Capital Formation and Productivity Growth in South Korea and Taiwan: Beating Diminishing Returns through Realising the Catch-Up Potential

by

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Abstract

In this paper we reconstruct the fixed non-residential capital stocks of South Korea and Taiwan. These are based on long-term series of investment in non-residential buildings and machinery and equipment, using the perpetual inventory method with assumptions on life-times and age-efficiency patterns that are standardized across countries. We compare our estimates of gross capital stock with those from previous estimates and examine the sensitivity of our assumptions. Secondly, we look at the impact of quality-adjusted capital input on total factor productivity growth. Finally, to assess the potential for continued catch-up of the emerging economies we compare levels of capital intensity and labour productivity with those in the United States.

For both Korea and Taiwan we find a rapid growth of the capital stock for the total economy and for manufacturing, with growth rates peaking between the mid-1960s and the mid-1980s. These findings do not change with variations in lifetime and age-efficiency assumptions. With capital inputs measured in terms of service flows, total factor productivity growth is low up to the mid 1980s. Since then TFP growth slightly improved which is related to the slowdown of labour input growth relative to output growth.

In terms of comparative levels of capital-labour ratios and labour productivity, there are still large gaps between the two East Asian countries and the USA. This indicates that despite the diminishing returns to capital, especially in manufacturing, opportunities for further growth on basis of accumulation are far from exhausted. This would be all the more true in case the asset lifetimes in the Asian countries are actually shorter than in more advanced countries, which might be due to exceptionally high rates of investment and rapid structural change.

JEL codes: Macroeconomics, Growth and Fluctations (N1); Economic Development (O1); Technological Change (O3), Economic Growth and Aggregate Productivity (O4)

1. Introduction[1]

Well before the start of the recent financial and economic crisis in Asia, a vigorous debate emerged on the causes of accelerated growth performance in East and Southeast Asia since the 1960s and the barriers to further growth. Originally, the debate revolved around the question whether the region's exceptional growth performance could be primarily explained from the successful performance of markets in reallocating resources to their most efficient use, or from interventionist measures such as regulation of financial markets and industrial policy. In 1993 the World Bank further complicated the debate by introducing the concept of a 'market friendly' approach as a way to blend aspects of the orthodox and revisionist viewpoints (World Bank, 1993).

More recently the debate focused on the rapid accumulation of capital in East Asia. Krugman (1994) suggested that future growth in the region is likely to slow down because of diminishing returns to capital. Indeed some scholars report rapid accumulation in combination with low total factor productivity growth in Asia (Kim and Lau, 1994; Young, 1995), but others emphasize that, despite rapid capital accumulation, total factor productivity (TFP) growth in East Asia has been quite respectable compared to other developing regions in the world (Nehru and Dhareshwar, 1994, Collins and Bosworth, 1996; Nadiri and Son, 1997, Yusuf, 2001). Indeed Easterly and Levine (1999) argue that it is TFP growth rather than capital accumulation which accounts for a substantial amount of cross-country differences in per capita income.

Much of this debate has lacked clarity for several reasons, three of which are addressed in this paper. The first is related to the measurement of the domestic capital stock; the second to measuring the contribution of capital input to total factor productivity growth; and the third to assessing the evidence on diminishing returns to capital in relation to the remaining catch-up potential for growth in the emerging economies.

Lack of reliable data in combination with the sensitivity of the measurement procedures limits the number of countries for which one can derive reliable estimates of the domestic capital stock (Nehru and Dhareshwar, 1993; Sarel, 1997). As a result many studies, in particular those that made use of cross-country regressions, have used investment-output ratios as a proxy for the change in the capital stock. This procedure assumes that marginal and average capital-output ratios are the same. A recent study by Fukuda and Toya has emphasised that this assumption is particularly unrealistic for East Asian countries. These

1 The authors wish to thank Barbara Fraumeni, Kyoji Fukao, Masahiro Kuroda, Angus Maddison, Konosuke Odaka, Hak Pyo, Ngo Tak-Wing and participants at seminars at the University of Leiden, Tilburg University, Hitotsubashi University, National University of Seoul, National University Taiwan, Academia Sinica and the 26th General conference of the IARIW (Cracow) for their comments on previous versions of this paper. We also thank Andries Hof and Erik J. Monnikhof for their statistical assistance.

countries are characterised by relatively low capital-output ratios in combination with high rates of capital accumulation (Fukuda and Toya, 1999).

Those scholars who constructed more sophisticated capital stock estimates reverted to different procedures. Essentially two basic methods are available, namely direct estimates of assets in place through surveying capital assets (wealth surveys) and indirect estimates based on the perpetual inventory method (PIM) which are obtained by cumulating investment data using assumptions concerning the lifetime of assets and the depreciation pattern.[2]

This paper concentrates on capital stock estimates and related measures of TFP for two East Asian countries with rapid economic growth over the past decades, namely the Republic of Korea and the Republic of China, Taiwan Area.[3] As Korea and Taiwan are among the few countries in the world that carry out full-scale wealth surveys, we are in the position to compare existing wealth estimates with newly constructed PIM estimates using internationally standardized assumptions concerning age-efficiency patterns. The estimates in this paper will be for the total economy as well as for the manufacturing sector. The debate on the role of capital accumulation in growth often ignores the crucial differences concerning these relations at the sectoral level vis-à-vis the total economy level. In particular the manufacturing sector is likely to show different patterns, as the process of capital intensification was of greater importance than in other sectors of the economy.

In this paper two series of capital stock are presented, using the distinction between the gross and the productive capital stock. Section 2 describes both concepts as well as the perpetual inventory method that is used to obtain both types of estimates. In Section 3 the gross capital stock is first calculated and compared with previous estimates based on wealth surveys. Both growth rates and levels can differ substantially between the PIM and the wealth estimates. By varying the assumptions we examine the sensitivity of the gross stock estimates. It is found that growth rates are rather insensitive to a particular set of assumptions but levels differ considerably. At the end of Section 3 we also derive the productive capital stock, which takes into account the decline in productive capacity with increasing age. The latter is the most suitable capital concept for productivity analysis and growth accounting, and is used in the remainder of the paper. In Section 4 we obtain estimates of capital services to obtain a quality-adjusted measure of capital input and present estimates of total factor productivity growth. Finally, in Section 5, we put our findings in a comparative perspective and analyse changes in the levels of capital-labour ratios (capital intensity) and output-labour ratios (labour productivity). The use of PPP-adjusted output and capital input measures allows us to analyse both the development of the returns to capital and the remaining potential for a catch-

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2 The latter approach has been applied in two international datasets that aimed to include as many countries as possible, namely the World Bank dataset on physical capital (Nehru and Dhareshwar, 1993) and the Penn World Tables (Summers and Heston, 1991). The series from both datasets involve very substantial measurement problems, as the estimates are either based on indirect procedures, such as using investment/GDP ratios (Penn World Tables) or rough methods to derive a reliable benchmark estimates for the stock (World Bank dataset).

up in capital intensity and labour productivity relative to the level of the United States, which we assume as the productivity leader in the world economy. We find a large potential for continued catch-up growth both through further capital intensification and improving productivity.

2. Measuring the Capital Stock for Growth and Productivity Studies

With the introduction of the *System of National Accounts 1993* a major step forward has been made in developing the capital account of the national accounts, providing an internally coherent set of guidelines consistent with neoclassical production and consumption theory.[4] The SNA recommends the valuation of assets at the 'remaining present value', which may be defined as the sum of discounted values of future rentals. This valuation is essentially approached by computing the net (or wealth) stock of capital, i.e. the value of the stock adjusted for asset revaluation and depreciation. The latter refers to the Hotelling-Hicks definition of depreciation, i.e., the amount of capital value that must be put back in order to keep the real value of the wealth intact.

The net or wealth concept of capital, however, is less useful for studies of productivity and economic growth because it adjusts for the loss of asset value instead of the productive capacity of the stock. The net capital stock concept understates the productive capital stock when economic depreciation is faster than the efficiency decline. One possibility is to assume that the assets do not loose any of the productive capacity during their lifetime. In that case one computes the gross capital stock, i.e., the assets valued as if they are new without any adjustment for wear and tear. The gross capital stock is then identical to the productive capital stock. The alternative is to make an adjustment for efficiency decline of the stock, which indicates the decline in capital services yielded by a capital good as it ages due to wear and tear.[5]

To obtain capital stock estimates, *SNA 1993* recommends the use of the perpetual inventory method (PIM). Gross and productive capital stock estimates based on this method are presented here, each with a different purpose. The gross capital stock concept is used to compare our results with those based on direct wealth surveys. Ideally, wealth surveys are on a net basis when assets are valued at replacement costs, but in practice valuation comes closer to a gross concept. The productive capital stock, which takes account not only of retirements, but also of efficiency declines, is used in the analysis of productivity and catch-up later on.[6]

The perpetual inventory method, which was pioneered by Goldsmith (1951), estimates the gross capital stock as the sum of past investments corrected for retirements. The actual

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3 In the remainder of this paper we refer to these two countries as (South) Korea and Taiwan.
4 See Hulten (1996) for a review of the capital account in the System of National Accounts 1993.
5 See Triplett (1998) and OECD (2001a) for an extensive discussion of these issues.
6 See OECD (2001b) for a review of (and recommendations for) the use of capital estimates in productivity analysis.

retirement pattern depends on the average lifetime and the range of years around the average service life during which retirements occur. In the simplest version, assets are discarded in one stroke after their service lifetime. This is known as the one-hoss-shay retirement pattern. In that case, the gross capital stock can be measured as:

$$K_{i,T} = \sum_{T-d_i+1}^{T} I_{i,t} \tag{1}$$

with $I_{i,t}$ investment at constant prices in asset type *i* at time *t* and d_i the service lifetime of asset *i*.

