in lieu of the standard Solow (1957) residuals commonly used in empirical studies of real business cycles, and international comparisons thereof.

The paper proceeds as follows. The aggregate technology is described in the next section, and the GDP growth accounting framework that we use is presented in Section 3. Section 4 gives a description of the data. Our estimates are presented in Section 5, and Section 6 concludes.

2 Description of the Aggregate Technology

We treat the endowments of labor (L) and capital (K) as fixed in the short run, and we consider the prices of imports and outputs as given. Imports (M) are treated as a negative output; the other output components are: private consumption (C), investment (I), government consumption (G), and exports (X). The quantity vectors, measured at time t, are denoted $\mathbf{x}_t \equiv [x_{jt}], j\epsilon\{L, K\}$, and $\mathbf{y}_t \equiv [y_{it}], i\epsilon\{C, I, G, M, X\}$, respectively. The corresponding price vectors are $\mathbf{w}_t \equiv [w_{jt}]$ and $\mathbf{p}_t \equiv [p_{it}]$. Let T_t be the production possibilities set at time t; i.e. the set of all feasible inputs and outputs. We assume constant returns to scale, decreasing marginal returns,

[6] Admittedly, while most sudies on growth accounting are still based on the Cobb-Douglas functional form, measures of total factor productivity tend more and more to rely on Törnqvist indexes. See Christensen, Cummings and Jorgenson (1980) for a review of the early literature.

and free disposals.[7] The technology is allowed to shift over time as the result of technological change and exogenous productivity shocks. Assuming profit maximization and perfect competition, the technology can be represented by the following GDP function:[8]

$$\pi(\mathbf{p}_t, \mathbf{x}_t, t) \equiv \max_{\mathbf{y}}\{\mathbf{p}_t'\mathbf{y} : (\mathbf{y}, \mathbf{x}_t)\epsilon T_t\}. \tag{1}$$

The Translog functional form is well suited to represent the GDP function; it is as follows:[9]

$$\begin{aligned}\ln \pi_t \quad = \quad & \alpha_0 + \sum_i \alpha_i \ln p_{it} + \sum_j \beta_j \ln x_{jt} + \frac{1}{2}\sum_i\sum_h \gamma_{ih} \ln p_{it} \ln p_{ht} + \\ & \frac{1}{2}\sum_j\sum_k \phi_{jk} \ln x_{jt} \ln x_{kt} + \sum_i\sum_j \delta_{ij} \ln p_{it} \ln x_{jt} + \\ & \sum_i \delta_{iT} \ln p_{it} t + \sum_j \phi_{jT} \ln x_{jt} t + \beta_T t + \frac{1}{2}\phi_{TT} t^2, \qquad (2) \\ & \qquad i, h\epsilon\{M, X, I, G, C\};\ j, k\epsilon\{L, K\},\end{aligned}$$

where $\sum \alpha_i = 1$, $\sum \beta_j = 1$, $\gamma_{ih} = \gamma_{hi}$, $\phi_{jk} = \phi_{kj}$, $\sum \gamma_{ih} = 0$, $\sum \phi_{jk} = 0$, $\sum_i \delta_{ij} = 0$, $\sum_j \delta_{ij} = 0$, $\sum \delta_{iT} = 0$, and $\sum \phi_{jT} = 0$. It is well known that differentiation of the GDP function with respect to output prices yields the import demand and output supply functions, while differentiation with respect to factor quantities produces the inverse input demand functions.[10] In terms of shares, we get:

$$s_{it} = \alpha_i + \sum_h \gamma_{ih} \ln p_{ht} + \sum_j \delta_{ij} \ln x_{jt} + \delta_{iT} t, \qquad i\epsilon\{M, X, I, G, C\} \tag{3}$$

$$s_{jt} = \beta_j + \sum_i \delta_{ij} \ln p_{it} + \sum_k \phi_{jk} \ln x_{kt} + \phi_{jT} t, \qquad j\epsilon\{L, K\} \tag{4}$$

where $s_{it} \equiv p_{it}y_{it}/\pi_t$ and $s_{jt} \equiv w_{jt}x_{jt}/\pi_t$ are the GDP shares of output i and factor j, respectively.

[7] Formally, T_t is assumed to be a closed, non-empty, convex cone.

[8] See Kohli (1978, 1991) and Woodland (1982) for details.

[9] See Christensen, Jorgenson and Lau (1973) and Diewert (1974). See Kohli (1978, 1991) for empirical applications.

[10] See Diewert (1974) and Kohli (1978, 1991), for instance.

