Revista de Análisis Económico, Vol. 8, Nº 1, pp. 37-59 (Junio 1993)

A NEW DATABASE ON PHYSICAL CAPITAL STOCK: SOURCES, METHODOLOGY AND RESULTS

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Abstract:

This paper describes the derivation of a new database of physical capital stock estimates for a selected group of 92 developing and industrial countries from 1960 to 1990 (of which 68 are from developing countries). This work is part of a larger research effort to analyze the sources of growth in developing countries and assess the effects of changes in the international economic environment on developing countries prospects. A special effort was made to compile investment series from 1950 onward for as many countries as possible and these were then aggregated according to a perpetual inventory method. In addition, various techniques were evaluated for the estimation of an initial capital stock and a modified Harberger approach was considered most suitable. The derived capital stock series prepared for this paper were compared to other capital stock series prepared by other researchers. The tests show the series correlated well with the results of most other similar exercises. The capital stock estimates were used to calculate median-capital output ratios and aggregate growth rates of the capital stock by country group; again, the results seem reasonable and consistent with our prior understanding of the relevant developing regions. Finally, the capital stock series were used to calculate total factor productivity growth rates using a constant returns to scale Cobb-Douglas production function with imposed factor shares. The results of this exercise were presented both on a regional basis as well as against per capita income in 1960 and were found to be consistent with the findings of other researchers.

* We are grateful to Ingmar Prucha, Ron Duncan, Paul Armington, William Easterly, Lant Pritchett and an anonymous referee for comments on earlier drafts, and to Alain D'Hoore and Kavita Mathur for research assistance. All errors, however, remain the responsibility of the authors.

Introduction

1. This paper describes the derivation of a new database of physical capital stock for a selected group of developing and industrial countries. It represents the outcome of work that was undertaken in the context of a larger research effort focused on the extent to which economic growth can be explained by the accumulation of factor inputs and the growth of total factor productivity. This paper has been written, in part, to explain the methodology used in preparing these estimates and the data sources that were used. It examines the results for their consistency and also tests them by comparing them with the results of other researchers. The database on capital stock estimates is available for distribution in electronic format and will be updated when new information becomes available.

2. Surprisingly, while economists appear to agree with remarkable unanimity that capital is a key input into the production process and is critical to explaining economic growth, there seems to be an equally remarkable lack of consensus on what capital is, how it can be measured, and whether it can be aggregated into a single measure. The long history and intensity of controversies surrounding the measurement of capital stock reflect the complexity of the issues involved and the difficulties associated with obtaining the appropriate data. In this light, trying to measure the capital stock of a wide range of developing and industrial countries appears particularly audacious, and it is important to remind ourselves constantly that the task needs to be approached with a large consignment of humility and the results need to be viewed with a healthy dose of skepticism. Nevertheless, measuring capital is a task that economists can hardly avoid; it is a concept that lies at the heart of too many major economic issues requiring empirical investigation –growth analysis, economic forecasting, the role of technical progress, and so on.

3. The term "capital" employed in this paper refers to goods that are fixed, tangible, durable, and reproducible. Implicitly, then, we rule out such items as "goodwill" normally associated with the capital base of a company (because it is intangible) or natural and environmental resources (because they are not reproducible). The latter is a serious omission but, given the difficulties inherent in measuring such resources, there is little that can be done about it. Moreover, the definition is consistent with the United Nations classification of gross fixed capital formation.

4. The approach taken toward measuring the stock of capital in an economy depends to a large extent on the use to which the measure is to be put. If the measure is intended in some way to gauge the level of real wealth, then the appropriate approach would be to assess and quantify the net present value of the stream of future services expected from the stock of capital goods. If, on the other hand, the intention is to measure the role of capital in the production process, the appropriate approach would be to measure the level of current capital services generated by the existing stock of capital goods. As we shall see, the two approaches are not independent of one another, and search for theoretical consistency between the two approaches has a considerable bearing on the methodological approach that should be adopted.

5. In the rest of this paper we investigate the theoretical issues involved in the estimation of the physical capital stock, assess the estimates that we derive by testing

them and by way of comparing them with selected alternative estimates, and derive standardized estimates which allows us to compare capital stocks across countries.

Methodology

6. One difficulty in measuring the value of capital services in an economy stems from the fact that owners of capital goods tend also to be users of capital goods. Consider an economy in which all capital goods were rented. The rental price of a capital asset would be the point at which the marginal cost to the renter would equal the marginal value of the capital service generated by the asset. Estimating the value of capital services in an economy would then be much the same conceptual problem as estimating the value of labor services. But the fact that capital goods are used for periods longer than a year (the normal accounting period in the national accounts) and that the value of capital services cannot be observed directly (because owners of capital tend also to be users of that capital), requires that the value of capital services has to be estimated *indirectly*. In general, the approach taken has been to measure the *stock* of capital, and to assume that the level of capital services is related to the level of stocks through some proportionality constant.

7. Of course, measuring the stock of capital has proved equally difficult and, as noted earlier, has generated raging controversy within the economics and statistics profession. By and large, two methods have been employed –an evaluation of the stock of capital through direct surveys[1], or the more indirect perpetual inventory method[2]. We have, like most other researchers before us, decided to adopt the perpetual inventory method to estimate the capital stock, and the rest of this section explains the details of this methodology that we use and why[3].

8. ***The perpetual inventory method.*** In essence, the perpetual inventory method argues that the stock of capital is the accumulation of the stream of past investments. But a number of questions need to be addressed before an acceptable formulation can be designed. For example: how long do capital goods last before they are retired from service? how well do older vintages of capital compare (in terms of productivity) with more recent additions to the capital stock? Consider the most generalized equation describing the perpetual inventory method:

$$K_t = \omega_t I_t + \omega_{t-1} I_{t-1} + ... + \omega_{t-T} I_{t-T} \qquad (1)$$

where $\omega_t = 1$, $0 < \omega_{t-i} < 1$, and t–T is the vintage of the oldest surviving capital asset. A feature of equation (1) is that, implicitly, the efficiency of investment in period t–T is equivalent to ω_{t-T} times the efficiency of investment in period t. Old capital is the same as a smaller amount of new capital –the difference in efficiency being represented by a proportionality constant. The profile of the ω_{t-i}'s or the "efficiency sequence" (Hulten, 1990) then becomes the focus of empirical investigation. It turns out to depend on the nature of the capital asset, the production process, and the technology used.

