The Sun Also Rises:

Productivity Convergence between Japan and the USA

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Abstract: The growth process for a technological leader is different from that of a follower. While followers can grow through imitation and capital deepening, a leader must undertake original research. This suggests that as the gap between the leader and the follower narrows, the follower must undertake more formal R&D and possibly face a slower overall growth rate. This paper constructs measures of relative total factor productivity for eleven Japanese manufacturing industries and uses dynamic panel data methods to test whether a smaller productivity gap leads to slower growth, and whether R&D takes over as the engine of growth as Japan approaches the technological frontier. The results suggest that Japanese and US productivity have been growing at similar rates since the mid-1970s, and that some of the Japanese growth slowdown is attributable to the exhaustion of imitation possibilities.

Keywords: Economic Growth, Total Factor Productivity, Catch-Up, Innovation, Heterogeneous Dynamic Panels.

JEL Classifications: C13, C23, O30, O47.

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1. Introduction

In 1952, Japan had a per capita GNP of $188 in the prices of the day, below that of Brazil, Malaysia, and Chile. Like many present-day low income countries, Japan then had a high proportion of its labour force in agriculture; a relatively small capital stock; and a relatively low level of technology. However, it also possessed a highly educated and skilled workforce in manufacturing; large productivity differences between well-developed sectors and under-developed sectors; and significant strengths in management and organisation. By 1992, Japan had the fourth highest GNP per capita in the world, ranking only behind Luxembourg, Switzerland and the USA.[1]

Many estimates have been made of labour productivity levels in Japan, but less effort has been devoted to the estimation of relative levels of *Total Factor Productivity*.[2] This paper advances the literature in two ways. First, it provides detailed estimates of relative total factor productivity levels in eleven US and Japanese manufacturing industries between 1955 and 1989. Second, it estimates the effects of two separate influences on relative Japanese productivity performance - catch-up and domestic innovation. The paper argues that after Japanese industries exhausted catch-up gains from imitation, they had to increase their R&D efforts to maintain their growth rates.

For the panel data used in this paper, the simplest approach is to restrict the coefficients on R&D to be the same across industries using either the Dynamic Fixed Effects (DFE) estimator or the Mean Group (MG) estimator. Pesaran, Shin and Smith (1999) have recently proposed a Pooled Mean Group (PMG) estimator which allows short run coefficients and error variances to differ across groups in a panel, but constrains the long run coefficients to be identical. This paper estimates models based on all three of these estimators. A fourth approach is to allow the long-run coefficients to differ by allowing the speed of adjustment to differ across industries, in line with industry characteristics that are assumed to be at least weakly exogenous. For example, it might be that a sector that has a high capital to labour ratio or faces a good deal of foreign competition will have a higher catch-up rate than a typical sector. The rôle played by such industry characteristics could be thought of as causal - higher capital to labour ratios might lead to faster catch-up; or merely due to a correlation with unobservable factors - a high capital to labour ratio might be a feature of industries that catch-up quickly.[3] This approach therefore enables estimates to be made of the interactions between various industry characteristics and the effect of the productivity gap on TFP growth.[4]

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[1] Good introductions to the phenomenon of Japanese economic growth are provided by Denison and Chung (1976), Patrick and Rosovsky (1976) and Balassa and Noland (1988).

[2] Exceptions to this are provided by Denny et al. (1992), Dollar and Wolff (1994), and Kuroda (1996) who all construct relative measures of Japanese and US TFP. Their results are discussed in section 3.2.

[3] See Basu and Weil (1998) and Temple (1998) for broader discussion of appropriate technology issues.

[4] See Cameron, Proudman and Redding (1999) for a similar analysis of the UK and the USA.

This paper has five sections. The second discusses endogenous leapfrogging and presents a simple model of growth through catch-up and innovation. The third discusses the measurement of relative total factor productivity and presents estimates of relative productivity levels in the US and Japan. The fourth develops a dynamic panel data econometric model of relative productivity and presents estimates of the effect of catch-up and innovation. The fifth draws conclusions. A data appendix discusses data sources.

2. Leapfrogging in International Competition

2.1 Theories of Endogenous Leapfrogging

Why do technological leaders sometimes lose their advantage and consequently get overtaken? Many authors have suggested that leaders eventually stumble or that international knowledge spillovers are sufficiently large, so that their rivals are able to catch-up (see Barro and Sala-i-Martin, 1991, Benhabib and Spiegel, 1994, Sachs and Warner, 1995, and Bernard and Jones, 1996a). For example, Olson (1982 and 1996) suggests a complex sociological analysis whereby successful nations eventually accumulate so many institutional rigidities that other nations can catch-up and surpass them.