3 Growth Accounting in the Open Economy

In their path-breaking paper, Diewert and Morrison (1986) define the following Laspeyres-like *productivity index* to capture the GDP effect of the change in technology between times $t-1$ and t:

$$R^L_{t,t-1} \equiv \frac{\pi(\mathbf{p}_{t-1}, \mathbf{x}_{t-1}, t)}{\pi(\mathbf{p}_{t-1}, \mathbf{x}_{t-1}, t-1)}. \tag{5}$$

$R^L_{t,t-1}$ measures the change in GDP between periods $t-1$ and t that is imputable to the change in technology alone, holding all output prices and domestic factor endowments constant at their level of period $t-1$. Of course, these could have been held constant equally well at their level of period t, rather than $t-1$. Indeed, Diewert and Morrison (1986) also define the corresponding Paasche-like productivity index:

$$R^P_{t,t-1} \equiv \frac{\pi(\mathbf{p}_t, \mathbf{x}_t, t)}{\pi(\mathbf{p}_t, \mathbf{x}_t, t-1)}. \tag{6}$$

Next, one can define the Fisher-like geometric mean of (5) and (6):

$$\begin{aligned} R_{t,t-1} &\equiv \sqrt{R^L_{t,t-1} R^P_{t,t-1}} \\ &= \sqrt{\frac{\pi(\mathbf{p}_{t-1}, \mathbf{x}_{t-1}, t)}{\pi(\mathbf{p}_{t-1}, \mathbf{x}_{t-1}, t-1)} \cdot \frac{\pi(\mathbf{p}_t, \mathbf{x}_t, t)}{\pi(\mathbf{p}_t, \mathbf{x}_t, t-1)}}. \end{aligned} \tag{7}$$

GDP function $\pi(\cdot)$ is generally unknown, and hence $R_{t,t-1}$ cannot be calculated from (7).[11] Fortunately, Diewert and Morrison (1986) demonstrated a truly remarkable result, namely that as long as the GDP function has the Translog form as given by (2), an *exact* measure of $R_{t,t-1}$ can be derived from knowledge of the data alone in the following way:

$$R_{t,t-1} = \frac{\Gamma_{t,t-1}}{P_{t,t-1} \cdot X_{t,t-1}}, \tag{8}$$

[11] Estimates the GDP function can be obtained by econometric techniques, in which case (7) can be applied; see Kohli (1990, 1991). However, this requires the selection of a stochastic specification and of an estimation technique, choices that are always somewhat arbitrary and subject to criticism.

where

$$\Gamma_{t,t-1} \equiv \frac{\sum p_{it} y_{it}}{\sum p_{it-1} y_{it-1}} \tag{9}$$

$$P_{t,t-1} \equiv \exp\left\{\sum_i \left[\frac{1}{2}(s_{it} + s_{it-1}) \ln \frac{p_{it}}{p_{it-1}}\right]\right\} \tag{10}$$

$$X_{t,t-1} \equiv \exp\left\{\sum_j \left[\frac{1}{2}(s_{jt} + s_{jt-1}) \ln \frac{x_{jt}}{x_{jt-1}}\right]\right\}. \tag{11}$$

$\Gamma_{t,t-1}$ is (one plus) the rate of increase in nominal GDP between times $t-1$ and t; $P_{t,t-1}$ is the Törnqvist *output price index*, and $X_{t,t-1}$ is the Törnqvist *domestic endowment quantity index.*[12]

Next, consider the GDP effect of a change in the terms of trade between times $t-1$ and t. Proceeding along the same lines as for the change in technology, Diewert and Morrison (1986) devised the following *terms-of-trade adjustment index*, $A_{t,t-1}$:

$$A_{t,t-1} \equiv \sqrt{\frac{\pi(p_{Mt}, p_{Xt}, \mathbf{p}_{Nt-1}, \mathbf{x}_{t-1}, t-1)}{\pi(p_{Mt-1}, p_{Xt-1}, \mathbf{p}_{Nt-1}, \mathbf{x}_{t-1}, t-1)} \cdot \frac{\pi(p_{Mt}, p_{Xt}, \mathbf{p}_{Nt}, \mathbf{x}_t, t)}{\pi(p_{Mt-1}, p_{Xt-1}, \mathbf{p}_{Nt}, \mathbf{x}_t, t)}}, \tag{12}$$

where $\mathbf{p}_N$ is the vector of domestic prices: $\mathbf{p}_N \equiv [p_I, p_G, p_C]'$. $A_{t,t-1}$ can also be interpreted as the geometric mean of Laspeyres and Paasche indexes. Diewert and Morrison (1986) demonstrate that, as long as the GDP function has the Translog form, $A_{t,t-1}$ can be calculated from knowledge of the data alone in the following way:[13]

$$A_{t,t-1} = \exp\left[\frac{1}{2}(s_{Mt} + s_{Mt-1}) \ln \frac{p_{Mt}}{p_{Mt-1}} + \frac{1}{2}(s_{Xt} + s_{Xt-1}) \ln \frac{p_{Xt}}{p_{Xt-1}}\right]. \tag{13}$$

To assess the contribution of the domestic factors of production we can

[12]Note that $R_{t,t-1}$ given by (8) is not quite equivalent to a commonly used measure of total factor productivity growth, where a Törnqvist index of real output is divided by a Törnqvist index of input quantities. Indeed, the ratio $\Gamma_{t,t-1}/P_{t,t-1}$ in (8) can be interpreted as an *implicit* Törnqvist output quantity index, which is numerically different from a straight Törnqvist output quantity index since Törnqvist indexes do not satisfy the Fisher factor reversal test. This implies that the conventional method is not exact for the Translog GDP function.