9. In computing the capital stock database, we use a geometric pattern of decay. Apart from possessing features that make it a relatively easy technique for computing the capital stock, the method has two appealing theoretical characteristics:

* it can be consistent with other decay patterns (such as "one hoss shay" or the straight line method) for an individual asset or a sub-cohort of assets; and
* it is the only method which allows internal consistency between a decay pattern in the valuation of capital stock and a decay pattern in the rental value of assets (the depreciation rate).

These two features are briefly explained below.

10. It is important to distinguish between the decay pattern for an individual asset and the decay pattern for a cohort of assets. In other words, the average efficiency sequence for a cohort of assets can be very different from the individual efficiency sequence of the individual assets that comprise the cohort. This would be especially true if T, the useful life of an asset, differs for each sub-cohort. Indeed, the ω_{t-i}'s of each sub-cohort of assets can follow a "one-hoss shay" pattern whereas the cohort as a whole can approximately follow a geometric pattern of decay. The choice of the "one-hoss shay" method to describe the efficiency sequence of an aggregation of capital assets assumes that the useful life of all those assets are the same and that the time profile of their ω_{t-i}'s is rectangular –both strong assumptions. It should also be noted that a cohort of assets may have an aggregate efficiency sequence that exhibits a geometric pattern of decay, but that the aggregate capital stock which is based on it is *still the gross capital stock.* Conceptually, the use of a geometric decay function does not deviate from the view that the gross capital stock is the appropriate variable to employ in production function analysis.

11. In addition, for the same efficiency sequence to underpin both the estimate of the capital stock and the depreciation rate, the rate of efficiency decay must be geometric[4]. Were the efficiency sequence to be based on the "one-hoss shay" method, then the decline of the value of the asset must take on a different, non–linear shape. If physical deterioration is a linear function of time, then asset values are a curvilinear function[5]. Thus, estimates of the capital stock that use a "one-hoss shay" method or a straight line method to estimate gross capital stocks and which subsequently use a constant depreciation rate to estimate net capital stocks are being internally inconsistent[6].

12. Studies that have attempted to derive the depreciation rate from data on vintage prices, rental prices, or replacement investment, tend to show that a geometric decline is relatively commonplace. For example, using econometric models for vintage price functions, Hulten and Wykoff (1981) conclude that "[the evidence] supports those who use the single parameter depreciation approach in calculating capital stocks using the perpetual inventory method". This was further buttressed by Hulten, Robertson, and Wykoff (1989). Similarly, rental price profiles for residential property display a declining geometric pattern with age (Malpezzi, Ozanne, and Thibodeau, 1987). And Coen (1980), using a model of investment behavior, finds that two-thirds of industries are characterized by a geometric decline in the efficiency profile, whether the investment is in equipment or in structures.

13. On the strength of the theoretical considerations described above and the empirical support for geometric decay patterns, the perpetual inventory method used in constructing the capital stock estimates was of the kind:

$$K_t = (1-\varphi)^t K(0) + \sum_{i=0}^{t-1} I_{t-i}(1-\varphi)^i \qquad (2)$$

where φ is the rate of geometric decay and K(0) is the initial stock of capital in period 0.

14. ***The initial capital stock.*** Because the capital stock database described in this paper was prepared for a research project aimed at analyzing total factor productivity (TFP) growth, the emphasis was on developing a relatively long series. Unfortunately, for most developing countries, data on gross investment does not go back farther than 1950 (see the next section on data availability). This raises the importance of K(0) (or the initial capital stock) in equation (2) in the determination of aggregate capital stock growth rates. Setting the initial capital stock to zero, as some researchers have done, would bias the capital stock growth rate upward. For example, if the rate of decay was set at 7 percent a year, then investment undertaken 15 years ago would have at least a third of the efficiency of investment in the current year. Estimating the initial capital stock can, therefore, have a significant bearing on the final results. Unfortunately, there is no "best" way *a priori* to estimate the initial capital stock. We discuss below various approaches, each with its faults and problems. In the third section of the paper, we choose one of these approaches after examining the results.

15. A quick approach would be to assume that the capital–output ratio in the initial year is the same as the capital-output ratio in the current year (in our case, 1991). The capital-output ratio in the current year can be calculated using the capital stock generated by the perpetual inventory method assuming an initial capital stock of zero[7]. A drawback of this technique is that it assumes the relationship between capital and output holding in the current year is the same as in the initial year; moreover, it takes only one year's data into account. This latter problem can be overcome by assuming that the average capital-output ratio of the last five years is more representative of the relationship between capital and output, and this ratio can then be applied to estimate the initial capital stock. But this is probably the least important of the problems with this approach.

16. An improvement on this technique would be to assume that the capital-output ratio is a function of the labor-output ratio (Benhabib and Spiegel, 1992). Consider a simple two–factor (capital and labor) Cobb-Douglas aggregate production function with constant returns to scale:

$$Y = K^{\alpha} L^{\beta} \qquad (3)$$

which can be rearranged as follows:

$$\frac{\log K}{\log Y} = a + b\,\frac{\log L}{\log Y} + \sum_i c_i D_i \qquad (4)$$

where a and b are the direct estimates of α and β, and $\sum c_i D_i$ are country or regional dummies. Initial estimates for a and b can be calculated using cross sectional data capital stock data for 92 countries for the period 1985–90. These can then be used to calculate the initial capital stock and the perpetual inventory method can then be used

to build the capital stock series. The regression can be run again, and the entire procedure can be repeated several times (this time using panel data in each iteration) until convergence on the initial capital stock estimates is reached.

17. The weakness with this methodology is that it relies on the assumption that all countries are on the same production frontier at all times. A more important weakness is the absence of a constant term in the production function depicted in equation (3). Were this term to be introduced, the specification in equation (4) would change to:

$$\frac{\log K}{\log Y} = a + b\ \frac{\log L}{\log Y} + \sum_i c_i D_i + d\ \frac{1}{\log Y} \qquad (5)$$

where $d\ \frac{1}{\log y}$ is the additional term. When this specification was estimated, however, the coefficients were of the wrong sign. The technique was, therefore, dropped, although it should be noted that the initial capital stock estimates that it produced were very close to those produced by equation (4)[8].