An important problem in comparing perpetual inventory estimates of the capital stock across countries is that not only the retirement patterns, but in particular the assumptions concerning the asset lives can differ substantially.[7] For example, even within the OECD, asset lives for non-residential structures vary between 39 years in the United States, 57 years in Germany and 66 years in the United Kingdom (Maddison, 1995). The (limited) amount of direct and indirect evidence that is available does not support these large differences (O'Mahony, 1996). Hence as a second-best approach, until internationally comparable asset lives are available, one might calculate the stock on the basis of standardised asset lives across countries. The standardisation method was pioneered by Maddison (1995) for France, Germany, Japan, Netherlands, UK and the USA, and was replicated for the manufacturing sector in Germany, Japan and USA by Van Ark and Pilat (1993) and for other sectors of the economy in France, Germany, Japan, the UK and the USA by O'Mahony (1996). Hofman (1998) applied the standardisation procedure to six Latin American countries. Following the presentation of our standardised estimates for Korea and Taiwan in section 3, we will compare the results for their sensitivity to alternative assumptions concerning service lifetimes.

Although the gross stock has been favoured for usage in productivity analysis by some researchers (see e.g. Kendrick, 1993 and Maddison, 1995), there is increasing support for the use of the productive capital stock, which takes into account declines in efficiency alongside retirements. This necessitates the choice of a particular age-efficiency pattern. Jorgenson and associates have opted for the geometric efficiency pattern (Jorgenson 1995). This choice is primarily based on two considerations, one empirical and one more practical. A large and diverse body of empirical studies (predominantly for the US) suggests that a geometric efficiency pattern is the most suitable given evidence from, for example, used asset price studies.[8] Geometric efficiency patterns also have the desirable side-effect that the wealth concept of the capital stock (the net stock) and the productive stock coincide. This is because

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7 It is received wisdom that capital stock estimates are rather insensitive to the choice of mortality functions, see for example O'Mahony (1996).

8 The seminal study is by Hulten and Wykoff (1981). See Fraumeni (1997) and Jorgenson (1996) for overviews of the literature. The geometric pattern for depreciation calculations does not always match the empirical evidence. For example, the BEA makes exceptions for computers and peripherals, autos, missiles and nuclear fuel (Fraumeni, 1997)

in the case of geometric patterns, the age-price profile and the age-efficiency profile are identical.[9]

With geometric depreciation, the productive capital stock is given by:

$$K_{i,T} = \sum_{t=0}^{\infty} (1-\delta_i)^t I_{i,T-t} \qquad (2)$$

with $I_{i,T-t}$ investment in asset i at T-t in constant prices and $(1-\delta_i)^t$ the relative efficiency of asset type i of vintage t. The efficiency parameter δ includes the effects of both retirements and decay due to wear and tear.

3. The Gross and Productive Capital Stock for Korea and Taiwan

Estimating the Gross Capital Stock

The capital stock estimates for South Korea and Taiwan in this paper are based on the standardized perpetual inventory method described above. In this paper we concentrate on the non-residential fixed capital stock distinguishing between non-residential buildings and other construction (except land improvement), and machinery, equipment and transport equipment. Estimates for the total economy are provided from 1951 (Taiwan) or 1953 (South Korea) to 1997, and for manufacturing from 1963 to 1997. In general the method involves the following data requirements: gross investment series at current prices, price indices to revalue investment to constant base year replacement costs, asset service lifetimes or rates of actual depreciation, and a benchmark capital stock figure. An important feature of our benchmark capital stock figure for the beginning year of the period is that it is fully based on investment series which go back to the beginning of the 20th century. The estimates and sources are presented in Appendix 1. Below we summarize the main elements of our procedures.

<u>South Korea, total economy</u>

For the period 1953-1997 two series on capital formation were obtained from the Korean national accounts, namely one for non-residential buildings and other construction (except land improvement) and one for transport equipment and machinery and equipment. For the period 1914-1940, we obtained similar series from Pyo (1996). To bridge the period 1940-1953, we estimated capital formation on the basis of output series assuming investment-output ratios at 0.10 for the period 1940-1944, at 0.00 for 1945 and 1946, at 0.05 for 1947-1950 and at 0.00 for 1951 and 1952. After linking, the investment series was expressed in 1990 Won. As the 1940-1953 figures were not divided into series for non-residential structures and machinery and equipment, we used an average of the pre- and post- five year

[9] This also ensures consistency between the efficiency pattern used in the calculation of the productive capital stock, and depreciation used in the calculation of the user cost of capital of which economic depreciation is one important element. User cost of capital is necessary for the calculation of capital services (see Section 4). The relationship between depreciation and changes in efficiency is much more complicated for other patterns such as the one-hoss-shay or linear pattern. See Hulten and Wykoff (1981) and Jorgenson, Gollop and Fraumeni (1987, Chapter 4).

period share. Next we applied the perpetual inventory method, by using the standardised asset lives of 39 years for structures and 14 years for equipment from Maddison (1995). Moreover we discounted all pre-1953 investment by 40 per cent to account for war damage (Maddison, 1998, Table 3.10, p. 66). The first cumulated benchmark estimate is provided for 1953. The estimates are adjusted from end-year to mid-year basis.

Taiwan, total economy

The procedure for the estimation of the capital stock of the Taiwanese economy was similar to that used for South Korea. For the period 1951-1997 two series on capital formation were obtained from the Directorate-General of Budget, Accounting and Statistics (DGAS) for non-residential structures and for plant and equipment. For the period 1912-1938, we obtained similar figures from Mizoguchi (1997). To bridge the period 1938-1951, we estimated capital formation on the basis of output series assuming investment-output ratios at 0.10 for the period 1939-1944, at 0.00 for 1945 and 1946 and at 0.05 for 1947-1950. After linking, the whole investment series was expressed in 1991 Taiwanese dollars. As the 1938-1951 figures were not divided into series for non-residential structures and machinery and equipment, we used an average of the pre-five year period share and the post-five year period share. Next we applied the perpetual inventory method, by using the standardised asset lives of 39 years for structures and 14 years for equipment from Maddison (1995). The first cumulated benchmark estimate could be provided for 1951. The estimates were adjusted from end-year to mid-year basis. In contrast to the measures for Korea, we judged that no adjustment for war damage was necessary for Taiwan.

South Korea and Taiwan, manufacturing

For manufacturing only one series for total capital formation (but excluding residential structures) could be obtained from the post-war national accounts. To obtain an average standardized asset life for the aggregated manufacturing investment series, we used the average asset lives in manufacturing for a number of OECD countries from van Ark and Pilat (1993, p.42), namely 45 years for investment in non-residential structures and 17 years for investment in equipment and vehicles. These asset life estimates were then weighted by the share in gross fixed capital formation for Taiwan in 1987, which provided an average lifetime of 25 years.[10] Investment series for manufacturing go back to 1953 for South Korea and 1951 for Taiwan. We obtained investment series for the pre-1953 (Korea) and pre-1951 (Taiwan) period using the trend in capital formation for the total economy. For Korea we applied a 40 per cent war-damage adjustment.[11]

[10] The share in gross fixed capital formation in Taiwanese manufacturing is 31 per cent for structures and 69 per cent for equipment in 1987 (MOEA (1987) *Annual Report on the Corporated Enterprises Survey, Taiwan Area, ROC*, No. 19, Table 2-4).

[11] This procedure improves upon Timmer (2000) where the pre-1953 and pre-1951 series were derived from the average growth rates from 1951 to 1956 (for Taiwan) and 1953 to 1957 (for South Korea).

For both South Korea and Taiwan official capital stock estimates, which are based on national wealth surveys, exist. In a series of papers, Pyo (1988, 1992, 1998) provides estimates of gross fixed capital stock in South Korea based on wealth surveys in 1968, 1977 and 1987, linked with investment from the national accounts. For linking between benchmark years, Pyo uses the polynomial-benchmark method. For the period before the first and after the last benchmark year the perpetual inventory method is applied as described above. In his earlier work Pyo estimated gross and net capital stocks independently, but inconsistencies of the benchmarks and the investment series forced Pyo in his latest study to first estimate net capital stocks, which are converted to gross stocks using interpolated net-gross conversion ratios from the wealth surveys (Pyo, 1998). This revision led to a downward adjustment of the estimates, especially before 1968. Kim and Hong (1997) also base their estimates on wealth survey data, but use only the survey of 1987 which they considered to be more reliable than the earlier surveys.[12] Table 1 compares the value of the capital stock according to our standardised estimates derived from the perpetual inventory method with those from Pyo for the total economy and manufacturing. Our estimates are much lower than those from Pyo, and even though subperiod growth rates move up and down together, the gap varied substantially over time.[13]

Official capital stock estimates for Taiwan are provided by the Directorate General of Budget, Accounting and Statistics (DGBAS), which uses the benchmark extrapolation method (DGBAS 1999). However, the series are not fully comparable with ours as capital formation in agriculture is excluded in the estimates by DGBAS.[14] Liang and Jorgenson (1995) used a similar method for calculating the stock of various asset types as they 'adjust the time series data of capital stock by employing the National Wealth Censor (1988).' In Table 2, the series from DGBAS are compared with our estimates. Again, our estimates are lower than those based on the survey estimates. The gap in the early years is particularly large for manufacturing. However, the gap between the DGBAS estimates and our figures becomes much smaller over time, which implies that our estimates show more rapid capital accumulation than the wealth based estimates.

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12 Pyo (1998, Table 12) provides a comparison of his old and new estimates. The pre-1977 figures in this table for Pyo (1992) are based on erroneously aggregated figures in the original publication (see Pyo 1992, Table A2). Pyo also shows that the results of Kim and Hong (1997) lead to very high estimates of the capital stock in the 1960s and 1970s. In 1962, their estimate of the gross stock is 3.5 times higher than his and five times higher than our estimate.

13 All growth rates in this paper are exponential rates.

14 It is not clear whether residential buildings are included in the DGBAS estimates. As they are based on a wealth survey amongst firms, probably part of the residential buildings stock will be included.