[13]Note that (13) is similar to a Törnqvist price index, except that the weights — the GDP shares of imports and exports — do generally not add up to one.

define the following *factor endowments effects*:

$$X_{jt,t-1} \equiv \sqrt{\frac{\pi(\mathbf{p}_{t-1}, x_{jt}, x_{kt-1}, t-1)}{\pi(\mathbf{p}_{t-1}, x_{jt-1}, x_{kt-1}, t-1)} \cdot \frac{\pi(\mathbf{p}_t, x_{jt}, x_{kt}, t)}{\pi(\mathbf{p}_t, x_{jt-1}, x_{kt}, t)}}, \qquad (14)$$

$$j, k \epsilon \{L, K\}, j \neq k.$$

$X_{jt,t-1}$ measures the contribution of factor j to GDP growth between times $t-1$ and t. Assuming once again that $\pi(\cdot)$ is given by (2), $X_{jt,t-1}$ can be measured as follows:

$$X_{jt,t-1} \equiv \exp\left[\frac{1}{2}(s_{jt} + s_{jt-1}) \ln \frac{x_{jt}}{x_{jt-1}}\right], \qquad j \epsilon \{L, K\}. \qquad (15)$$

Finally, we can evaluate the GDP contribution of domestic good prices. Consider the following *nontraded good price effect*:

$$P_{Nt,t-1} \equiv \sqrt{\frac{\pi(p_{Mt-1}, p_{Xt-1}, \mathbf{p}_{Nt}, \mathbf{x}_{t-1}, t-1)}{\pi(p_{Mt-1}, p_{Xt-1}, \mathbf{p}_{Nt-1}, \mathbf{x}_{t-1}, t-1)} \cdot \frac{\pi(p_{Mt}, p_{Xt}, \mathbf{p}_{Nt}, \mathbf{x}_t, t)}{\pi(p_{Mt}, p_{Xt}, \mathbf{p}_{Nt-1}, \mathbf{x}_t, t)}}. \qquad (16)$$

$P_{Nt,t-1}$ measures the growth in GDP that is due to domestic price changes only. If the GDP function has the Translog form, $P_{Nt,t-1}$ can be measured as:

$$P_{Nt,t-1} = \exp\left\{\frac{1}{2}(s_{It} + s_{It-1}) \ln \frac{p_{It}}{p_{It-1}} + \frac{1}{2}(s_{Gt} + s_{Gt-1}) \ln \frac{p_{Gt}}{p_{Gt-1}} + \frac{1}{2}(s_{Ct} + s_{Ct-1}) \ln \frac{p_{Ct}}{p_{Ct-1}}\right\}. \qquad (17)$$

Kohli (1990) has shown that, in the Translog case, (8), (13), (15), and (17) together give a *complete* decomposition of nominal GDP growth:

$$\Gamma_{t,t-1} = R_{t,t-1} \cdot A_{t,t-1} \cdot X_{Lt,t-1} \cdot X_{Kt,t-1} \cdot P_{Nt,t-1}. \qquad (18)$$

The product of the first two terms on the right hand side make up Diewert and Morrison's (1986) welfare change index. Multiplying this by the labor and capital quantity effects, one obtains the change in GDP after one also allows for changes in factor endowments; this can be interpreted as the change in real national income, since none of the domestic prices has yet been allowed to vary. Finally, multiplying by the domestic good price effect, we get GDP growth.[14]

4 Data

The framework of the previous section is used to analyze the determinants of growth in a sample of 24 open economies for the period 1967–1996 using annual data. We require price and quantity series on all domestic inputs (labor and capital), on imports, and on all outputs (exports, investment goods, government purchases, and consumption goods).

All data for the United States have been derived from U.S. sources since these are easily accessible and they have been widely used in prior work on productivity measurement. Thus, price and quantity series for the main GDP components, together with data on indirect taxes and subsidies, have been obtained from the U.S. national income and product accounts (NIPA). Since the GDP function model adopts the producers' viewpoint, we have corrected output prices for indirect taxes and subsidies: subsidies have been distributed equally to all outputs, whereas indirect taxes were imputed to consumption goods. The rental price of labor and capital, together with their national income shares, have been obtained from the U.S. Bureau of Labor Statistics (BLS). The quantities of labor and capital services were then obtained by deflation.

For all the other countries, constant and current price series for imports, exports, investment (including increases in stocks), government final consumption expenditures and private final consumption expenditures were obtained from the OECD National Accounts, Main Aggregates. These are available from 1960 onwards. Output prices were once again corrected for indirect taxes and subsidies. The OECD National Accounts also provide data on the compensation of employees and the operating surplus, which we treat as the income of labor and capital, respectively. These data, in turn, enable us to calculate the GDP shares of labor and capital. The quantity of la-

[14]Note also that the product of the productivity index and of the two domestic factor endowment effects yields an *implicit* Törnqvist index of real GDP.

bor services is obtained by multiplying civilian employment (OECD Labour Force Statistics) by the number of hours worked per week (ILO Yearbook of Labour Statistics).