18. In a more recent paper, Benhabib and Spiegel have revised their approach, using instead a production function which includes both a constant term as well as a human capital term[9]. However, the specification of the production function uses log levels and there does not appear to be any attempt to test for co-integration and/or stationarity. In addition, the implicit capital output ratio of this series is virtually uncorrelated with the earlier estimates (based on equation (4))[10]. When we estimated a similarly specified function, some of the estimated coefficients were of the wrong sign, so we decided not to pursue this approach further, at least for the purposes of this paper[11].

19. A third approach to calculating the initial capital stock would be to estimate it from a production function together with the coefficients for labor and technical progress[11]. Consider the log linear production function:

$$\log Q_t = \log A + \alpha \log K_t + \beta \log L_t + u_t \qquad (6)$$

Substituting for K from the perpetual inventory equation (2) gives:

$$\log Q_t = \log A + \alpha \log \{(1-\varphi)^t K(0) + \sum_{i=0}^{t-i} I_{t-i}(1-\varphi)^i\} + \beta \log L_t + u_t \qquad (7)$$

It should be noted that K(0) is a constant, like A, and can be estimated as a coefficient of the variable $(1-\varphi)^t$. But to estimate this equation requires non–linear estimation procedures if the estimates are to be unbiased and consistent. The results from this approach are presented later in this paper.

20. A fourth approach to estimate the initial capital stock would be based on the assumption that under competitive markets and constant returns to scale, total income is shared among the factors in the following manner:

$$p_t Y_t = \sum_i \mu_{it} X_{it} \qquad (8)$$

where X_i are the individual factors of production and μ_i represent their rates of return. In a model where the only two inputs are labor and capital, for example, the stock of capital can be calculated if both the total wage bill and the rate of return on capital is known. However, reliable economy-wide estimates of the wage bill or the rate of return on capital are not available for most developing countries, and so this was not considered an appropriate technique to adopt.

21. A final approach, and one that has been most popular among researchers, is based on Harberger (1978). This approach begins with the observation that if the capital-output ratio is constant in a given period, the rate of growth of capital and output are equal during that period. From the accumulation equation:

$$(K_t - K_{t-1}) / K_{t-1} = -\delta + (I_t / K_{t-1}) \qquad (9)$$

and since the left hand side is the rate of growth of capital, here assumed equal to the rate of growth of output, equation (9) can be rewritten as:

$$K_{t-1} = I_t / g + \delta) \qquad (10)$$

where g is the rate of growth of output. Harberger suggested that short term variations in output and investment may make it appropriate to use, say, a three–year average growth rate of output and the corresponding three-year average investment level. If this were done, the base–year capital stock would be centered in the middle of the three year period, and the recursion formula (equation 2) for capital accumulation would have to be applied in reverse to arrive at the initial capital stock. Similarly, if longer averages are adopted, the base level capital stock would have to be centered accordingly and the recursion formula used over a longer period until the initial capital stock is reached. In the case of several developing countries, however, output growth was negative in the relevant period –which either inflated the initial capital stock estimate significantly or turned it negative.

22. We, therefore, explored an alternative way of obtaining the value of investment in the first period which was to estimate a linear regression of the log of investment against time and calculate the fitted value of the initial investment level by this equation. This fitted investment level in the first period is then used to calculate the initial capital stock using equation (10). The advantage of this approach is that information contained in the entire investment series is used, making the result less sensitive to initial period conditions. It assumes the economy to be in steady state growth only in order to fix the initial benchmark stock[13]. Subsequent levels of the capital stock are calculated using the perpetual inventory method using equation (2). The procedure was made a little more sophisticated by recognizing the existence of structural breaks in the investment series. Chow tests showed that 1973 represented an important structural break for 82 countries out of our 92 country sample. The linear regressions of the log of investment over time were accordingly done with a series truncated in 1973 to derive the fitted level of investment in the initial period.

23. In conclusion, there are many possible approaches to calculating the initial capital stock, none of them perfectly satisfactory[14]. Nor does theory help in determining which approach leads to the least error. We, therefore, estimate the initial capital stock for the countries in our sample using most of these techniques; however, for various reasons (see para. 33), we are inclined toward using the modified Harberger technique (described in para. 22). But whatever technique is used to estimate the initial capital stock, it should be some comfort that errors in the estimate are dampened rather fast with time, so that by using the last 30 years of the capital stock series (from 1960 to 1990) one can be fairly sure that the effects of the errors are small.

Data

24. ***Investment data.*** For the years 1960–91, the data for gross domestic fixed investment at constant prices was taken from the World Bank's Economic and Social Database (BESD). This is available for 92 countries. To obtain as long a series of capital stock data as possible, special efforts were made to push the data back to 1950 without compromising quality. In doing so, a range of sources were used. Unfortunately, these were often expressed in differing units, used different bases, or employed varying definitions. Among the sources used were:

- The 1971 World Tables –which documents the average annual rate of growth of gross domestic investment over the 1950–60 period for 45 countries. In some cases, the average share of three components of investment –machinery and equipment, structures, and other– is also given.
- Internal documents within the World Bank –which were used to conserve and maintain country statistics prior to the computerization of data bases. The documents cover only 22 countries.
- The data base used in the study by Chenery and Syrquin, "Patterns of Development" –which includes data for benchmark years for some countries. This database did not contain information on the components of investment.
- The ECLAC paper by A. Hofman (1991) on the capital stock for six Latin American countries plus Korea, which includes GDFI series going back to 1900.
- The database of the Macro Economic Data System (MEDS) of the Department of Economic and Social Development of the United Nations. This was the primary source of data on pre-1960 investment used in Summers-Heston (1991). Most of the series are complete but the documentation of these series is, for the most part, non-existent.

25. Before putting these series together in an eclectic manner, the data from these sources were tested to assess their differences. Such tests included a comparison of turning points, coefficients of variation, growth rates (over different periods) and, of course, levels. These tests were useful in finding out which series behaved in similar fashion and which did not, and also served to raise warning flags on individual data points which were questionable. On the strength of these tests, the following procedure was adopted in putting together the database:

- For reasons of consistency, documentation, compatibility, and overall quality, World Bank data were used for the period 1960-90, and remained the reference data in most cases.
- Next, for the 1950-60 period, data from the Chenery and Syrquin database on "Patterns of Development" were used whenever complete series were available or whenever such data were consistent with data culled from internal documents within the Bank.
- For the remaining countries, the MEDS database was used to complete the database.
- Data were also used where a long time series was available from individual studies and these were considered to be well documented (as in the Hofman study).