Table 1 Gross Capital Stock in South Korea according to this Study and Pyo (1998) Total Economy and Manufacturing, 1953-1996

	Total Economy			Manufacturing		
	This Study	Pyo (1998)	This study/ Pyo (1998)	This Study	Pyo (1998)	This study/ Pyo (1998)
	bln. 1990 Won		(%)	bln. 1990 Won		(%)
1953	8,666	11,241	77			
1963	13,108	19,518	67	2,936	3,848	76
1973	46,226	55,256	84	9,344	14,673	64
1985	224,602	297,191	76	59,855	102,137	59
1996	736,682	980,149	75	247,448	404,847	61
	annual growth rate (%)			Annual growth rate (%)		
1953-63	4.1	5.5				
1963-73	12.6	10.4		11.6	13.4	
1973-85	13.2	14.0		15.5	16.2	
1985-96	10.8	10.8		12.9	12.5	

Note: all growth rates in this paper are exponential rates.
Source: See Appendix Tables 1 and 3 and explanations in text. Survey estimate from Pyo (1998), Table A4.

Table 2 Gross Capital Stock in Taiwan according to this Study and DGBAS (1999) Total Economy and Manufacturing, 1953-1996

	Total Economy			Manufacturing		
	This Study	DGBAS (1999)	This study/ DGBAS	This Study	DGBAS (1999)	This study/ DGBAS
	Mln. 1991 NT$		(%)	mln. 1991 NT$		(%)
1953	326,050					
1963	490,476	645,910	76	83,078	340,038	24
1973	1,402,549	1,545,568	91	414,371	727,338	57
1985	5,339,055	5,707,863	94	1,816,015	2,316,079	78
1996	13,667,004	13,220,471	103	4,691,847	5,754,758	82
	Annual growth rate (%)			Annual growth rate (%)		
1953-63	4.1					
1963-73	10.5	8.7		16.1	7.6	
1973-85	11.1	10.9		12.3	9.7	
1985-96	8.5	7.6		8.6	8.3	

Note: DGBAS (1999) excludes capital in the agricultural sector of the economy.
Source: See Appendix Tables 1 and 3 and explanations in text. Survey estimate taken from DGBAS (1999).

Both because of reporting errors and theoretical differences, the PIM estimates will inevitably differ from the wealth survey results. Pyo (1998) mentions two main limitations of the PIM method. The first is the need for long historical investment series. In this paper, we show that this limitation can be overcome using historical national accounts studies. A second limitation is the need to assume particular retirement patterns. Although wealth surveys have the advantage that they measure the assets actual in use, when extrapolating the benchmark stock to obtain a time series, assumptions concerning depreciation and retirements still need to be made. An important advantage of the polynomial-benchmark method is that these can be directly calculated from the model. However in practice the estimated parameters are often implausible and sometimes even negative (see Pyo, 1998, Table 7), casting doubt on the consistency between the various benchmarks, and between the benchmarks and the used investment series.

Ward (1976) argues that the exact nature of the wealth survey is crucial for its usefulness for capital stock measurement. Ideally, the survey should be one of physical assets on a case by case basis and it should have a complete coverage, but such surveys are complicated and prone to measurement errors. If instead the survey is based on company records showing book values, as often reported in censuses, its use is much more circumspect. Balance sheets valuations reflect a cumulation of historical prices of different time periods, they depend on the depreciation accounting practices of firms which are mainly influenced by tax conventions rather than the actual decline in productive capacity, and the vintage composition of the stock is unknown. Even though the Korean wealth survey comes close to a survey of physical assets, revalued at constant prices (Pyo, 1998, p.19), the official Taiwanese capital stock figures seem to be based on balance sheets.[15] Another important shortcoming of using wealth surveys is the problem of obtaining consistent methods of evaluation both across countries and over time (Ward, 1976). Therefore we prefer to use our internationally consistent estimates based on the PIM method.

The Sensitivity of the Gross Capital Stock Estimates

Clearly the standardization procedure may be sensitive to the particular assumptions made. In particular the assumptions concerning asset lifetimes may affect the results. Blades (1993) argues that international differences in asset lifetimes may exist due to a variety of reasons which include differences in composition of the capital stock, differences in tax incentives for new capital investment and differences in maintenance cost. It is not clear in which direction this would push lifetimes in the East-Asian countries compared to, say, the USA. One might argue that at lower per capita income levels, asset lives tend to be longer because of lower maintenance cost (due to relative lower wages) (Heston and Summers, 1996). On the other hand, lifetimes in developing countries might be shorter because of adverse circumstances (such as climate) and the lack of specific skills which might be required for maintenance activities.

In rapidly growing countries, like those in East Asia, the most important factor which reduces asset lives over time, however, is associated with rapid obsolescence due to high rates of technical change, large changes in relative prices of inputs, and rapid structural change. For example, during the 1980s the textile industry in East Asia faced severe competition from low-wage producers. As a consequence a process of industrial upgrading was initiated in which old technology processes were transplanted across the border or abandoned. Rapid

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15 Comparison with the Taiwanese production census data suggests that the census is used as a benchmark. According to DGBAS, Report on the Industrial and Commercial Census in Taiwan-Fukien district of the ROC 1991, Table 10, the total gross value of fixed assets in the manufacturing sector in use in 1991, excluding land, was 3,544 billion NT$ (in 1986 prices) which is almost identical to the 3,537 billion NT$ given in DGBAS (1994).

obsolescense suggests that asset lifetimes are likely to be shorter in faster growing countries (in terms of GDP or investment growth) because of the higher speed of upgrading processes.

To test the sensitivity of our PIM estimates to a change in lifetimes, we recalculated the standardised estimates for the total economy and manufacturing in South Korea and Taiwan using alternative asset life assumptions. First, in Table 3 we show the effects of a change in lifetimes on the growth rates of the capital stock. For total economy we varied lifetimes from 15 years for buildings and 5 years for equipment, to 45 years and 19 years, respectively. For manufacturing, the lifetimes for total investment were varied from 10 to 30 years. In the last column of the Table we abandoned the assumption of fixed lifetimes over time. Instead we assume that lifetimes are likely to be shorter in periods of faster GDP growth as discussed above. We also assumed that there was a general decline in lifetimes over the period 1963-1997 from the highest to the lowest alternative lifetime. Even though we determined the upper and lower bounds exogenously, the actual decline was obtained endogenously by scaling it on the growth rate of real GDP, suggesting faster obsolescence in times of accelerated growth.

Table 3: Growth of Gross Capital Stock using Alternative Lifetimes, Total Economy and Manufacturing (average annual growth rates)

	Alternative lifetime assumptions					
Total Economy	15+5 years	23+8 years	30+10 years	**39+14 years**	45+19 years	Declining from 45+19 to 15+5 years
South Korea 1963-73	17.2	14.6	12.8	**12.6**	12.2	12.1
South Korea 1985-97	10.4	10.3	10.5	**10.7**	10.9	7.9
Taiwan 1963-73	14.2	13.0	11.0	**10.5**	10.4	9.5
Taiwan 1985-97	8.5	8.8	8.8	**8.6**	8.8	6.4
Manufacturing	10 years	15 years	20 years	**25 years**	30 years	Declining from 30 to 10 years
South Korea 1963-73	15.0	15.2	14.4	**11.6**	10.5	10.5
South Korea 1985-97	12.1	12.3	12.6	**12.8**	12.8	10.9
Taiwan 1963-73	20.2	19.7	18.8	**16.7**	15.2	14.7
Taiwan 1985-97	8.6	8.0	8.3	**8.9**	9.1	6.8

Note: bold is our base-scenario of standardised asset lives. In the last column lifetimes decline in proportion to real GDP growth.
Source: Growth rates of PIM estimates for total fixed non-residential capital with rectangular retirement pattern, war-damage adjustment (for Korea) and alternative lifetimes using investment series from Appendix Tables 1 to 3.

The Table shows that small variations in lifetimes have a limited impact on the estimated growth rates of the gross capital stock estimates for the Asian countries. This reflects the fact that in periods of high investments, investments made long ago have a very small impact on the growth rates. For example, the range of estimates for the annual growth of the total stock in Korea during the period 1985-97 ranges in between 10.3 to 10.9 per cent. For the earlier period 1963-73 differences are bigger due to the effects from the idiosyncratic investment patterns of the wartime period. In contrast, the effect of declining asset lifetimes is biggest for the later period. With a fall in the lifetime of assets the growth rates of the total capital stock in Korea and Taiwan are at least 2 percentage points lower than the growth rate of stocks calculated with fixed lifetimes over the period considered. This suggests that if lifetimes indeed decline, our estimates which assume a fixed lifetime overestimate the growth of the stock of capital.

Differences in lifetime assumptions have a bigger impact on the level of the capital stock than on the growth rates. This is borne out by Table 4 which provides comparisons of capital stock levels under various lifetimes assumptions. For 1997, small variations in lifetimes have a limited impact on the capital stock estimates. If the assumed asset lifetime for South Korea and Taiwan is reduced to 30 years for structures and 10 years for plant and equipment, the total economy stock in 1997 declines with 9 and 7 per cent respectively. The effects for manufacturing are smaller because the faster growth of investment in this sector compared to the total economy reduces the impact of changes in asset lives. Again, for estimates further back in history, the impact of a change in the lifetime assumption is much bigger, for example for 1963 up to fifty per cent.

Table 4: Gross Capital Stock Estimates using Alternative Lifetimes, Total Economy and Manufacturing, 1963 and 1997 (as per cent of preferred estimate)

	Alternative lifetime assumptions					
Total Economy	15+5 years	23+8 years	30+10 years	**39+14 years**	45+19 years	Declining from 45+19 to 15+5 years
South Korea 1963	50	65	84	**100**	107	107
South Korea 1997	64	83	91	**100**	109	64
Taiwan 1963	50	70	89	**100**	107	107
Taiwan 1997	67	85	93	**100**	106	67
Manufacturing	10 years	15 years	20 years	**25 years**	30 years	Declining from 30 to 10 years
South Korea 1963	59	65	74	**100**	116	116
South Korea 1997	73	87	96	**100**	102	73
Taiwan 1963	60	73	79	**100**	117	117
Taiwan 1997	64	81	92	**100**	105	64

Source: PIM estimates with rectangular retirement patterns, war-damage adjustment (for Korea) and alternative lifetimes for total fixed non-residential capital using investment series from Appendix Tables 1 to 3, compared with the preferred estimates discussed in main text.