Some researchers have argued that leaders may become 'locked-in' to old-fashioned technologies.[5] Redding (1996) develops a model of competition, where there are both primary and secondary innovations, as a development of Aghion and Howitt (1992). Primary innovations can be adopted by any country and represent new best-practise technologies, while secondary innovations are country-specific (they may, for example, be related to physical investment). When a new primary innovation arises, its relative profitability at first will depend on how much secondary innovation has occurred in the previous best-practise technology in each country. The lead nation may have done so much secondary innovation that it is not profitable to adopt the new primary innovation immediately, whereas a nation without a presence in the industry may find it profitable to adopt and so reap rapid 'learning-by-doing' economies and overtake the leader. This argument can also be applied to a variety of two-sector models, whether the sectors are food and manufactures (as in Brezis et al., 1993) or labour-intensive and capital-intensive techniques (as in Broadberry, 1994).

Redding (1999) makes the distinction between *static* and *dynamic* comparative advantage. His model assumes that there are two countries, one of which is the technological leader (that is, has an absolute advantage) in both sectors of production, the high-technology sector and the low-technology sector. In order for the incomes of two countries to converge, the backward country must be incompletely specialised under free trade, while the leader specialises in high-technology goods. If the backward country has a dynamic comparative advantage (that is, has the potential eventually to acquire a static comparative advantage), then per capita income in the backward country will converge towards that of the leader. Clearly, even if the backward country has a dynamic comparative advantage in the high-technology

[5] See David (1985) and Nelson and Winter (1982) for discussion.

sector, it will not converge if, in free-trade equilibrium, it specialises in the low-technology good, since there are few opportunities for learning in this sector.

An alternative to the technological lock-in theories is provided by Barro and Sala-i-Martin (1997). In their model, firms can choose to grow through either imitation or research. In the long run, growth is driven by innovation in technological leaders, but followers converge towards the leaders because imitation is cheaper than innovation for some range of technology gaps. As the technology gap closes, the cost of imitation rises so that convergence in total factor productivity occurs.

2.2 A Simple Model of Catch-Up and Innovation

Quah (1996) also argues that there are two separate aspects of the growth process. The first is the mechanism by which agents in an economy push back technological and capacity constraints. The second is the way in which a poor economy can learn from an advanced economy. Both the *growth* process and the *convergence* process may occur at the same time, or separately, depending on the country in question, but they are distinct concepts. Benhabib and Spiegel (1994) present a model of endogenous growth where countries grow through research and imitation. Following Nelson and Phelps (1966), they argue that simply including an index of human capital in a growth regression is a mis-specification. They argue that human capital helps with the adoption and implementation of new technologies, rather than causing growth directly. Nelson and Phelps suggest that the growth of technology, or the Solow residual, depends on the gap between its level and the level of theoretical knowledge', T_t:

(1) $$\frac{\dot{A}_t}{A_t} = c(H_t)\left[\frac{T_t - A_t}{A_t}\right]$$

The rate at which the gap is narrowed depends upon the level of human capital, H, through the function, c(H), where $\delta c/\delta H>0$ and $T_t>A_t$. In Nelson and Phelp's model, the level of theoretical knowledge grows at a constant exponential rate, such that $T_t=T(0)e^{\lambda t}$. In the short run, the rate of growth of total factor productivity is a function of human capital and the productivity gap, but in the long run it grows at the rate λ.

Benhabib and Spiegel extend this analysis to allow both for a higher level of human capital leading to a higher level of technology in its own right, and also to allow for international knowledge spillovers. For a country *i*, they specify the growth rate of total factor productivity as:

(2) $$\frac{\dot{A}_{it}}{A_{it}} = g(H_i) + c(H_i)\left[\frac{\max_j A_{jt} - A_{it}}{A_{it}}\right], \qquad i=1,....,n,$$

where the endogenous growth rate $g(H_i)$ and the catch-up coefficient are non-decreasing functions of H_i. In their view, the level of education both increases the ability of a country to develop new technologies, and its ability to import and adapt technologies from abroad. Note that a leading country with the highest initial level of A, say $A_L(0)$, will be overtaken by a country that has a higher level of education. This follows because the lead country grows at the rate $g(H_L)$, or:

(3) $$A_{Lt} = A_L(0)e^{g(H_L)t}$$

while the growth rate of a laggard country with a higher level of human capital, say H_i, will be higher since it also benefits from catch-up. So:

(4) $$A_{it} = A_i(0)e^{g(H_i)t}$$

and since $g(H_i)>g(H_L)$, there exists some τ such that, for $t+\tau>t$, $A_{it}>A_{Lt}$. Even so, once country i is the leader, it can also be overtaken by another country with a lower initial level of technology, but a higher level of education. Asymptotically, A_i and A_L grow at the same rate $g(H_i)$. In the long-run the country with the highest level of H acts as the 'locomotive' of growth by expanding the production frontier, and all other countries are pulled along by the catch-up effect and grow at the same rate.

Consider a simple model where relative TFP in each Japanese industry i may grow either as a result of domestic innovation or as a result of catch-up with the level of TFP in its US counterpart.[6]

(5) $$\Delta \log A_{i,t} = \gamma_i - \phi_i \log(A_{i,t-1}/A^{us}_{i,t-1}) \quad \text{with } \phi_i > 0 \quad \text{when } A_{i,t-1} < A^{us}_{i,t-1}$$

$$\Delta \log A_{i,t} = \gamma_i \quad \text{with } \phi_i > 0 \quad \text{when } A_{i,t-1} > A^{us}_{i,t-1}$$

where $A_{i,t-1}/A^{us}_{i,t-1}$ is the ratio of TFP in Japanese industry i at time t relative to the US, γ_i parameterizes the rate of domestic innovation in the Japanese industry, and ϕ_i is the rate at which catch-up occurs.[7] Re-writing equation (5) in terms of the level of relative TFP yields the following first-order difference equation:

(6) $$\log(A_{i,t}/A^{us}_{i,t}) = (\gamma_i - \gamma_i^{us}) + (1-\phi_i)\log(A_{i,t-1}/A^{us}_{i,t-1})$$

where γ_i^{us} is the rate of growth of TFP in the US. From this, solving for the steady-state level of relative TFP in each industry:

(7) $$\log(A_{i,t}/A^{us}_{i,t})^* = (\gamma_i - \gamma_i^{us})/\phi_i$$

where, for an initially backward industry to remain so in steady-state, requires that $\gamma_i^{us} > \gamma_i$. In the long run, the model implies that TFP in an industry grows at the same steady-state rate in both countries. An important implication of the model is that, after controlling for determinants of steady-state TFP growth,

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[6] See Bernard and Jones, 1996b and 1996c, and Cameron, Proudman and Redding, 1999, for related models, and Quah, 1999, for discussion. See Currie, Levine, Pearlman and Chui (1999) for a North-South endogenous growth model of innovation and imitation.

[7] Note that this can also be thought of as an equilibrium-correction mechanism, since $\phi = 1 - \lambda$, where λ is the coefficient on the lagged dependent variable in a levels equation.

industries with low initial levels should experience the highest rates of growth of relative TFP. That is, the model implies that 'conditional β-convergence' of TFP levels should be observed across countries. The specification assumes that imitation is easier, the larger is the gap between foreign productivity and domestic productivity, $A^{us}_{i,t-1}/A_{i,t-1}$, and that as ϕ_i rises, the steady-state gap falls since a smaller gap is consistent with the same amount of catch-up growth. In the econometric specification discussed below in section 4, the industry-specific TFP growth rate is modelled as a function of R&D efforts and human capital in each industry as well as the productivity gap. A constraint is placed upon the value of the productivity gap: if $A_{Japan}>A_{US}$ then the gap is set to 0, otherwise it would imply that if domestic TFP were higher than foreign TFP, domestic TFP would regress back to the foreign TFP level.[8]

3. International Comparisons

3.1 The measurement of relative Total Factor Productivity

The simplest way to calculate a measure of productivity is to apply fixed weights to the appropriate inputs. When the factor shares are changing over time, however, an alternative approach to a fixed weight index is to use a Divisia index (see Diewert, 1976). Instead of comparing discrete situations, a Divisia index analyses the continuous effect of changes. This section discusses how to construct, and analyse, discrete-time approximations to Divisia indices for relative total factor productivity.