26. The resulting database on gross domestic fixed investment covers 92 countries for the period 1950–90. Of these, 68 countries begin their investment series in 1950; 14 begin some time between 1951 and 1955; and 10 begin in 1960. For 52 countries, investment data were disaggregated into two components –equipment (including machinery and transportation equipment) and structures (including residential and non–residential construction, land improvement etc.). It would have been desirable to disaggregate the series further, especially differentiating machinery from transport equipment, but we decided that it would not be possible to do this without seriously compromising the quality of the data or reducing the sample size to an unacceptable level.

27. Table 1, which depicts aggregate gross fixed investment (GDFI) as a ratio of GDP from 1960 to 1990, provides a quick overview of the investment data collected for this exercise[15]. For the world as a whole, the decline in the GDFI/GDP ratio is apparent in the 1980s, although for the high income countries, this ratio had already begun to decline during the 1970s following the first and then the second oil shock. Among the developing regions, East Asia's performance is striking. Its GDFI/GDP ratio grew by over 5 percentage points in each of the three decades shown in Table 1, displaying remarkable resilience in the face of the oil shocks of the 1970s and the interest rate shock of the 1980s. South Asia's GDFI/GDP ratio also showed some resilience, albeit at levels that are much lower than for East Asia. Nevertheless, South Asia's fixed investment share now exceeds Latin America's and Sub-Saharan Africa's, partly because of the investment slowdown in the latter two regions.

28. ***Decay rate.*** The choice of the decay rate is in many ways more important than the initial capital stock. Whereas errors in the initial capital stock estimate are dampened over time by the rate of decay, errors in the rate of decay are compounded over time. Indeed, an error in the rate of decay affects not only the final capital stock but also the initial capital stock — and these two errors tend to reinforce one another. If the estimate of the rate of decay is higher than the actual, the initial capital stock estimate would be lower, and the capital stock estimates in subsequent years would also be lower by greater amounts.

TABLE 1

THE RATIO OF GROSS DOMESTIC FIXED INVESTMENT TO GDP
BY DEVELOPING REGION, 1960–90
(Median shares; in percent)

	1960	1970	1980	1990
World a/	17.0	19.8	21.6	20.1
High income	20.2	25.1	21.1	22.2
Low and middle income	15.0	18.1	22.8	17.7
East Asia	14.1	20.0	25.6	30.9
Latin America	17.8	17.7	23.8	16.9
South Asia	13.5	16.2	18.3	18.6
Sub-Saharan Africa	15.1	16.4	17.2	14.8

Note: Both numerator and denominator are expressed in 1987 constant prices.
a/ Ninety two countries in all.
Source: Authors' estimates.

29. Unfortunately, data on the rate of decay is scant and is available for only a few countries, none of them in the developing world. Data on the service lives of capital assets are equally scarce. The OECD provides service lives of capital assets for 15 OECD countries (OECD, 1991), but many of these data are based on industry surveys in the 1970s or reflect depreciation guidelines in tax schedules. Virtually all the studies on capital stock estimates for developing countries assume a particular decay rate.

30. In this paper, therefore, we have been forced, in the absence of better information, to assume a single decay rate when estimating capital stock. We decided to use a 4 percent rate after analyzing service lives for a wide variety of capital goods and examining their shares in gross domestic fixed investment. For comparison, in its estimates of the capital stock in 1988 for several industrial countries, the OECD estimated the decay rate to be 4.1 percent in France, 1.7 percent in Germany, 2.6 percent in Great Britain, 4.9 percent in Japan, and 2.8 percent in the U.S. Similarly, a rough estimate of the decay rate can be derived by appealing to steady–state characteristics of economies:

$$\delta = \frac{D}{Y}\frac{Y}{K} = \frac{D}{Y}\frac{g+\delta}{I/Y} = \frac{(D/Y)\ g}{(I/Y) - (D/Y)} \qquad (11)$$

where D/Y is the ratio of total depreciation to total output, I/Y is the ratio of gross domestic fixed investment to output, and g is the growth rate of output. According to Maddison (1987), a rough estimate of D/Y for high income economies would be about 0.12. Using other plausible values for I/Y of 0.22 and for g of 0.03, a rough estimate for δ would be between 0.03 and 0.04 (see Romer, 1989). In the case of developing countries, which on average experienced higher growth rates but where the D/Y ratio would be expected to be lower, a rough estimate for d would be between 0.4 and 0.5. It is recognized that it would have been best to use individual decay rates for each country, but in the absence of such data for developing countries, we decided in the interest of transparency to adopt a single rate for all countries. All the results reported in the next section were re-done using both higher and lower decay rates, but the principal conclusions remained unchanged.

Results

31. We begin by reporting the results for the initial capital stock estimates. The correlation coefficients of the initial capital stock estimates obtained from the various approaches were extremely high (usually above 0.99)[16]. These results hold whether the sample of countries is stratified along income or regional lines, or even after the initial capital stocks are normalized by the working age population[17]. At first glance, such a result may appear comforting as it seems to suggest that the choice of technique in estimating the initial capital stock was not as crucial as first thought.

32. These results are deceptive, however. When the initial capital stock is normalized by GDP, the correlations are much poorer and closer to our expectation that the estimation technique *does* make a substantial difference to the initial stock estimate (see Table 2). These correlation coefficients show that the non-linear estimation technique produces results that are sometimes quite different from the other methods. An examination of the individual country estimates reveals that the non-linear technique is not adept at handling cases where real GDP declines for a particular sub-period, as in the case of Bangladesh, Mauritius, and Zambia. Similarly, the technique adapted from Benhabib and Spiegel (called "khab" in Table 2) yields results on the initial capital stock that are poorly correlated with those using the modified Harberger technique ("kpaa" in Table 2) and the simpler capital–output ratio approach ("kcor" in Table 2).