The overall conclusion from Tables 3 and 4 is that small variations in lifetimes do not have much impact on the capital stock estimates for the Asian countries when investment shows a continuously increasing trend. Further study of international differences in asset lifetimes is called for, which will crucially depend on more and comparable national surveys. In the remainder of this paper we use our standardised estimates, as the procedures to let asset lives change across countries and periods are still too hypothetical to support international comparisons. In addition, the estimation procedure is transparent and it is possible to check the sensitivity of the results.

Productive Capital Stock Estimates

If one assumes that repair and maintenance keep the physical production capabilities of an asset constant until it is retired, the gross capital stock is identical to the productive capital stock. In practice, however, a certain amount of efficiency decline is likely. In Table 5 we provide a comparison of the gross and the productive capital stock estimates. For the productive stock we assumed a geometric age-efficiency pattern where the rate of efficiency decline is defined as the ratio of the declining-balance rate and the asset's service life. The declining-balance rate determines the steepness of the curve. Hulten and Wykoff (1981) determined that, on average, the declining-balance rate for producers' durable equipment was 1.65, and for private non-residential structures 0.91. These standardized values are used here. For service lives we took the same values as used in the gross stock estimate.

Table 5: Comparison of the Gross and Productive Capital Stock, Total Economy and Manufacturing

	South Korea Total economy	South Korea Manufac-turing	Taiwan Total economy	Taiwan Manufac-turing
Productive stock as % of gross stock (a)				
1963	74	72	73	77
1973	81	82	78	84
1985	76	77	72	74
1996	75	76	73	71
Growth rate of productive stock minus growth rate of gross stock (b)				
1963-73	0.9	1.2	0.8	0.8
1973-85	-0.5	-0.5	-0.7	-1.1
1985-96	-0.1	-0.2	0.3	-0.2

Sources: Growth rates and levels of PIM estimates for total non-residential fixed capital with rectangular (for gross stock) and geometric efficiency patterns (for productive stock) using investment series from Appendix Tables 1 to 3 (including war-damage adjustment for Korea). Assumed lifetimes are 39 years for total economy investment in non-residential structures and 14 years for investment in equipment and vehicles, and 25 years for manufacturing investment. Declining balance rate of 1.65 for equipment and 0.91 for structures (total economy) and 1.2 for manufacturing.

Notes: (a) Level of productive stock (using a geometric efficiency pattern) as percentage of gross stock (using rectangular pattern).

(b) Average annual growth rate of productive capital stock with PIM (using a geometric efficiency pattern) minus growth rate of gross stock (using rectangular pattern).

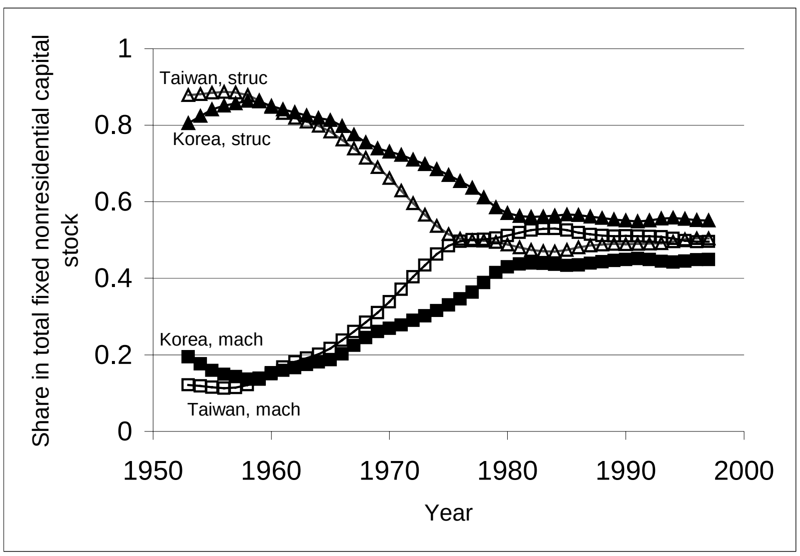
Table 5 shows that, in growth terms, the productive stock estimates are rather similar to those for the gross stock, especially for the more recent periods. There is no clear bias towards a systematic under- or overestimation. With respect to the level estimates, we find that levels of the productive stock are systematically lower at between 70 and 85 per cent of the gross stock levels. These results indicate that the use of the gross capital stock rather than the productive capital stock can have considerable effects on the results of growth accounting studies and especially of level accounting studies.

4. Quality-Adjusted Capital Input and Growth Accounting

The contribution of capital input to growth can be measured by the growth of the aggregate capital stock, as obtained in the previous section, weighted at the share of capital income in total output. This essentially reflects capital input which is unadjusted for quality. However, by disaggregating the capital stock into various assets and weighting those at the user cost of capital, one obtains the flow of capital services from the installed capital stock. This flow approach takes account of the differences in capital services delivered by the various types of capital assets (Jorgenson and Griliches, 1967). A dollar invested in buildings will yield a lower annual revenue product than a dollar invested in machinery. Hence, growth in the machinery stock should be weighted more heavily than growth in the buildings stock, rather than treated equally as in the stock approach. Typically, the share of machinery in the capital stock increases over time, especially during a period of rapid industrialisation. This is shown in Figure 1 which presents the compositional change in the aggregate capital stock for the two asset types, as obtained from the previous section.

It follows from Figure 1 that both in South Korea and Taiwan the asset composition of the capital stock changed rapidly between 1950 and the mid 1970s. After an initial decrease in the 1950s, the share of machinery gradually increased in the 1960s and 1970s from about 20 per cent to 50 per cent of the total non-residential fixed capital stock. Afterwards the share remained stable. In the capital service approach, the change towards faster growing machinery stock implies a quality adjustment. Consequently, the use of quality-adjusted capital input implies that TFP growth rates will be somewhat lower than on the basis of the unadjusted aggregated stock approach. This difference is quantified below.

Figure 1 Share of Non-Residential Structures and Machinery in Total Fixed Non-Residential Capital Stock, South Korea and Taiwan, 1953-1997 (share in total stock)



Source: Appendix Table I

Capital Services

In obtaining capital service flows, we follow Jorgenson, Gollop and Fraumeni (1987) and assume that the growth of aggregate capital input (K^T) is given by a weighted growth of individual capital inputs (K^T_k) using a Tornqvist index where weights are given by the shares of each asset type in the total value of property compensation:[16]

$$\ln K^T - \ln K^{T-1} = \sum_k \bar{v}_k [\ln K_k^T - \ln K_k^{T-1}] \tag{3}$$

with $\bar{v}_k = \frac{1}{2}[v_k^T + v_k^{T-1}]$ and $\bar{v}_k^T = \frac{p_k^T K_k^T}{\sum_k p_k^T K_k^T}$ with p_k the rental price of asset type k. From formula (3) it can inferred that if the stocks of the various assets types grow at similar rates, the aggregate capital service flows will grow at the same rate as the aggregate capital stock. Hence the two approaches will only generate different results in the case of a change in the asset composition of the aggregate capital stock.

The rental prices of the different asset types are difficult to observe in practice and need to be estimated. Three approaches can be distinguished with an increasing degree of sophistication. The most straightforward way to estimate the user cost of capital (i.e., the rental price of capital services divided by the acquisition price) is by the depreciation rate (Ward, 1976, used in Timmer, 2000). This captures the idea that longer lived assets provide less services per year. More sophisticated is the opportunity-cost approach in which the cost of capital is approximated by a standard cost-of-capital formulation as follows (Jorgenson and Griliches 1967):

$$\frac{p_k}{P_k} = i + \delta_k - \frac{\Delta P_k}{P_k} \tag{4}$$

with i the nominal interest rate, δ_k the depreciation rate and P_k the purchase price of asset type k. The last term is included to represent capital gains. This external approach is ex ante, in contrast to the more elegant third approach, the residual or internal (ex post) approach. The latter method is used in Jorgenson, Gollop and Fraumeni (1987) who use national accounts data on property compensation to estimate rental prices internally. Instead of taking the ex ante interest rate, the ex post realised rate of return, which is assumed equal across all assets, is estimated using the national accounting identity between total value of capital services (rental price times asset quantity) and total property compensation. When industry level data is available, this method allows for varying rates of returns across industries. In their estimation Jorgenson and associates also take into account differences in tax rates. The residual approach has been used by Liang and Jorgenson (1999) in their study of Taiwanese growth, but as it puts high demands on data (such as fully integrated production and income accounts), it is not attempted in this multi-country study.

For this study we apply the opportunity-cost approach.[17] One of the problems with the opportunity-cost approach is to pick an appropriate interest rate. As a variety of interest rates exist, we chose a rate for which long time series are available and which reflect general interest rate movements. For both countries the end-of-year discount rate for commercial bills for prime enterprises was used.[18] For the depreciation rate we took the reciprocal of the asset lifetime.[19]

The third and fourth columns of Table 6 compare the alternative outcomes for capital using the capital stock or capital flow approach. The third column presents the growth rates according to the stock method (representing the quantity of capital input) and the fourth the differences in growth rates between the flow method and stock method, representing the rise in quality of capital input. Because of a higher depreciation rate, machinery generally has a higher rental price than buildings, and hence capital service increases faster than the aggregate capital stock if the share of machinery increases. This is confirmed by the results presented in Table 6. In both countries, capital quality increases, especially for the period 1963-73 in Taiwan, and 1973-1985 in Korea. For Taiwan the quality adjustment is bigger than for Korea because the shift towards equipment was more radical and proceeded faster, and because of the high discount rate in Korea in the 1960s, which dominated the rental price calculations, giving largely equal weights to both asset types as in the stock approach.

Total Factor Productivity[20]

Table 6 also shows the total factor productivity growth rates using the quality adjusted measure of capital input. To maintain consistency between our estimation of capital input with that of labour input, we adjusted the total number of working hours for labour quality. A labour quality index, measuring educational attainments, was obtained from Lee and Kim (1997) for Korea, and a similar index was constructed for Taiwan. For the weighting of the input series we applied a variant of formula (4), which applies the average weights of the current and previous years according to the following translog formula (Jorgenson, Gollop and Fraumeni, 1987):

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16 See also OECD (2001b).