As regards the quantity of capital services, we assume that the flow of capital services is proportional to the beginning-of-period capital stock.[15] Unfortunately, for most countries in our sample there are no official capital stock data available. We therefore construct a capital stock series by cumulating real gross investment,[16] subject to a constant rate of depreciation, δ:

$$x_{Kt} = (1-\delta)x_{Kt-1} + y_{It-1} = \sum_{h=0}^{\infty}(1-\delta)^h y_{It-h-1}, \qquad t = -\infty, \ldots, 1996. \quad (19)$$

In order to get an initial value for x_K, we proceed as in Kohli (1982). That is, we assume that prior to some period T, real investment grew at a constant rate γ:

$$y_{It} = y_{It-1}(1+\gamma), \qquad t = -\infty, \ldots, T. \quad (20)$$

Making use of (20) in (19) for period T, we obtain an expression for the initial capital stock:

$$x_{KT} = \frac{y_{IT}}{1+\gamma}\sum_{h=0}^{\infty}\left(\frac{1-\delta}{1+\gamma}\right)^h = \frac{y_{IT}}{\gamma+\delta}. \quad (21)$$

Since we have investment data starting in 1960, we set T to 1960. We devote the first seven observations to the computation of the initial capital stock. That is, we calculate γ as the average rate of growth of real investment between 1960 and 1967, and we assume that this rate of growth is representative of the average growth rate prior to 1960. We set δ to 0.05 and we compute the 1960 capital stock using (21). The capital stock for the following years is then obtained by applying (19). This procedure ensures that the 1967 value

[15] Due to the lack of reliable data, no attempt is made to correct for variations in the rate of capacity utilization. Unless capacity utilization steadily increases or decreases over time, however, this should have little impact on the *long-run* measure of the GDP growth contribution of capital.

[16] The investment series we use is gross fixed capital formation, and it is drawn directly from the national accounts. The resulting capital stock series therefore encompasses all forms of tangible capital, including residential constructions and public capital.

of the capital stock is independent of all intra-sample (1967–1996) data, and, moreover, that it is relatively insensitive to the 1960 initial value.[17] The depreciation rate itself has a fairly large impact on the level of the capital stock, but much less so on its rate of growth, which is what matters for the purpose of this study. Nevertheless, in what follows we will report estimates for alternative values of γ and δ. This procedure is repeated for each country other than the United States.

5 Estimates

Table 1 presents our main results in the form of geometric averages for the 1967–1996 period. We show the productivity index ($R_{t,t-1}$), the terms-of-trade adjustment index ($A_{t,t-1}$), the labor endowment effect ($X_{Lt,t-1}$), the capital endowment effect ($X_{Kt,t-1}$), the nontraded good price effect ($P_{Nt,t-1}$), and the nominal GDP index ($\Gamma_{t,t-1}$) for all 24 countries.

The last column shows nominal GDP growth; these are actual data. As mentioned in the introduction, GDP growth has averaged 48.8% in Turkey, and it was as low as 5.7% in Switzerland.

Looking at the various factors explaining growth, one sees that they differ greatly between countries. There are some important similarities, however. Thus, it appears that in all countries but one (Japan), price increases have accounted for more than half of nominal GDP growth. In Turkey, domestic inflation explains over 90% of GDP growth, but even in low-growth Switzerland, domestic price increases account for over half of the growth in GDP. It is noteworthy that, strictly speaking, $P_{Nt,t-1}$ is not a price index. As shown by (17), the weights used to compute $P_{Nt,t-1}$ normally do not add up to unity. However, if the trade account is close to equilibrium, $P_{Nt,t-1}$ comes close to a Törnqvist index of domestic prices.

It is evident that the two main engines of real growth are capital accumulation and technological change. Capital accumulation is the first factor

[17] Clearly, one would like to base the estimate of γ on as many observations as possible. Unfortunately, one faces a trade-off since the more observations are used for the construction of the initial capital stock, the less will be left for the actual analysis.

of real growth in 14 of the 24 countries in our sample, and the second cause in all the other ones. Its contribution to growth is in excess of 1% in all countries except in Sweden and Germany, and it is as high as 3.5% in Japan and 4.7% in Turkey. Technological change is the prime engine of growth in nine countries, all European. Its growth contribution is as high as 2.6% in Ireland, and it exceeds one percent in 14 countries.[18]

The most striking discrepancy across the various countries in our sample has to do with the GDP growth contribution of employment. This effect is actually negative in nearly half the European Union member countries: Belgium, Denmark, Finland, France, Germany, Spain, and Sweden, and it is barely positive in the remaining E.U. countries, except for Luxembourg. In contrast, the contribution of labor is close to, or in excess of, one percent per year in the United States, Canada, Australia, and New Zealand. It is striking that employment contributed so little to European economic growth. This is largely due to the low rate of growth in civilian employment and to the steady decline in the length of the workweek. It is important to stress that $X_{Lt,t-1}$ does not measure the growth in employment, but rather the contribution of labor growth to GDP growth. It reflects both the increase in the endowment of labor and changes in the GDP share of labor. As indicated by (4), these changes in the labor share are mostly due to technological change, and to movements in relative factor endowments and in relative output prices.