TABLE 2

CORRELATION COEFFICIENTS OF THE CAPITAL–OUTPUT RATIO IN 1950, USING DIFFERENT ESTIMATION TECHNIQUES FOR THE INITIAL CAPITAL STOCK

	kcor	kpaa	kn1	khab
kcor	1.00			
kpaa	0.41	1.00		
kn1	–0.03	0.54	100	
khab	0.15	0.27	0.02	1.00

kcor : assumes the capital output ratio in 1990 is the same as in 1950 (see para. 15).
kpaa : modified Harberger method with investment series truncated in 1973 (see para. 22).
knl : uses a non–linear estimation procedure to estimate equation (18) (see para. 19).
khab : technique adopted by Benhabib and Spiegel, but modified to accommodate regional dummies (see para. 16).

Source: Authors' estimates.

33. It is difficult to design "objective" criteria which can help us choose one method over another in estimating the initial capital stock. On *a priori* grounds, the modified Harberger approach appears to be the most preferable technique. First, it uses data from the entire series (unlike the Harberger approach which uses only a subset of the series)[18]. Second, it uses data from the country alone; the Benhabib and Spiegel approach requires both cross-sectional and time series data which tends to introduce "noise" to the estimates. And third, the technique is not subject to the same methodological concerns that some of the other techniques are prone to[19]. For the rest of the analysis presented in this paper, then, we use the modified Harberger initial capital stock estimates.

34. Having settled on the modified Harberger technique to estimate the initial capital stock, we nevertheless decided, for added comfort, to test the four different series to see how best they fit a simple constant returns to scale Cobb-Douglas production function using only cross section data for a single year. The year chosen was 1965, the first year for which data on per capita income is available for a sufficiently large number of developing countries[20]. Starting with a production function of the form:

$$Y = \Gamma K^{\frac{b}{1+b}} \quad L^{\frac{1}{1+b}} \tag{12}$$

we estimated the equation:

$$\log = \frac{Y}{L} \quad a + b \log \frac{K}{Y} \tag{13}$$

The results are shown in Table 3. The modified-Harberger approach appears to fit the data best[21]. The estimate of the coefficient for the capital output ratio is significant at the 90 percent confidence level and the overall fit of the equation (given by the F-statistic) is also significant at the 95 percent confidence level. Similar results are achieved irrespective of the year chosen.

35. As a further test, we used the modified Harberger technique to directly estimate the capital stock in 1972, the last-but-one year of the truncated series that had been used to derive the fitted investment levels and the growth rate of output (see para. 23)[22]. We then compared these estimates for 1972 with the estimates for 1972 which used as their basis the initial capital stock in 1950. The correlation coefficient for the real capital stock variable was 0.99 and for the capital–output ratio was 0.90. This evidence provides additional grounds for believing that the modified Harberger technique yields initial capital stock estimates that are reasonably robust.

36. The capital stock series based on the modified Harberger initial capital stock estimates were then tested against the results derived from other studies. If the data were not normalized and thus were non–stationary, the correlation coefficients were usually high, above 0.9 in most instances and above 0.99 in several. Similarly, the series tend to have a high rank correlation. But such correlations are meaningless. It was important, therefore, to ensure stationarity in the series before conducting

TABLE 3

REGRESSION RESULTS USING DIFFERENT ESTIMATES OF THE INITIAL CAPITAL STOCK: DEPENDENT VARIABLE - LOG PER CAPITA INCOME OF DEVELOPING COUNTRIES IN 1965

	kcor	kpaa	knl	khab
log capital-output ratio in 1965	0.37	0.39**	0.14	0.20
(t-ratio)	(1.50)	(2.14)	(0.86)	(0.67)
constant	5.18***	5.25***	5.39***	5.32***
(t-ratio)	(24.00)	(36.79)	(40.33)	(22.37)
Adjusted-R^2	0.02	0.06	–0.005	–0.01
F-statistic	2.24	4.58	0.74	0.45
Prob > F	0.14	0.04**	0.39	0.51
Number of observations	55	55	53	55

kcor : assumes the capital output ratio in 1990 is the same as in 1950 (see para. 15).
kpaa : modified Harberger method with investment series truncated in 1973 (see para. 22).
knl : uses a non–linear estimation procedure to estimate equation (18) (see para. 19).
khab : technique adopted by Benhabib and Spiegel, but modified to accommodate regional dummies (see para. 16).

* significant at the 90 percent level of confidence.
** significant at the 95 percent level of confidence.
*** significant at the 99 percent level of confidence.

Source: Authors' estimates.

correlation tests. Perhaps the stationary variable of most interest to researchers is the capital–output ratio. Correlation coefficients were estimated for this variable using the results from this study and the results of six other studies (Table 4). The comparator studies used different techniques to estimate capital stock; they also cover different groups of countries over different periods. To ensure comparability across the different series, all the estimates were converted to a 1987 base year, and the denominator for the capital–output ratio was taken from the World Bank's Economic and Social Database. In the case of the Summers–Heston capital stock dataset and the Benhabib and Spiegel dataset (which used Summers–Heston investment data), the output data (RGDP) was taken from Penn World Tables (Mark 5)[23].

37. The results in Table 4 show that our estimates are relatively well correlated with the OECD and Maddison datasets. The poor correlation with the Summers–Heston and Benhabib–Spiegel datasets is partly because these two datasets use the Penn World Table (Mark 5) data where not only is the capital stock estimated at international prices but so is output. Hence, the low correlation coefficient may not be due to differences in the numerator alone but also due to differences in the denominator. This suspicion is given some confirmation by the fact that while the S&H series are relatively well correlated with the B&S series (correlation coefficient of 0.58) , neither is well correlated with the OECD, Hofman, or Maddison series.

TABLE 4

CORRELATION COEFFICIENTS FOR ESTIMATES OF THE CAPITAL OUTPUT RATIO FROM VARIOUS STUDIES

	This paper	OECD	S&H	B&S	Hofman	Maddison	Fok
This paper	1.00						
OECD	0.53 (244)	1.00					
S&H	0.35 (290)	0.02 (95)	1.00				
B&S	–0.15 (503)	0.39 (39)	0.58 (58)	1.00			
Hofman	0.22 (317)	–	–0.08 (50)	0.20 (48)	1.00		
Maddison	0.55 (172)	0.54 (119)	0.25 (48)	–0.03 (36)	–	1.00	
Fok	0.83 (1,691)	0.37 (200)	0.54 (233)	–0.009 (548)	0.31 (240)	0.52 (172)	1.00

Note: Figures in parentheses are the number of observations available for the calculation of the correlation coefficient.