17 Harper, Berndt and Wood (1989) provide a thorough discussion of the merits of the various approaches.

18 The discount rate is the lower limit for most other interest rates. Rates were taken from KSA, *Korea Statistical Yearbook* and IMF, *International Financial Statistics*, various issues, for Korea, and from DGBAS, *China Statistical Yearbook*, various issues, for Taiwan.

19 A number of adjustments had to be made to empirically implement the rental price calculation. First, the measure of depreciation is not completely consistent with the rectangular efficiency pattern, see footnote 14, but the difference will be small. Secondly, inflation in the Asian countries and especially in South Korea is highly volatile and this is reflected in rental prices frequently becoming negative. This phenomenon is not uncommon and appeared also in studies of OECD countries, even when using the internal approach (Harper, Berndt and Wood, 1989; Oulton and O'Mahony, 1994). To remedy this, we used a real capital gains formulation, adjusting the price change in asset type i by the overall asset price change.

20 For a more extentive discussion focused on the growth accounts for Korea and Taiwan, see van Ark and Timmer (2001)

$$\ln\frac{A_{t+1}}{A_t}=\ln\frac{Y_{t+1}}{Y_t}-\sum_j \bar{v}^j_{t+1}\ln\frac{X^j_{t+1}}{X^j_t} \quad (7)$$

with $\bar{v}^j_{t+1}=1/2(v^j_t+v^j_{t+1})$ and v^j_t the value share of input j in output at t. Here we consider only labour and capital input.

Table 6: Total Factor Productivity (TFP) Growth and Its Components (average annual growth rates, %)

	GDP	Labour input (a)	Capital quantity (based on aggregate productive stock	Capital quality (based on service flows) (b)	Capital share in value added	TFP using capital services
South Korea						
1963-73	8.4	5.6	12.6	0.2	0.44	-0.3
1973-85	7.3	3.8	13.2	0.6	0.39	-0.4
1985-96	8.2	3.3	10.8	0.1	0.36	2.2
1963-96	8.0	4.2	12.2	0.3	0.39	0.5
Taiwan						
1963-73	10.6	4.1	10.5	1.5	0.51	2.4
1973-85	7.7	3.0	11.1	0.4	0.51	0.4
1985-96	7.4	2.0	8.5	0.1	0.50	2.2
1963-96	8.4	3.0	10.1	0.5	0.51	1.6

Notes: (a) Labour input is based on hours worked, corrected for changes in labour quality based on changes in educational attainment using the same method as for capital input as described in main text. Labour quality index for Korea was taken from Lee and Kim (1997, Appendix I, series I). Labour quality index for Taiwan was calculated by authors using same methodology and data from DGBAS, *Yearbook of Manpower Survey Statistics*, *1993*, Table 11 for 1978-1993 and from DGBAS, *Social Indicators in Taiwan Area*, *1993*, Table 29 for 1963-1977. Quality change for 1993-97 based on average change during 1988-1993.
(b) difference between capital input based on service flows and capital input based on aggregate stock. Capital services are based on decomposition into two asset types: non-residential buildings and machinery. See main text for methodology.
Sources: Employment and working hours from GGDC Total Economy Database. Capital stock and capital services from Appendix 1. Capital share in value added for Korea from Pilat (1994, Annex Table I.7) assuming no change after 1990. Capital share in value added for Taiwan from DGBAS (1994, Table 7) assuming no change before 1978 and after 1993.

The results are shown in the last column of Table 6. It is clear that the TFP growth rates were in fact quite high during the period 1985-1996 and well above those for the two earlier subperiods. Both studies show much faster growth in TFP for the 1960s and 1970s. This is mainly explained by the difference in the growth rate of capital. Both previous studies use capital stock data based on wealth surveys without an adjustment for the rise in quality of capital. Young (1995) uses a similar approach as ours, but he excludes the agricultural sector from his analysis. His TFP results for Korea and Taiwan are comparable to ours showing a clear improvement during the 1980s compared to the 1970s. Young’s TFP growth rates for the 1960s are higher than ours due to his short-cut method to estimate investment growth in the pre-1953 period, necessitated by his lack of historical series. A similar improvement in TFP growth for Taiwan is found by Liang and Jorgenson (1999) who apply a gross-output approach to growth accounting and take account of changes in the use of intermediate and energy inputs, apart from factor inputs.

It should be emphasised that the TFP calculations in this section are not meant to provide an estimate of technological change. It is clear from the literature that technological change is at least partly embodied in the inputs. In its most extreme form all technological change, as far as it is captured by the investors in their returns, is embodied in the inputs. The TFP residual then solely represents non-pecuniary spillovers (Jorgenson, 1995). Others, like Denison (1967), would argue that after accounting for various residual factors, such as improved resource allocation, economies of scale, etc., the final residual may represent advances in knowledge, as a form of disembodied technological change.[21]

5. Diminishing Returns and Catch-Up Potential

In this final section a 'catch-up' perspective is provided by comparing developments in South Korea and Taiwan with those in the USA. The catch-up concept stems from the work of Gerschenkron (1962) and Abramovitz (1979). The potential for catch-up, in terms of an inverse relationship between the starting level of productivity and subsequent growth rates, arises from 'advantages of backwardness'. According to Abramovitz (1979) the catch-up potential can be realised through benefiting from the diffusion of technological and organisational knowledge.[22] In this respect one must distinguish between two mechanisms. One is through investment opportunities, that is the realizing of potential for further investments, given the gap in capital intensity (i.e, the amount of capital per worker) relative to the leading countries in the world. Another potential is found in closing the gap in productivity levels compared to the world technology leaders. This gap indicates the gains which can be made through further diffusion of (disembodied) technology from the global frontier. In reality these two vehicles through which the catch-up potential is realized strongly interact (Abramovitz, 1986). But what is crucial here is that in both cases we need to look not only at growth rates but also at levels in an internationally comparative perspective.

In order to compare relative levels of labour productivity and capital intensity with those of the United States, which was taken here as representing the productivity leader, all figures are converted to 1990 US dollars using PPPs. GDP for the total economy was converted to 1990 US$ with 'Geary-Khamis'-type purchasing power parities which were obtained from Maddison (1995) for Korea and Taiwan. For manufacturing GDP we used binary PPPs based on unit value ratios from Pilat (1994) for South Korea and Timmer (2000) for Taiwan. The manufacturing UVRs are derived using the industry-of-origin approach on the basis of matching a large number of manufacturing products. These PPPs are substantially lower than

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21 See also studies of this nature for Korea, in particular Kim and Park (1985), Pilat (1994) and Kim and Hong (1997).

22 Gerschenkron (1962) assigns a greater role to financial and educational institutions and government intervention to support catch-up growth, which was recognised by Abramovitz as the 'social capability' to catch-up.

the exchange rate. In 1987 the relative price level (i.e. the purchasing power parity relative to the exchange rate) of South Korea vis-à-vis the United States was 85 per cent for manufacturing output, but only 58 per cent for the total economy. For Taiwan the difference was smaller, i.e. a relative price level of 78 per cent for manufacturing versus 61 per cent for the total economy (Timmer, 2000). This corroborates the stylized fact that price levels of developing countries relative to the USA (or any other advanced country) are higher in manufacturing than in non-manufacturing. Capital stock was converted into 1990 US$ by using investment PPPs for 1990 for Korea and Taiwan which were divided by the relative price levels of investment to GDP in the USA when expressed in international prices.[23] The investment PPPs indicate a relative investment price level of 133 per cent and 126 per cent of the US level for Korea and Taiwan, respectively.

Table 7 shows the non-residential productive capital stock per hour worked in South Korea, Taiwan and the United States. The Table shows an extraordinary rapid growth of capital intensity in Korea and Taiwan, in particular since the early 1970s both in manufacturing and the total economy. Despite the rapid growth in capital-labour ratios, the gap in capital intensity relative to the United States was still huge by 1996. For the total economy the capital-labour ratio was 32 per cent of the US level in Korea and 34 per cent in Taiwan in 1996. For manufacturing the relative capital intensity levels were somewhat higher but still left a gap of 50 per cent or more compared to the United States.[24] This indicates that relative labour intensive activities still dominate manufacturing production. This is even true at a more detailed of manufacturing industries. Timmer (2000) found large gaps in capital intensity between the East Asian countries and the USA in all 2-digit manufacturing industries, except textiles.

To analyze the issue of diminishing returns comprehensively, we need to look not only at the capital-labour ratios but also at the labour productivity ratios relative to the United States. Table 8 shows the level of value added per hour worked in South Korea, Taiwan and the United States for the total economy and manufacturing. It is clear that the rapid catch-up in capital intensity is reflected in labour productivity catch-up. Still productivity gaps of more than 50 per cent with the USA remain by 1996. A particular finding is that despite the higher level of capital intensity for the total economy, the labour productivity level for manufacturing is substantially lower than for the total economy. This again points at the different relative output price levels in manufacturing and non-manufacturing sectors when

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23 These estimates are obtained from Penn World Tables (version 5.6; described in Summers and Heston, 1991) and are consistent with Maddison's PPP estimates for total GDP. The division of the investment PPP by the US relative price level for investment to GDP is far from trivial. In international prices, investments in the US are 'cheap' relative to total GDP and hence the investment PPP is considerably lower than 1.

24 The levels of capital intensity in South Korean manufacturing differ substantially from those presented in Timmer (2000). This is due to the differences in the labour series used. Here we used employment series from the national accounts which are about 50 per cent higher than those found in the manufacturing censuses which were used by Timmer. Further investigation into these differences is warranted.

using international prices. In domestic prices manufacturing tends to create more output per working hour with more capital per working hour, but when expressed in international prices manufacturing productivity for Korea and Taiwan does not look as good as the productivity figures for the total economy.