The second column of the table shows the terms-of-trade contribution. As expected, this effect is small on balance. Nevertheless, it averages over one tenth of a percentage point in absolute value in 14 of the 24 countries in

[18]For the United States, technological change accounted for about 0.4% of annual growth, on average. This may seem small compared to the very high "headline" rates of productivity growth that have been reported repeatedly in recent years. It must be remembered, however, that our figures are an average over a thirty-year period. Productivity growth has been very low during much of the seventies and the eighties, even though it has been higher in recent years (thus, our estimate for $R_{1996,1995}$ is 1.5%). Furthermore, among the figure published by the BLS, the ones that receive the most attention by the media are for the increases in the average productivity of labor, rather than total factor productivity. That is, the contribution of capital is effectively added to the effect of technological change. Finally, one must realize that the BLS figures are for the private business sector, and they thus exclude the government and the household sectors where productivity growth is much lower or even inexistant.

our sample. It has added one quarter of a percentage point to real growth in Canada and one third of a percentage point in Switzerland. Over three decades this has added up to over 10% of real income in the case of Switzerland. On the other hand, terms-of-trade movements have severely penalized Turkey, Greece, Ireland, and Portugal. Japanese growth too has been reduced, by about 0.2% annually, as a result of adverse terms-of-trade changes.

The numbers in Table 1 are yearly averages over a 30-year period, and they mask the fact that some of the annual figures are fairly volatile. This is particularly true for the terms-of-trade adjustment indexes, and for the contribution of technological change and other productivity shocks. Rather than reporting all yearly numbers in details, we present in Figure 1 a summary of our findings. The various country panels show the cumulated products of the various factors explaining real growth. Thus, the upper fat line represents the path of real income, when its 1967 value is normalized to unity. The lowest line shows the cumulated effect of employment growth. To this, one adds the contribution of capital accumulation to get the second line. The third line is obtained by adding the terms-of-trade adjustment index (which is negative in some cases). The top line is then obtained by adding the contribution of technological change. The nontraded good price effects have been purposely left out, in order not to flatten out the graphs and to dwarf the real effects.

It is also of interest to look at the cross-country correlations between productivity and terms-of-trade shocks. Tables 2 and 3 summarize these links for the *G-7* countries. Productivity shocks tend to be positively correlated across nations, but the corresponding correlation coefficients are generally not significant. The strongest correlations are between Canada and the United States, and between France and Italy.

The international linkages of terms-of-trade shocks seem to be much stronger. It is difficult to predict what the expected sign of these correlation coefficients should be. In a two-country world, one would expect the terms-of-trade effects to be negatively correlated.[19] In a world with more countries, the effect is less clear-cut. If two countries trade a great deal with each other,

[19]The correlation would not necessarily be perfect since the $A_{t,t-1}$'s reflect changes in the GDP shares of imports and exports as well as in the terms of trade themselves.

one might still expect a negative correlation. If the countries are very similar — so that much of the trade among them tends to be intra-industry — and if they tend to trade a fair bit with third nations, one might expect positive correlations. It is clear from Table 3 that both situations occur. There are some very strong negative correlations between Canada and all the other *G-7* countries, whereas terms-of-trade effects appear to be positively correlated between the remaining countries. The links are particularly strong between the United States, Japan, France, Germany, and Italy.

As mentioned earlier, the capital stocks series that we computed depend to some extent on the values of γ and δ. For the purpose of this study, δ was set to 0.05. A larger depreciation rate would have meant a lower value for the initial capital stock, but since it would also tend to lower the level of net investment, the net impact on the rate of growth of the capital stock would have been small. Similarly, a larger value of γ would lower the initial capital stock. Other things equal, this would tend to increase its rate of growth and it would tend to reinforce the contribution of capital to GDP growth. In order to assess the importance of these factors, we conducted a number of sensitivity tests, by successively lowering and increasing the values of δ and γ by 20%. The results of these calculations are summarized in Table 4. Note that alternative values of γ and δ only impact on the values of $X_{Kt,t-1}$ and $R_{t,t-1}$. They have no effect on the estimates of $A_{t,t-1}$, $X_{Lt,t-1}$, $P_{Nt,t-1}$, and $\Gamma_{t,t-1}$.

The first column of Table 4 shows the values of $X_{Kt,t-1}$ based on our original assumptions.[20] The second and third columns show the contribution of capital to GDP growth based on the alternative assumptions $\delta = 0.04$ and $\delta = 0.06$, respectively. It can be seen that a lower depreciation rate slightly increases our estimates of $X_{Kt,t-1}$, whereas the higher rate of depreciation lowers it. The differences compared to the figures in the first column are very small, though, being typically less than one tenth of a percentage point.

The estimates in the fourth and fifth columns of Table 4 were obtained

[20] We do not show the implied values of $R_{t,t-1}$ since these would simply mirror those of $X_{Kt,t-1}$. Note also that no sensitivity results are reported for the United States since our data for the U.S. capital stock are not based on (19)–(21), but were derived instead from official sources.

after having lowered each country's γ by 20%, and increased it by 20%, respectively. As expected, a higher value of γ leads to a higher value of $X_{Kt,t-1}$, but the differences compared to the estimates in the first column are again very small, generally less than one tenth of a percentage point.

This sensitivity analysis has shown that even though the path of the capital stock and its contribution to growth do reflect the values of γ and δ, this does not alter our results to a significant extent. Thus, even if, for each country, we take the lowest values of $X_{Kt,t-1}$ shown in Table 4, our earlier conclusion that capital accumulation is the first or second most important engine of growth in every country in our sample remains intact.