OECD from OECD (1991).
S&H from Summers and Heston (1991).
B&S from Benhabib and Spiegel (1992).
Hofman from Hofman (1991).
Maddison from Maddison (1992).
Fok from Fok and Hee (1993).

38. We now put our capital stock dataset through its paces, asking whether the results it generates for the growth rate of capital, for capital-output ratios, and for total factor productivity accord with our priors. The estimates of the growth rate of the physical capital stock by developing region suggests that they do (Table 5). The first point to notice is the steady decline in the growth rate of the capital stock in high-income economies as well as in the developing regions. The only exception is in the low and middle income (developing) countries in East Asia, where the growth rate of the capital stock appears to have grown faster in the post–1973 period. But much of this was due to China; when it is excluded from the East Asia aggregate, the region shows a decline in the post-1973 period (albeit a less steep one than in the other developing regions). The post-1973 decline in the growth rate gained momentum during the 1980s in most developing regions, especially in Latin America and Sub-Saharan Africa. This is consistent with the literature on the effects of the debt crisis on investment and capital formation in Latin America and the corroding consequences of declining international commodity prices on most Sub-Saharan African economies during the 1980s. MENA also exhibited a rapid deceleration in capital accumulation, in part because the Iran-Iraq war exacerbated the consequences of a period of relatively low oil prices.

TABLE 5

REAL GROWTH RATE OF THE PHYSICAL CAPITAL STOCK BY REGION, 1960-90
(Annual average percentage change at 1987 prices)

	1960-73	1973-90	1980-90	1960-90
High income economies	6.0	4.0	2.6	5.3
Low and middle income				
East Asia	5.5	8.8	8.9	7.4
East Asia (without China)	10.0	9.4	8.2	9.9
South Asia	5.5	4.7	4.7	4.8
MENA a/	6.3	6.2	1.8	7.7
Sub-Saharan Africa	5.7	3.9	2.0	5.3
Latin-American	5.5	4.5	2.7	5.6
Europe b/	7.7	4.5	2.7	6.2

a/ Middle East and North Africa.
b/ Portugal, Turkey, and Greece.

Note: All growth rates were calculated using ordinary least squares regression. Local currency units were converted US Dollars using the World Bank's Atlas exchange rate.

Source: Authors' estimates.

39. An examination of the growth of the capital-labor ratio in high income countries and in various developing regions tells the same story (Table 6). In East Asia, the capital-labor ratio grew rapidly in the post-1973 period, mostly as a consequence of China's sharp growth acceleration, but partly also due to a reflection of a rapid rise in foreign direct investment in the region by Japan, Hong Kong, and Taiwan (China). In the remaining developing regions, the growth of the capital labor ratio slowed markedly. In MENA, the widening gap between the pace of capital formation and the growth of the capital labor ratio could be the result of large labor inflows from their South Asian neighbors. And in Sub-Saharan Africa, the growth of the capital labor ratio was the slowest (1.1 percent per annum in the post-73 period), partly because of a rapidly growing labor force, but also because of a poor domestic savings performance in the wake of the oil crisis, falling terms of trade, and poor economic management.

40. An analysis of the capital-output ratios is presented in Table 7. The numbers indicate a steady rise in the median capital–output ratio over the last three decades in all developing regions and even in the high income countries. An examination of individual countries reveals much the same trend with few exceptions. The trend in the capital–output ratio is positive and significant with respect to time in all but 11 of the countries in the sample (at the 95 percent confidence level). This trend does not appear to be broken structurally in 1973 except in the case of MENA, where the post-1973 oil boom clearly led to a marked increase in the capital intensity of production. Rising capital-output ratios in developing countries is consistent with the view that with development comes structural change, usually from less capital-intensive to more

TABLE 6

GROWTH RATE OF THE CAPITAL–LABOR RATIO BY REGION, 1960–90 a/

	1960-73	1973-90	1960-90
High income countries	4.7	2.9	3.7
Low and middle income			
East Asia	3.2	6.7	5.1
East Asia without China	7.1	7.2	7.2
South Asia	3.8	2.6	3.2
MENA b/	4.3	2.7	3.4
Sub-Saharan Africa	3.5	1.1	2.1
Latin America	3.0	1.9	2.4
Europe c/	7.0	3.0	4.7

a/ The working age population aged between 15 and 64 is take as proxy for the labor force.
b/ Middle East and North Africa
c/ Portugal, Turkey, and Greece.

Note: All growth rates are calculated using ordinary least squares regression.

Source: Authors' estimates.

TABLE 7

MEDIAN CAPITAL–OUTPUT RATIOS BY REGION, 1960, 1973 AND 1990

	1960	1973	1990
High income countries	2.2	2.5	3.1
Low and middle income			
East Asia	1.2	1.7	2.4
South Asia	1.7	2.0	2.6
MENA	1.0	1.2	2.6
Sub-Saharan Africa	1.4	2.0	2.6
Latin America	2.0	2.1	3.0
Europe	2.5	2.9	3.2

Source: Authors' estimates.

capital intensive production activities. But the finding that the capital-output ratio has been rising over the last thirty years even in high income countries appears to be inconsistent with the results of other studies which show that the ratio tends to be stable. For example, in an analysis of the role of capital accumulation and long-run growth, Romer uses data from Maddison (1982) to show that in the case of seven high income countries, the growth of capital and the growth of output have been remarkably similar[24]. Romer examines three periods to arrive at this conclusion –1870-1913, 1913-1950, and 1950-1979. Since the period 1950-79 is common with the period of our dataset, this period was examined more carefully with regard to the G-7 countries. Our data show that the capital-output ratio displays no rising trend in Canada and the U.S., but has a clear rising trend in Japan, Germany, Great Britain, Italy, and France. Casual empiricism would suggest that the capital stock in these latter five economies was destroyed to varying degrees during the Second World War, and that the period following the war was one of reconstruction of their infrastructural and manufacturing base. One would therefore expect to find, as the data suggest, a rising capital-output ratio in these economies for the period in question, and a relatively stable capital-output ratio in the U.S. and Canada which were relatively unaffected by the war.