Figures 2 and 3 show the relation between the non-residential productive capital stock per hour worked and GDP per hour worked in 1990 US dollars for the total economy and for manufacturing respectively. The figures clearly show the rapid catching-up of Korea and Taiwan with the USA but also indicate the remaining potential for further growth in these countries through narrowing of the two mentioned gaps: one through increasing capital intensity and another one through a rise in productivity. For the total economy the gap in capital intensity is especially large. In manufacturing the gap in labour productivity appears to be relatively large. With the same amount of capital per hour worked, the United States generated much more output in the 1960s than the two East Asian countries at the end of the 1990s.

The concave nature of the growth paths depicted in the figures is not surprising. It reflects the rise in the capital-output ratio which is a stylized fact of the capital-intensive nature of industrialization. This hints at diminishing returns as in the traditional growth model of Solow (1956), although the conclusion that continued growth in East Asia on the basis of expansion of inputs is ‘inevitably subject to diminishing returns’ (Krugman, 1994, p.63) seems too rash. There remains substantial scope for further investment in East Asia, but it must be accompanied with measures that help to realize the potential of productivity improvements through disembodied technical change.

Table 7: Productive Capital Stock per Hour Worked in Total Economy and Manufacturing, 1963-1996, South Korea, Taiwan and USA, in 1990 US$ and as % of USA

	South Korea		Taiwan		United States	
	Total Economy	Manufac-Turing	Total Economy	Manufac-turing	Total Economy	Manufac-Turing
	1990 US$		1990 US$		1990 US$	
1963	0.88	1.93	1.28	0.99	32.74	17.24
1973	2.17	2.52	2.81	3.38	40.11	23.53
1985	6.77	7.29	7.71	8.05	47.10	35.66
1996	16.37	23.62	17.31	21.32	51.21	46.84
	US = 100		US = 100		US = 100	
1963	2.7	11.2	3.9	5.7	100.0	100.0
1973	5.4	10.7	7.0	14.4	100.0	100.0
1985	14.4	20.4	16.4	22.6	100.0	100.0
1996	32.0	50.4	33.8	45.5	100.0	100.0

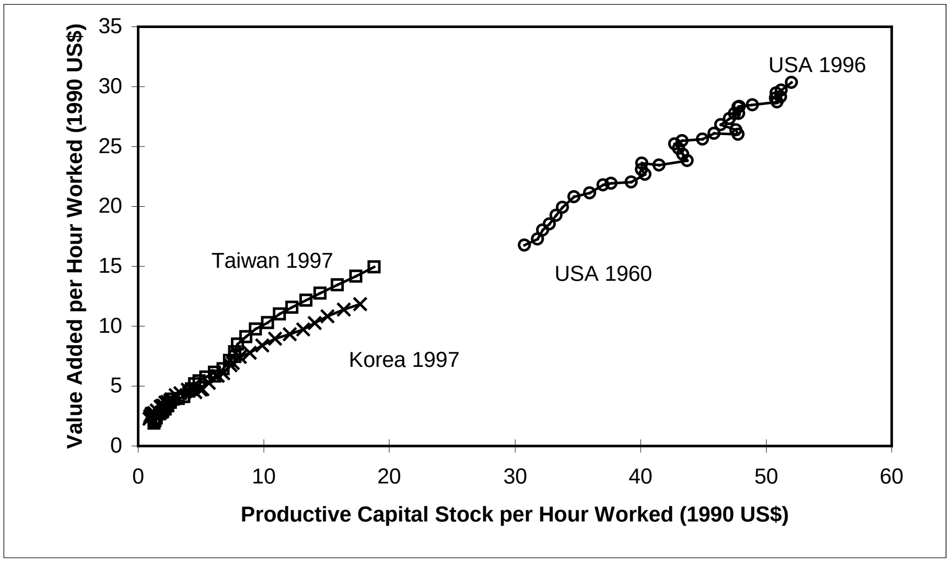
Source: Productive non-residential capital stock for Korea and Taiwan from Appendix Tables 1 to 3. US stock estimates based on similar methodology using investment series up to 1992 from Maddison (1995), updated to 1996 with estimates from *Survey of Current Business* (May and August, 1997). Employment for South Korea from EPB, *Annual Report on the Economically Active Population*; for Taiwan from DGBAS, *Statistical Yearbook of the Republic of China* and *Monthly Bulletin of Manpower Statistics*; for United States from BEA, *National Income and Product Accounts of the United States* (updated to 1996 with estimates from *Survey of Current Business*, various issues). Working hours for total economy from GGDC Total Economy Database and for manufacturing updated from Pilat (1994) for Korea and USA, and from DGBAS, *Monthly Bulletin of Earnings and Productivity* for Taiwan.

Table 8: Value Added (at factor cost) per Hour Worked in Total Economy and Manufacturing, 1963-1996, South Korea, Taiwan and USA, in 1990 US$ and as % of USA

	South Korea		Taiwan		United States	
	Total Economy	Manufac-Turing	Total Economy	Manufac-turing	Total Economy	Manufac-Turing
	1990 US$		1990 US$		1990 US$	
1963	2.28	0.83	1.90	1.23	18.52	14.19
1973	3.63	1.76	3.90	2.85	23.60	19.10
1985	6.07	3.56	7.45	5.00	27.33	24.19
1996	11.38	8.36	14.17	9.80	30.35	32.91
	US = 100		US = 100		US = 100	
1963	12.3	5.8	10.3	8.7	100.0	100.0
1973	15.4	9.2	16.5	14.9	100.0	100.0
1985	22.2	14.7	27.3	20.7	100.0	100.0
1996	37.5	25.4	46.7	29.8	100.0	100.0

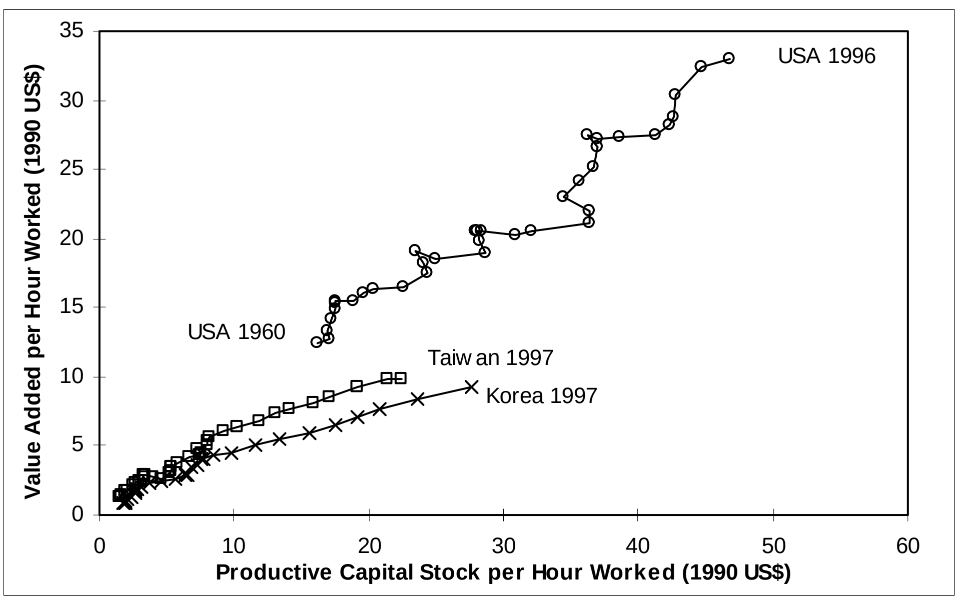
Source: GDP and value added from Bank of Korea, *National Income in Korea 1975*, and *National Accounts* (various issues) linked with OECD, *National Account Statistics, 1997*; Taiwan from DGBAS, *National Income in Taiwan Area of the Republic of China*, various issues*;* United States from BEA, *National Income and Product Accounts of the United States* (updated to 1996 with estimates from *Survey of Current Business*, various issues). Converted to 1990 US$ on the basis of 1990 Geary Khamis purchasing power parities from Maddison (1995) for total economy. For manufacturing on the basis of unit value ratios from Pilat (1994) for South Korea and from Timmer (2000) for Taiwan. Employment and hours as for Table 6.

Figure 2: Labour Productivity and Capital Intensity, Total Economy, 1990 US$



Sources: see Tables 6 and 7.

Figure 3: Labour Productivity and Capital Intensity, Manufacturing, 1990 US$



Sources: see Tables 6 and 7.

6. Conclusions

In this paper we present new evidence to address the question whether capital accumulation in South Korea and Taiwan was so rapid that the growth process turned typically extensive and opportunities for further growth became exhausted. To this end we present new estimates of the productive capital stock and put these in an international comparative perspective. We first reconstructed the fixed capital stock using the perpetual inventory method and long-term historical series of investment in non-residential buildings and machinery and equipment. Using standardised assumptions on asset lifetimes, we find high growth rates of the capital stock for the total economy and for manufacturing in both countries, peaking between the mid 1960s and the mid 1980s. It was shown that this finding is robust to changes in assumptions of asset lifetimes and age-efficiency profiles. The results are compared with alternative estimates based on wealth surveys. Although the general trends are the same, growth rates can differ considerably, especially for the earlier sub-periods. Presumably, this hints both at problems in comparability of wealth surveys over time and in the assumptions used in the PIM. We prefer to use our PIM estimates as they are based on a transparent and internationally comparable methodology.

Second, we looked at the impact of quality-adjusted capital input measures on total factor productivity growth. Because of the rapid increase in the share of equipment in the total stock during the early period of industrialisation, capital services show faster growth than the aggregate stock. Hence with capital input adjusted for quality change, total factor productivity growth was fairly low (or, in the case of Korea, even negative) up to the mid 1980s but since then showed some improvement.

Finally, to assess the potential for continued catch-up of the emerging economies with productivity levels of more advanced countries, we analyzed the change in comparative levels of capital intensity and labour productivity. We found that gaps in capital intensity between the USA and the East-Asian countries are still large, suggesting ample scope for further investment-driven growth, not only at the total economy level but also in manufacturing. There is also further catch-up potential through improvements in productivity levels which, although they grew rapidly in the previous decades, are still far lagging behind the US levels.