By using a two-input, one-output framework, by neglecting the international trade dimension, and by relying on a Cobb-Douglas representation of the technology, the Solow approach produces much cruder residuals than ours.[21] Although the differences between the two sets of measures can be viewed as of being of second-order smallness,[22] there is little point in using the Solow residuals if better estimates are available at hardly any extra cost. To document the difference between the two sets of measures, we have calculated traditional Solow residual indexes ($S_{t,t-1}$) for the 24 countries in our sample. They are defined as follows:

$$\ln S_{t,t-1} \equiv \ln \frac{q_{Yt}}{q_{Yt-1}} - \overline{s}_L \ln \frac{x_{Lt}}{x_{Lt-1}} - \overline{s}_K \ln \frac{x_{Kt}}{x_{Kt-1}}, \tag{22}$$

where q_Y is the conventional measure of real GDP, and $\overline{s}_j, j \in \{L, K\}$ are the sample means of the labor and capital shares. In the first column of Table 5, we report the same estimates of $R_{t,t-1}$ as were shown in Table 1. The second column shows the Solow residual indexes, whereas column 3 gives the correlation coefficients (ρ^2) between the two series. It can be seen that even though the correlation is very high, it is far from perfect. The correlation coefficients range from 90.80% for Iceland to 99.87% for the United States. Although the differences between the two series also depend on changes in

[21]Needless to say, the Solow approach faces exactly the same challenges as ours when it comes to measuring the capital stock.

[22]The Cobb-Douglas functional form can be viewed as a first-order approximation in logarithms to an arbitrary production function, whereas the Translog provides a second-order approximation.

factor shares over time and the composition of output, they largely reflect the size of the foreign sector and the volatility of the terms of trade.

6 Concluding Comments

One impression that emerges from Table 1 and Figure 1 is that the causes of GDP growth vary greatly from period to period and across nations, even if one abstracts from domestic price inflation that is notoriously volatile. Nevertheless, the contribution of capital seems to be dominating the real growth picture. Technological change and productivity shocks vary greatly through time and across countries, and they are the prime cause of long-run growth in just over one third of the countries in our sample. Terms-of-trade changes do add up over time and should not be neglected. One point that distinguishes European nations is the low — and sometimes even negative — contribution of labor. Not surprisingly, the countries that experience the fastest population growth are also the ones where employment contributes the most to economic activity. European nations are not only characterized by low employment growth, which reflects both a slow growing population and a high level of unemployment, but also a rapidly shortening workweek.

The residual $R_{t,t-1}$ comes close to the concept of unexpected, and transitory, productivity shock that is a driving force in real business cycle models.[23] In our opinion, the estimates of $R_{t,t-1}$ reported in Table 1 could advantageously replace the Solow residuals commonly used in empirical work on real business cycles and the international propagation of productivity shifts. Indeed, it is surprising that so many of these studies, which use very sophisticated times series analysis and other econometric techniques, rely on such crude measures of technological change. Unlike Solow residuals, $R_{t,t-1}$ is based on a flexible, multiple-input, multiple-output representation of the aggregate technology. Furthermore, it may be useful in empirical work on real business cycles to also take account of the GDP effects due to changes in the terms of trade, as measured by $A_{t,t-1}$; such changes are often unforeseen, and thus they can be associated with unexpected productivity shifts.

[23]See Kydland and Prescott (1982), and Prescott (1986), for instance.

The framework presented in this paper could easily be expanded to allow for additional inputs and/or outputs. It would be of particular interest to disaggregate labor according to skills and education in order to assess the GDP growth contribution of education and human capital. Another interesting research avenue would be to take public goods and infrastructure into account. These and other extensions may be undertaken in future work.

References

Christensen, Laurits R., Dianne Cummings, and Dale W. Jorgenson (1980) "Economic Growth, 1947–73; An International Comparison", in J.W. Kendrick and B.N. Vaccara (eds.) *New Developments in Productivity Measurement and Analysis*, Studies in Income and Wealth, Vol. 44, National Bureau of Economic Research (Chicago: University of Chicago Press).

Christensen, Laurits R., Dale W. Jorgenson, and Lawrence J. Lau (1973) "Transcendental Logarithmic Production Frontiers", *Review of Economics and Statistics* 55, 28–45.

Diewert, W. Erwin (1974) "Applications of Duality Theory", in M.D. Intriligator and D.A. Kendrick (eds.) *Frontiers of Quantitative Economics*, Vol. 2 (Amsterdam: North-Holland).

Diewert, W. Erwin and Catherine J. Morrison (1986) "Adjusting Output and Productivity Indexes for Changes in the Terms of Trade", *Economic Journal* 96, 659–679.

International Labour Organisation *Yearbook of Labour Statistics* (Geneva: ILO), various issues.

Kohli, Ulrich (1978) "A Gross National Product Function and the Derived Demand for Imports and Supply of Exports", *Canadian Journal of Economics* 11, 167–182

Kohli, Ulrich (1982) "Production Theory, Technological Change and the Demand for Imports: Switzerland, 1948–1976", *European Economic Review* 18, 369–386.