41. As a further check on the capital stock estimates presented in this paper, we calculated total factor productivity (TFP) growth for 80 high income and developing countries using the well-known technique of growth accounting. Consider the production function:

$$Y_t = f(K_t, L_t, A_t) \tag{14}$$

where K and L are the capital stock and labor respectively. The capital stock is assumed to be a good proxy for the level of capital services entering into the production processes of the economy; labor (as measured by the working age population aged between 15 and 64) is considered a reasonable proxy for the level of labor services[25]. The term A_t, or total factor productivity, represents a collection of factors that affect the overall efficiency of an economy, including the technology used in production, the management of the economy, the quality of governance, the strength of institutions, and the effects of cultural factors. Also, since L is not adjusted for the quality of labor services (a function of education and learning-by-doing), the term A_t is liable to pick up the effects of that as well.

42. From equation (22), we get the familiar growth accounting expression:

$$\hat{Y} = \zeta\hat{A} + \alpha\hat{K} + \beta\hat{L} \tag{15}$$

where ζ, α, and β are the elasticities of the three arguments in equation (22), and the "hats" represent growth rates. For ease of analysis, we assume that α and β are the factor share of capital and labor respectively and that these are the same across all countries at 40 percent and 60 percent respectively[26]. Assuming a capital-output ratio of 2.5 for developing countries, a 40 percent share for capital implies an implicit rate of return on capital of 16 percent; for high income countries with a capital-output ratio of the order of 3, the implicit rate of return on capital is about 13.3 percent[27]. Both these estimates of the rate of return seem reasonable; in the case of the high income countries, such rates are in line with the rate of return on non-residential capital stock

that prevailed in the 1960s and early 1970s, but is below the levels that prevailed in the 1980s[28].

43. The residual between output growth and the weighted sum of labor and capital growth is then estimated as total factor productivity growth[29]. More complicated techniques for estimating total factor productivity growth will be explored in a forthcoming paper, but in the meantime we seek refuge in the findings of others that various measures of TFP growth are highly correlated with the Solow residual given above (see, in particular, Fischer, 1993). Table 8 shows the median TFP growth rates for high income countries and developing regions. For virtually all groups of countries, the post-1973 TFP growth rates were lower than in the pre-1973 period. Asia was the only exception[30]. Not only did East Asia's capital stock grow faster in the 1980-90 period (see Table 5), so did its TFP. This is in stark contrast with MENA, where the capital stock grew faster in the 1973-90 period following the oil price shock, but the growth of TFP turned negative during the period. Latin America enjoyed relatively high TFP growth in the 1960s and early 1970s, but these gains were almost completely erased in the 1970s and 1980s when TFP growth was negative on average. Toward the latter half of the 1980s, however, this decline in TFP tended to slow as Chile and Mexico exhibited a sharp turnaround in economic performance. Sub-Saharan Africa is the only developing region with an average negative TFP growth rate for the entire 1960-90 period. Although the region had a small positive TFP growth rate before 1973, the post-1973 period displays a decline in TFP which is similar in pace to that of Latin America. The instability of TFP growth across time periods reflects the findings of Easterly et. al. (1993) who find GDP growth to be unstable across time periods, except that in our case, growth is controlled for capital accumulation and labor force expansion. The correlation coefficient of country level estimates of TFP growth across time period are surprisingly low –comparing 1960-73 with 1973-90, it was 0.13; and between 1960-80 and 1980-90, it was 0.16.

44. We can also use our TFP estimates to identify economies where TFP growth has been a more important contributor to economic growth than growth in the capital stock. We restricted our sample for this exercise to economies with average GDP growth rates that exceeded 2 percent a year. In the 1960-90 period, there were 8 economies where TFP contributed more to GDP growth than capital accumulation (see Table 9), but in the 1980-90 period, this number had more than tripled to 25[31]. The high income economies constitute more than half of all such economies in each instance. One interesting feature of Table 10 is that in the 1960-90 period, China is the only low and middle income economy which has a TFP growth rate higher than its capital stock growth rate; in 1980-90, the lone country in East Asia with this characteristic is Thailand. For the remaining developing countries in East Asia (in our sample, this includes Korea, Malaysia, Indonesia, and the Philippines), output growth seems to have been driven more by capital accumulation than TFP growth[32]. Another feature of Table 10 is the emergence in 1980–90 of five Sub-Saharan African economies and three South Asian economies where TFP mattered more than capital accumulation. Virtually all these economies underwent reform programs some time during the 1980s, and a rise in the contribution of TFP to overall growth is consistent with other evidence that not only do adjustment programs tend to improve the allocative efficiency of new investment but raise the x-efficiency of the existing capital stock.

TABLE 8

TOTAL FACTOR PRODUCTIVITY GROWTH BY REGION, 1960–90
(Median average annual percentage change)

	1960-90	1960-73	1973-90	1980-90
High income countries	1.1	1.8	1.0	1.1
Developing countries				
East Asia	1.2	1.2	1.2	1.8
South Asia	0.8	0.3	1.6	1.3
Latin America	0.2	1.4	–0.9	–0.7
Sub-Saharan Africa	–0.2	0.2	–0.9	–0.7
MENA a/	0.4	2.3	–0.5	–0.7
Europe b/	1.6	3.2	0.7	1.2

a/ Middle East and North Africa region.
b/ Greece, Portugal, and Turkey. The median growth rates were very close the sample means.

Source: Authors' estimates.

TABLE 9

COUNTRIES WHERE THE CONTRIBUTION OF TFP GROWTH TO OUTPUT GROWTH EXCEEDED THE CONTRIBUTION OF CAPITAL STOCK GROWTH

	1960-90		1980-90	
Region	High income	Low and middle income	High income	Low and middle income
East Asia		China	Australia	Thailand
South Asia				Bangladesh India Pakistan
The Americas			United States	Chile
Sub-Saharan Africa		Kenya Mauritius		Zimbabwe Senegal Ghana Kenya Mauritius
Europe	Cypress Belgium Finland Italy Norway		Sweden W. Germany Cypress Norway Finland Italy U.K. Ireland Norway Denmark Spain	Portugal Turkey

Note: Only countries with average GDP growth rates exceeding 2 percent a year are included. Countries are listed in the table if the estimated TFP growth exceeds 0.4 times the estimated growth of the capital stock.

Source: Authors' analysis.