In contrast to the findings on growth rates, the large gap in capital intensity levels is sensitive to the choices made in measuring the capital stock. In particular it was shown that changes in the asset lifetime assumptions can have a significant impact on comparative capital stock levels. In this paper we used internationally standardized asset lives. To explain away the found gap in capital intensity, lifetimes in Korea and Taiwan would have to be much longer than in the US. If, on the other hand, service lives are shorter than in the US, which seems plausible given the exceptional rate of investment and high speed of structural change in these countries, our finding of a large potential for catch-up is reinforced. The study of international differences in asset lifetimes is clearly a crucial area for further research.

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Appendix Table 1 Nonresidential Gross Fixed Capital Formation and Nonresidential Gross Fixed Capital Stock in South Korea, Total Economy in billion 1990 Won

	Gross Fixed Capital Formation			Gross Fixed Capital Stock			Productive Fixed Capital Stock		
	Structures	Equipment	Total	Structures	Equipment	Total	Structures	Equipment	Total
1913	58	33	92						
1914	67	32	99						
1915	73	24	97						
1916	67	25	91						
1917	83	42	125						
1918	102	72	174						
1919	106	79	185						
1920	116	43	159						
1921	133	47	181						
1922	189	46	235						
1923	181	52	234						
1924	151	56	207						
1925	184	50	233						
1926	221	74	295						
1927	251	101	352						
1928	250	134	384						
1929	281	160	441						
1930	272	184	456						
1931	245	142	387						
1932	233	135	368						
1933	295	163	458						
1934	381	225	606						
1935	438	276	714						
1936	498	212	709						
1937	492	189	681						
1938	580	227	807						
1939	658	369	1,028						
1940	692	490	1,182						
1941	803	395	1,198						
1942	798	393	1,191						
1943	810	399	1,209						
1944	775	382	1,156						
1945	0	0	0						
1946	0	0	0						
1947	226	112	338						
1948	244	120	364						
1949	262	129	391						
1950	282	139	421						
1951	0	0	0						
1952	0	0	0						
1953	266	88	354	6,976	1,690	8,666	4,913	736	5,649
1954	280	125	405	7,207	1,539	8,746	5,071	756	5,827
1955	369	158	527	7,490	1,415	8,904	5,277	808	6,085
1956	317	218	535	7,788	1,366	9,154	5,497	901	6,398
1957	420	231	651	8,101	1,353	9,454	5,737	1,020	6,757
1958	432	212	644	8,465	1,341	9,805	6,030	1,121	7,150
1959	497	189	686	8,863	1,427	10,289	6,353	1,189	7,543
1960	415	217	632	9,244	1,629	10,873	6,661	1,252	7,913
1961	523	229	752	9,616	1,819	11,435	6,975	1,328	8,302
1962	706	303	1,009	10,119	2,016	12,135	7,426	1,437	8,864

1963	887	399	1,286	10,816	2,292	13,108	8,049	1,619	9,668
1964	861	306	1,167	11,590	2,564	14,154	8,736	1,780	10,516
1965	1,135	379	1,514	12,467	2,865	15,331	9,530	1,913	11,443
1966	1,400	802	2,203	13,593	3,455	17,048	10,576	2,278	12,854
1967	1,640	1,059	2,699	14,963	4,342	19,305	11,850	2,940	14,789
1968	2,303	1,384	3,687	16,775	5,457	22,232	13,545	3,815	17,360
1969	3,272	1,678	4,950	19,397	6,846	26,243	16,016	4,897	20,913
1970	3,309	1,604	4,913	22,533	8,299	30,832	18,933	5,961	24,894
1971	3,197	1,974	5,171	25,642	9,864	35,506	21,744	7,047	28,791
1972	3,304	2,199	5,503	28,734	11,729	40,463	24,487	8,303	32,790
1973	4,178	2,652	6,830	32,272	13,954	46,226	27,657	9,750	37,407
1974	3,968	3,181	7,149	36,100	16,667	52,767	31,084	11,517	42,602
1975	4,443	3,484	7,927	40,024	19,777	59,801	34,564	13,493	48,057
1976	5,307	4,717	10,024	44,602	23,611	68,213	38,633	16,003	54,636
1977	6,616	6,312	12,928	50,242	28,775	79,017	43,693	19,632	63,325
1978	7,789	9,387	17,176	57,073	36,273	93,346	49,876	25,168	75,044
1979	8,846	10,875	19,720	64,985	46,061	111,047	57,030	32,333	89,362
1980	8,725	8,859	17,584	73,322	55,338	128,660	64,484	38,389	102,873
1981	8,639	8,900	17,539	81,524	63,287	144,811	71,661	42,744	114,406
1982	9,977	8,937	18,914	90,349	70,984	161,333	79,297	46,625	125,922
1983	11,936	9,695	21,631	100,830	78,769	179,599	88,403	50,446	138,849
1984	13,497	11,312	24,808	113,314	87,631	200,945	99,057	55,004	154,061
1985	14,225	11,860	26,085	127,175	97,428	224,602	110,606	60,107	170,713
1986	13,934	14,677	28,611	141,187	108,609	249,796	122,105	66,291	188,396
1987	16,467	17,483	33,950	156,246	122,264	278,510	134,457	74,558	209,014
1988	18,301	19,766	38,067	173,479	137,971	311,450	148,703	84,395	233,098
1989	21,147	22,567	43,713	193,039	155,805	348,844	164,957	95,615	260,572
1990	25,028	26,845	51,873	216,042	176,410	392,452	184,196	109,052	293,247
1991	28,284	30,088	58,372	242,698	199,361	442,059	206,553	124,666	331,219
1992	29,102	29,767	58,868	271,257	221,439	492,696	230,427	139,900	370,327
1993	31,419	29,722	61,140	301,244	241,052	542,297	255,310	153,156	408,466
1994	33,650	36,726	70,376	333,454	264,409	597,863	281,887	168,329	450,217
1995	36,613	42,521	79,134	368,243	295,153	663,396	310,441	188,114	498,555
1996	39,920	46,094	86,013	406,140	330,541	736,682	341,464	210,251	551,714
1997	42,245	40,868	83,112	446,796	364,706	811,502	374,578	228,952	603,530

Sources and notes: Total gross capital formation (excluding residential and land improvement) for 1914-1940 Pyo (1996) and for 1953-1997 from Bank of Korea, *National Accounts* (various issues). Capital formation from 1940-1953 on the basis of output series assuming investment-output ratios at 0.10 for the period 1939-1944, at 0.00 for 1945 and 1946, at 0.05 for 1947-1950 and at 0.00 for 1951 and 1952. Output from Maddison (1995), *Monitoring the World Economy, 1820-1992* (OECD Development Centre). After linking, the whole investment series was expressed in 1990 Won. 1940-1953 figures were divided into series for nonresidential structures and machinery and equipment using an average of the pre- and post-war period share of 67 per cent for structures. Moreover we discounted all pre-1953 investment by 40 per cent for war damage (Maddison, 1998, Table 3.10, p. 66). For gross stock, investment was accumulated by using the standardized asset lives of 39 years for structures and 14 years for equipment from Maddison (1995). For productive stock a geometric efficiency pattern is assumed with similar lifetimes and a declining balance rate of 1.65 for equipment and 0.91 for structures. Stocks adjusted to mid-year.

Appendix Table 2 Nonresidential Gross Fixed Capital Formation and Nonresidential Gross and Productive Fixed Capital Stock in Taiwan, Total Economy, in million 1991 NT$

	Gross Fixed Capital Formation			Gross Fixed Capital Stock			Productive Fixed Capital Stock		
	Structures	Equipment	Total	Structures	Equipment	Total	Structures	Equipment	Total
1912	3,177	849	4,026						
1913	2,818	439	3,257						
1914	2,314	394	2,708						
1915	1,858	384	2,242						
1916	1,919	348	2,268						
1917	3,448	538	3,986						
1918	2,793	508	3,301						
1919	4,138	847	4,986						
1920	6,579	867	7,445						
1921	5,924	982	6,906						
1922	4,834	675	5,509						
1923	4,841	743	5,585						
1924	3,955	570	4,525						
1925	5,475	745	6,220						
1926	5,456	898	6,355						
1927	6,474	1,051	7,525						
1928	7,767	1,377	9,144						
1929	8,291	1,360	9,651						
1930	7,265	1,560	8,825						
1931	7,104	1,289	8,393						
1932	8,807	1,259	10,066						
1933	9,579	1,554	11,133						
1934	10,314	2,198	12,512						
1935	13,269	2,816	16,085						
1936	14,247	2,974	17,221						
1937	10,564	3,099	13,663						
1938	11,411	3,633	15,043						
1939	13,481	4,494	17,975						
1940	13,432	4,477	17,909						
1941	14,777	4,926	19,702						
1942	15,864	5,288	21,151						
1943	10,814	3,605	14,419						
1944	7,427	2,476	9,902						
1945	0	0	0						
1946	0	0	0						
1947	4,710	1,570	6,280						
1948	5,097	1,699	6,796						
1949	5,518	1,839	7,357						
1950	5,973	1,991	7,964						
1951	7,337	2,783	10,120	273,794	38,937	312,731	189,713	18,633	208,346
1952	8,779	4,160	12,938	278,854	39,043	317,897	193,344	19,908	213,252
1953	11,654	4,974	16,628	286,504	39,546	326,050	199,049	22,128	221,178
1954	12,086	4,848	16,934	296,288	39,972	336,260	206,275	24,431	230,706
1955	10,404	4,279	14,683	305,645	39,834	345,479	212,707	26,116	238,822
1956	11,018	5,921	16,939	313,672	39,828	353,499	218,454	28,138	246,592
1957	10,121	6,353	16,474	321,120	41,518	362,639	223,927	30,959	254,885
1958	12,392	7,723	20,115	328,911	45,516	374,428	229,958	34,348	264,306
1959	14,997	9,371	24,368	337,248	52,825	390,073	238,288	38,847	277,134