Kohli, Ulrich (1990) "Growth Accounting in the Open Economy: Parametric and Nonparametric Estimates", *Journal of Economic and Social Measurement* 16, 125-136.

Kohli, Ulrich (1991) *Technology, Duality, and Foreign Trade: The GNP Function Approach to Modeling Imports and Exports* (Ann Arbor, MI: University of Michigan Press).

Kydland, Finn E. and Edward C. Prescott (1982) "Time to Build and Aggregate Fluctuations", *Econometrica* 50, 1345–1370.

Mankiw, N. Gregory, David Romer, and David N. Weil (1992) "A Contribution to the Empirics of Economic Growth", *Quarterly Journal of Economics* 152, 407–37.

Morrison, Catherine and W. Erwin Diewert (1990) "Productivity Growth and Changes in the Terms of Trade in Japan and the United States", in

Charles R. Hulten (ed.) *Productivity Growth in Japan and the United States* (Chicago, IL: University of Chicgo Press).

Organisation for Economic Co-operation and Development, *National Accounts: Main Aggregates* (Paris: OECD), various issues.

Organisation for Economic Co-operation and Development, *Labour Force Statistics* (Paris: OECD), various issues.

Pack, Howard and John M. Page Jr. (1994) "Accumulation, Exports, and Growth in the High-Performing Asian Economies," *Carnegie-Rochester Conference Series on Public Policy* 40, 199–236.

Prescott, Edward C. (1986) "Theory Ahead of Business Cycle Measurement", *Carnegie-Rochester Conference Series on Public Policy* 25, 11–44.

Solow, Robert M. (1957) "Technical Change and the Aggregate Production Function", *Review of Economics and Statistics* 39, 312– 320.

United States Department of Commerce, Bureau of Economic Analysis, "National Income and Product Accounts", *http://www.bea.doc.gov/bea/dn/nipaweb*.

United States Department of Labor, Bureau of Labor Statistics, "Multifactor Productivity and Related Data", *http://www.bls.gov/mprhome.htm*.

Woodland, Alan D. (1982) *International Trade and Resource Allocation* (Amsterdam: North-Holland).

Young, Alwyn (1994a) "Lessons from the East Asian NICS: A Contrarian View", *European Economic Review* 38, 964–73.

Young, Alwyn (1994b) "Accumulation, Exports, and Growth in the High Performing Asian Economies: A Comment," *Carnegie-Rochester Conference Series on Public Policy* 40, 237–250.

$\prod_t X_{Lt,t-1}$

$\prod_t X_{Lt,t-1} \cdot X_{Kt,t-1}$

$\prod_t X_{Lt,t-1} \cdot X_{Kt,t-1} \cdot A_{t,t-1}$

$\prod_t X_{Lt,t-1} \cdot X_{Kt,t-1} \cdot A_{t,t-1} \cdot R_{t,t-1}$

Figure 1: Cumulative, real effects, 1967-1996

Table 1: GDP Growth Accounting in the Open Economy
International Comparisons
(geometric averages, 1967–1996)

	$R_{t,t-1}$	$A_{t,t-1}$	$X_{Lt,t-1}$	$X_{Kt,t-1}$	$P_{Nt,t-1}$	$\Gamma_{t,t-1}$
USA	1.00382	0.99873	1.01307	1.01269	1.05041	1.08038
Canada	1.00199	1.00242	1.01220	1.01830	1.05095	1.08801
Japan	1.00987	0.99756	1.00247	1.03532	1.03900	1.08633
Australia	1.00838	0.99930	1.00997	1.01630	1.07088	1.10762
New Zealand	0.99980	0.99876	1.00954	1.01321	1.08708	1.11035
Austria	1.01379	0.99862	1.00010	1.01774	1.04407	1.07587
Belgium	1.01664	1.00032	0.99596	1.01385	1.04949	1.07770
Denmark	1.01478	0.99777	0.99837	1.01148	1.06472	1.08866
Finland	1.01916	1.00069	0.99979	1.01073	1.07244	1.10524
France	1.01088	1.00001	0.99871	1.01723	1.06620	1.09497
Germany	1.01982	1.00182	0.99903	1.00871	1.03709	1.06776
Greece	1.00067	0.98922	1.00179	1.03023	1.15124	1.17615
Iceland	1.00553	0.99861	1.01239	1.01674	1.25051	1.29250
Ireland	1.02621	0.99038	1.00271	1.02283	1.08947	1.13562
Italy	1.01389	0.99989	1.00034	1.01388	1.10172	1.13278
Luxembourg	1.02075	1.00089	1.00926	1.01156	1.04372	1.08863
Netherlands	1.01122	0.99960	1.00484	1.01331	1.04148	1.07191
Norway	1.01757	0.99703	1.00296	1.01647	1.06095	1.09735
Portugal	1.01312	0.99066	1.00165	1.02262	1.14041	1.17238
Spain	1.00690	0.99950	0.99805	1.02776	1.09967	1.13521
Sweden	1.01450	0.99971	0.99764	1.00885	1.06832	1.09050
Switzerland	0.99995	1.00332	1.00361	1.01220	1.03666	1.05653
Turkey	0.99513	0.98738	1.00489	1.04717	1.43866	1.48751
United Kingdom	1.01055	0.99933	1.00002	1.01102	1.08249	1.10524

Explanations:
$R_{t,t-1}$: productivity index
$A_{t,t-1}$: terms-of-trade adjustment index
$X_{Lt,t-1}$: labor quantity effect
$X_{Kt,t-1}$: capital quantity effect
$P_{Nt,t-1}$: nontraded good price effect
$\Gamma_{t,t-1}$: nominal GDP index.