Conclusion

45. This paper presents a new dataset for constant price capital stock series for 92 countries for the period 1950 to 1990 (of which 24 are from 1960). A special effort was made to compile investment series from 1950 onward for as many countries as possible, and these were then aggregated according to the perpetual inventory method. The aggregation procedure uses a geometric pattern of decay on the grounds that it is the only method which permits internal consistency between using a decay pattern for the valuation of the capital stock and the rental value of assets. A short survey of techniques to estimate the initial capital stock indicated that there were no objective criteria to favor one over the other. Thus the method that displayed the highest correlation with the other techniques –a technique we have dubbed the modified Harberger approach– was used to develop the capital stock series.

46. The capital stock series generated were then compared to similar series prepared by other researchers. These tests show that the series correlate well with the results of most other authors. The data were then used to calculate median capital–output ratios and growth rates of the capital stock by country groups; the results again seemed reasonable and in line with our understanding of the relevant developing regions. Finally, the capital stock series were used to calculate TFP growth rates using a simple constant returns to scale Cobb–Douglas production function with imposed factor shares. The results were again presented on a regional basis as well as against initial per capita income in 1960, and these formulations also seemed to be consistent with prior knowledge.

47. The capital stock series presented in this paper are available in electronic format to interested researchers. However, they should be regarded as preliminary as ongoing work will continue to improve, refine, and extend these estimates. Recognizing that disaggregation matters[33], work is also underway to develop capital stock estimates by category –machinery and equipment, and structures– for as many countries as possible. Finally, considerable further work is planned for a forthcoming paper which will use these capital stock estimates to develop total factor productivity growth estimates.

Notes:

1 These are expensive to undertake. Furthermore, in the absence of accurate market information on rental and second hand prices, it is not clear whether surveys are more accurate than indirect procedures.
2 A possible third method –using actual book values of capital items– tends not to be used because book values of capital goods are sensitive to the tax schedules of individual countries.
3 The theoretical underpinnings of this methodology are thoroughly examined in Hulten (1990).
4 See Jorgenson (1973).
5 See Hulten (1990).
6 See Jorgenson (1990) for a critique of the work of Denison and Kendrick which employs capital stock estimates prepared by the Bureau of Economic Analysis, U.S. Department of Commerce.
7 After 41 years (1950 to 1991), the initial capital stock is only 5 percent as efficient as investment in the current year.

8 Since the publication of this paper, Benhabib and Spiegel have revised their approach, using instead a production function which includes both a constant term as well as a human capital term. A comparison of their new approach with ours was not possible owing to lack of time, but shall be included in a revised version of this paper some time in the future.
9 See the Appendix in Benhabib and Spiegel (1992b).
10 The data made available to us contained only the years 1965 an 1985. The correlation coefficient of the implicit capital-output ratio of these data with the implicit capital output ratio of the earlier series is –0.0011.
11 It should be noted, however, that the data set used in our estimation of the production function was different from the one estimated in Benhabib and Spiegel (1992b). For example, the education stock data used in Benhabib and Spiegel (1992b) are from Kyriacou (1991); the data used in our estimation are from Nehru, Swanson, and Dubey (1993).
12 This approach is used in Stevens (1989) in the estimation of an investment equation.
13 We are grateful to Paul Armington for pointing out this approach. The technique is consistent with the steady stage growth requirement that the capital-output ratio is constant and hence equal to the incremental capital output ratio.
14 We examined other techniques that are not reported here, such as the one developed by Dadkhah and Zahedi (1990), which, we felt, had some econometric constraints that restricted its use.
15 We do not report results for 1950 because data for the full complement of 92 countries are available from only 1960 onward.
16 Note that the initial capital stock was first converted into 1987 constant US dollars before the correlations were calculated. Using the Summers-Heston PPP conversion factors yielded similar results. We also estimated the Spearman rank correlation coefficients for the capital stock in 1950 (the initial stock for the bulk of countries) and found them to be high too.
17 The working age population is used as proxy for the labor force.
18 Even though the investment series was truncated in 1973, the entire series had to be used to determine whether a structural break had indeed occurred in that year.
19 For example, the Cobb-Douglas production function used in Benhabib and Spiegel (1992) does not include a constant. When the constant is introduced, the coefficient of the labor productivity variable is of the wrong sign. An alternative specification was also tried that assumes constant returns to scale, but the coefficients are once again of the wrong sign. Besides the absent constant, the Benhabib and Spiegel (1992) method adopted in this paper suffers from two other shortcomings in our view: the equation that is estimated uses a ratio of two logs which is not scale invariant; and the initial capital stock is heavily dependent on the level of GDP in the initial year –which, for cyclical and other reasons, could be biased either upward or downward.
20 The per capita income estimates were taken from the World Bank's Economic and Social Database. The first year was chosen to amplify as much as possible the differences between the various iniitial capital stock estimates.
21 This is the modified Harberger version that tested for a break in 1973.
22 The last year of the truncated series, 1973, was not used for this result because it was an unusual year for investment levels following the oil price shock.
23 Summers and Heston (1991).
24 See Romer (1989).
25 This assumption is more reasonable for developing countries, where voluntary unemployment is usually small and underemployment is more a manifestation of low productivity employment than unemployment.
26 Empirical results on the share of capital and labor derived from production function analysis range between 30/70 percent and 45/55 percent. Most of the estimates, however, seem to be in the 40/60 range. See Ahluwalia (1985); Boretsky (1966); Chen (1970); Chen *et. al.* (1987); Christensen, Cummings, and Jorgenson (1980); Correa (1970); Economic Commission for Europe (1964); Elias (1978); Tsao (1980); and Balassa and Bertrand (1970).
27 If rK/Y = 0.4 and K/Y is 2.5, it follows that r = 0.16. Similarly, if K/Y = 3, then r = 0.133.
28 See OECD (1990). It should be noted, however, that the capital stock estimates in this paper include residential capital stock.
29 Note that all growth estimates were based on OLS regressions using a semi–log formulation.
30 Actually, East Asia's TFP growth did decline in the 1973-80 period following the oil price hike. Similarly, South Asia's TFP growth rate slowed in the 1980s.
31 Note that only those economies were examined which had positive TFP and capital stock growth rates for the period in question.
32 Note that Taiwan, China is a high income economy according to the World Bank's classification.
33 See De Long and Summers (1992).

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