1960	18,769	10,428	29,196	347,880	62,724	410,604	249,611	44,168	293,778
1961	19,153	12,277	31,431	361,462	73,292	434,754	262,747	50,315	313,062
1962	22,297	11,301	33,598	377,350	83,447	460,797	277,342	56,174	333,516
1963	25,077	13,019	38,096	396,638	93,838	490,476	294,557	61,714	356,271
1964	28,455	15,011	43,466	418,690	105,937	524,627	314,450	68,455	382,905
1965	29,736	23,115	52,852	442,320	122,614	564,934	336,209	79,450	415,659
1966	34,764	31,097	65,861	468,606	146,248	614,854	360,615	97,192	457,807
1967	42,166	38,862	81,029	499,950	176,661	676,612	390,666	120,717	511,383
1968	50,172	46,661	96,833	538,091	214,512	752,603	427,719	149,251	576,971
1969	53,667	56,034	109,700	582,232	261,296	843,528	469,659	183,009	652,667
1970	54,302	73,919	128,221	629,032	321,172	950,204	512,684	226,416	739,101
1971	57,600	94,585	152,186	677,028	399,287	1,076,315	556,673	283,984	840,657
1972	70,091	113,064	183,155	731,680	496,074	1,227,755	607,529	354,339	961,869
1973	72,636	130,785	203,421	793,097	609,452	1,402,549	664,717	434,502	1,099,219
1974	82,001	153,130	235,131	858,624	741,510	1,600,134	726,526	525,250	1,251,776
1975	116,709	164,760	281,470	944,221	889,103	1,833,324	808,929	622,291	1,431,220
1976	128,531	162,158	290,689	1,054,436	1,040,773	2,095,208	912,674	712,409	1,625,083
1977	146,938	149,732	296,671	1,181,183	1,184,558	2,365,741	1,029,113	784,392	1,813,505
1978	160,022	173,566	333,588	1,322,217	1,332,192	2,654,409	1,158,581	853,594	2,012,175
1979	170,747	212,233	382,980	1,474,145	1,506,028	2,980,173	1,296,932	945,891	2,242,823
1980	184,580	261,437	446,017	1,637,705	1,715,757	3,353,462	1,444,334	1,071,246	2,515,580
1981	181,567	280,945	462,512	1,805,458	1,951,968	3,757,426	1,593,706	1,216,183	2,809,889
1982	184,863	279,846	464,709	1,975,334	2,189,602	4,164,936	1,739,734	1,353,243	3,092,977
1983	181,788	278,575	460,362	2,149,539	2,417,465	4,567,004	1,882,466	1,472,964	3,355,429
1984	194,208	279,031	473,238	2,333,823	2,631,291	4,965,114	2,026,539	1,578,167	3,604,706
1985	203,696	239,452	443,148	2,532,774	2,806,280	5,339,055	2,178,205	1,651,410	3,829,615
1986	210,091	268,717	478,808	2,737,313	2,956,540	5,693,853	2,334,274	1,710,864	4,045,138
1987	246,986	344,289	591,275	2,960,949	3,141,118	6,102,067	2,508,346	1,815,730	4,324,076
1988	277,737	402,569	680,306	3,218,003	3,372,590	6,590,593	2,712,179	1,975,162	4,687,342
1989	307,768	483,570	791,338	3,505,010	3,656,714	7,161,724	2,941,648	2,185,445	5,127,092
1990	351,629	524,174	875,803	3,828,053	3,997,128	7,825,180	3,202,708	2,431,747	5,634,454
1991	416,769	548,503	965,271	4,204,194	4,377,521	8,581,715	3,512,177	2,681,486	6,193,663
1992	459,567	653,339	1,112,905	4,632,145	4,816,792	9,448,938	3,868,394	2,966,375	6,834,768
1993	522,251	667,796	1,190,047	5,111,184	5,284,460	10,395,645	4,269,040	3,277,333	7,546,373
1994	593,028	714,258	1,307,287	5,657,579	5,738,653	11,396,232	4,727,069	3,582,103	8,309,172
1995	641,714	796,995	1,438,709	6,264,239	6,223,089	12,487,328	5,234,141	3,915,554	9,149,695
1996	645,289	857,285	1,502,574	6,897,171	6,769,833	13,667,004	5,755,513	4,281,218	10,036,731
1997	676,282	1,031,064	1,707,346	7,546,700	7,434,797	14,981,497	6,282,003	4,720,820	11,002,823
1998	721,803	1,152,470	1,874,273	8,232,047	8,247,762	16,479,809	6,834,465	5,256,205	12,090,671

Sources and notes: Total gross capital formation (excluding residential and land improvement) for 1912-1938 Mizoguchi (1997), and for 1951-1998 from DGBAS, *National Income in the Taiwan Area of the Republic of China* (1998). Capital formation from 1938-1951 on the basis of output series assuming investment-output ratios at 0.10 for the period 1939-1944, at 0.00 for 1945 and 1946 and 0.05 for 1947-1950. Output from Maddison (1995), *Monitoring the World Economy, 1820-1992* (OECD Development Centre). After linking, the whole investment series was expressed in 1991 Taiwanese dollars. Pre-1951 figures were divided into series for nonresidential structures and machinery and equipment using an average of the pre- and post-war period share of 75 per cent for structures. For Gross stock, investment was accumulated by using the standardized asset lives of 39 years for structures and 14 years for equipment from Maddison (1995). For productive stock a geometric efficiency pattern is assumed with similar lifetimes and a declining balance rate of 1.65 for equipment and 0.91 for structures. Stocks adjusted to mid-year.

Appendix Table 3 Nonresidential Gross Fixed Capital Formation (GFCF) and Nonresidential Gross and Productive Fixed Capital Stock (GFCS and PFCS) in South Korea and Taiwan, Manufacturing

	South Korea			Taiwan		
	GFCF in 1990 bln. Won	GFCS in 1990 bln. Won	PFCS in 1990 bln. Won	GFCF in 1991 mln. NT$	GFCS in 1991 mln. NT$	PFCS in 1990 mln. NT$
1935				3,200		
1936				3,426		
1937				2,717		
1938	185			2,992		
1939	236			3,575		
1940	271			3,562		
1941	275			3,918		
1942	273			4,207		
1943	277			2,868		
1944	265			1,969		
1945	0			0		
1946	0			0		
1947	78			1,249		
1948	83			1,352		
1949	90			1,463		
1950	97			1,584		
1951	0			2,104		
1952	0			2,209		
1953	81			3,760		
1954	81			4,083		
1955	144			2,434		
1956	182			3,699		
1957	197			4,079		
1958	186			4,667		
1959	154			4,762		
1960	165			6,537	71,547	51,318
1961	163			6,853	74,929	55,550
1962	219			6,677	78,623	59,649
1963	285	2,936	2,122	7,943	83,078	64,095
1964	281	3,093	2,303	12,498	90,015	71,239
1965	388	3,275	2,527	15,144	100,268	81,641
1966	661	3,635	2,930	19,069	113,634	94,829
1967	656	4,129	3,448	28,999	133,606	114,311
1968	881	4,733	4,051	34,082	161,609	140,364
1969	1,000	5,511	4,797	37,386	194,924	169,361
1970	826	6,344	5,480	48,624	236,945	204,237
1971	1,067	7,291	6,164	51,432	286,973	244,461
1972	825	8,214	6,814	64,697	344,413	290,792
1973	1,532	9,344	7,665	77,820	414,371	348,092
1974	1,721	10,918	8,923	97,851	500,799	419,219
1975	2,270	12,857	10,490	118,325	607,363	507,185
1976	3,071	15,499	12,657	111,002	720,183	597,503
1977	4,348	19,208	15,759	93,332	820,194	670,990
1978	5,865	24,274	20,109	87,114	907,432	729,006
1979	6,364	30,308	25,259	114,742	1,004,439	794,941

1980	4,547	35,651	29,502	143,947	1,130,525	886,129
1981	4,202	39,862	32,460	151,978	1,275,421	991,557
1982	4,360	43,954	35,183	128,669	1,411,855	1,084,286
1983	4,498	48,191	37,923	125,661	1,534,647	1,159,405
1984	6,106	53,323	41,405	159,823	1,672,675	1,246,496
1985	7,277	59,855	46,109	138,157	1,816,015	1,335,654
1986	9,033	67,847	52,051	187,484	1,972,141	1,434,363
1987	12,603	78,474	60,371	220,953	2,169,594	1,569,732
1988	14,357	91,702	70,953	243,525	2,394,523	1,726,624
1989	16,273	106,734	82,861	251,988	2,632,059	1,891,502
1990	18,920	123,996	96,480	252,347	2,870,406	2,052,878
1991	19,991	142,927	111,305	266,761	3,112,853	2,213,894
1992	17,673	161,101	124,794	294,380	3,369,390	2,388,197
1993	16,891	177,614	136,086	296,212	3,633,145	2,568,860
1994	22,117	196,178	149,058	367,318	3,929,176	2,777,319
1995	26,816	219,731	166,370	429,405	4,284,532	3,042,369
1996	30,511	247,448	187,047	485,281	4,691,847	3,353,678
1997	30,831	277,173	208,740	622,355	5,187,601	3,746,520
1998				686,798	5,770,918	4,221,263

Sources and notes: Total gross capital formation (excluding residential and land improvement) for 1953-1997 (Korea) from Bank of Korea, *National Accounts* (various issues) and for 1951-1998 (Taiwan) from DGBAS, *National Income in the Taiwan Area of the Republic of China* (various issues). Pre-1953/1951 estimates of capital formation were obtained using trend of total economy series (see Appendix Tables 1.1 and 1.2). After linking, the whole investment series was expressed in 1990 Won and 1991 Taiwanese dollars. Moreover for South Korea we discounted all pre-1951 investment by 40 per cent for war damage (Maddison, 1998, Table 3.10, p. 66). For Gross stock, investment was accumulated by using the standardized asset lives of 25 years for all nonresidential capital, based on Van Ark and Pilat (1993). For productive stock a geometric efficiency pattern is assumed with similar lifetimes and a declining balance rate of 1.2. Stocks adjusted to mid-year.