Table 2: Productivity Index ($R_{t,t-1}$)
Correlation among the *G-7* Countries

	USA	Canada	Japan	France	Germany	Italy	UK
USA	1.00000	0.67815	0.10075	0.18638	0.27832	0.25086	0.26520
Canada		1.00000	0.06681	0.49061	0.24960	0.57225	0.31543
Japan			1.00000	0.20153	0.40810	0.26180	0.04053
France				1.00000	0.38058	0.64074	0.15307
Germany					1.00000	0.40794	-0.07931
Italy						1.00000	0.16980
UK							1.00000

Table 3: Terms-of-Trade Adjustment Index ($A_{t,t-1}$)
Correlation among the *G-7* Countries

	USA	Canada	Japan	France	Germany	Italy	UK
USA	1.00000	-0.65435	0.68262	0.60850	0.30829	0.44571	0.25502
Canada		1.00000	-0.74150	-0.62904	-0.52343	-0.63901	-0.37457
Japan			1.00000	0.77495	0.67323	0.60217	0.18728
France				1.00000	0.66939	0.72302	0.32992
Germany					1.00000	0.62533	0.01487
Italy						1.00000	0.56662
UK							1.00000

Table 4: Capital Quantity Effect ($X_{Kt,t-1}$)
Estimates for Alternative Parameter Values
(geometric averages, 1967–1996)

	$\delta = 0.05$ $1.0 \times \gamma$	$\delta = 0.04$ $1.0 \times \gamma$	$\delta = 0.06$ $1.0 \times \gamma$	$\delta = 0.05$ $0.8 \times \gamma$	$\delta = 0.05$ $1.2 \times \gamma$
Canada	1.01830	1.01850	1.01812	1.01761	1.01888
Japan	1.03532	1.03598	1.03472	1.03453	1.03594
Australia	1.01630	1.01678	1.01587	1.01556	1.01693
New Zealand	1.01321	1.01364	1.01282	1.01250	1.01383
Austria	1.01774	1.01810	1.01743	1.01696	1.01841
Belgium	1.01385	1.01441	1.01335	1.01314	1.01445
Denmark	1.01148	1.01223	1.01081	1.01085	1.01201
Finland	1.01073	1.01107	1.01040	1.01012	1.01128
France	1.01723	1.01787	1.01665	1.01649	1.01783
Germany	1.00871	1.00891	1.00853	1.00820	1.00917
Greece	1.03023	1.03138	1.02917	1.02900	1.03125
Iceland	1.01674	1.01744	1.01610	1.01595	1.01739
Ireland	1.02283	1.02356	1.02216	1.02211	1.02341
Italy	1.01388	1.01436	1.01345	1.01310	1.01457
Luxembourg	1.01156	1.01158	1.01154	1.01100	1.01207
Netherlands	1.01331	1.01394	1.01275	1.01261	1.01389
Norway	1.01647	1.01714	1.01586	1.01570	1.01712
Portugal	1.02262	1.02323	1.02207	1.02169	1.02338
Spain	1.02776	1.02868	1.02693	1.02696	1.02839
Sweden	1.00885	1.00935	1.00841	1.00833	1.00930
Switzerland	1.01220	1.01265	1.01179	1.01153	1.01277
Turkey	1.04717	1.04726	1.04709	1.04576	1.04835
United Kingdom	1.01102	1.01146	1.01063	1.01044	1.01151

Table 5: Productivity Index ($R_{t,t-1}$) and Solow Residual Index ($S_{t,t-1}$) (geometric averages, 1967–1996)

	$R_{t,t-1}$	$S_{t,t-1}$	ρ^2
USA	1.00382	1.00391	0.99869
Canada	1.00199	1.00248	0.96374
Japan	1.00987	1.00867	0.97048
Australia	1.00838	1.00767	0.98956
New Zealand	0.99980	0.99889	0.97277
Austria	1.01379	1.01310	0.97455
Belgium	1.01664	1.01616	0.99302
Denmark	1.01478	1.01340	0.96899
Finland	1.01916	1.01815	0.97535
France	1.01088	1.01069	0.97779
Germany	1.01982	1.01911	0.98884
Greece	1.00067	1.00251	0.98735
Iceland	1.00553	1.00575	0.90804
Ireland	1.02621	1.02054	0.93358
Italy	1.01389	1.01385	0.98941
Luxembourg	1.02075	1.01862	0.98507
Netherlands	1.01122	1.00987	0.98746
Norway	1.01757	1.01546	0.94768
Portugal	1.01312	1.01196	0.96904
Spain	1.00690	1.00640	0.95726
Sweden	1.01450	1.01332	0.95908
Switzerland	0.99995	1.00090	0.98413
Turkey	0.99513	0.99327	0.96632
United Kingdom	1.01055	1.01024	0.96136