Assume that gross output, Y, is produced using *three* factors of production - capital, K; labour, L; and materials, M. The aggregate input, F, is the weighted sum of the capital, labour, and material inputs, using a discrete time Thörnqvist-Divisia index to aggregate the inputs. Consequently, the rate of growth, $\Delta \log F$, of the aggregate input F, may be written as:

(8) $$\Delta \log F_t = w_{Kt}.\Delta \log K_t + w_{Lt}.\Delta \log L_t + w_{Mt}.\Delta \log M_t$$

where t and t-1 are time periods, $w_{it}=(s_{it}+s_{it-1})/2$, and s_{it}=cost share of input i in year t, i=K,L,M. The growth rate of TFP, $\Delta \log A$, equals the rate of growth of aggregate output minus the rate of growth of the aggregate input. $\Delta \log A$ is therefore defined as:

(9) $$\Delta \log A_t = \Delta \log Y_t - \Delta \log F_t$$

The last term on the right-hand side of the equation equals the rate of growth of the aggregate input, $d\log F_t$. Equation (9) can be written more fully as:

(10) $$\Delta \log A_t = \Delta \log Y_t - w_{Kt}.\Delta \log K_t - w_{Lt}.\log L_t - w_{Mt}.\Delta \log M_t$$

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8 Formally, this assumption means that TFP in the US is regarded as exogenous with respect to that of Japan, so that there is no productivity boost to the US if Japan moves ahead. This is probably not an unrealistic assumption given that the data used here end in 1989. Moreover, even if the restriction is relaxed, the econometric results reported in section 4 are not significantly affected.

While it may be informative to compare, say, the rate of productivity growth in the Japanese chemicals industry with that of the US chemicals industry, it does not reveal anything about relative *levels* of productivity. In fact, given an appropriate set of exchange rates, it is possible to analyse changes in relative productivity levels using the Divisia methodology. Following Denny et al. (1992), and assuming perfect competition and constant returns to scale, define the relative productivity level in country A relative to country B as:

(11)
$$\log(A_A / A_B) = \log(Y_A / Y_B) - 0.5 \cdot (sk_A + sk_B) \cdot \log(K_A / K_B)$$
$$-0.5 \cdot (sl_A + sl_B) \cdot \log(L_A / L_B) - 0.5 \cdot (sm_A + sm_B) \cdot \log(M_A / M_B)$$

The first term on the right-hand side of the equation is the log difference in the output levels of the two countries. The other three terms adjust the relative output levels for differences in relative input levels. Simply put, if country A produces twice as much output from twice as many inputs as country B, relative efficiency is one (i.e. A_A/A_B=1). If country A produces twice as much output with only the same level of inputs, relative efficiency is two.[9]

In order to estimate relative output and input levels it is necessary to convert the series into a common currency. This task is far from easy. This paper uses the industry-specific Purchasing Power Parities (PPPs) calculated by Kuroda (1996). A number of earlier studies, such as Dollar and Wolff (1994) have used a PPP deflator based on spending in the whole economy, which does not allow for differences in prices between outputs and inputs. The use of an aggregate deflator is a particular problem for estimates of relative Japanese TFP in the 1960s and 1970s, when the relative price of labour in Japan was about one-fifth of that in the USA. Use of the GDP-based PPP therefore understates the number of workers in Japanese manufacturing in that period, and hence over-estimates their relative productivity.

3.2 Relative TFP in the USA and Japan

The Japanese data cover the period 1955-89. Data on output and input (capital, labour hours, and material) quantities and price indices for eleven Japanese manufacturing industries were supplied by Ichiro Tokutsu.[10] These eleven industries cover all of Japanese manufacturing except petroleum and coal products[11], and miscellaneous manufacturing.[12] From these data I constructed estimates of total factor productivity for all years 1955 to 1989, and was able almost exactly to replicate the growth rates reported in Denny et al. (1992) and obtain broadly similar estimates to those of Kuroda (1996). I also constructed an index of total factor productivity in total manufacturing (excluding petroleum and coal products and

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9 See Jorgenson and Nishimizu (1978) and Denny and Fuss (1983a and 1983b) for further discussion of relative productivity measures.

10 See the data appendix and also Tokutsu (1994) for further details of this dataset.

11 Data on petroleum and coal products were available, but it was decided to exclude this sector because of the unreliability of its deflators in the 1970s.

12 In this dataset, miscellaneous manufacturing comprises the following industries - clothing (21), lumber (22), furniture (23), printing (25), rubber (28), leather (29), ordnance (38) and other manufacturing (39).

miscellaneous manufacturing) by taking the weighted average of the sectoral TFP levels using input share weights.[13] Data for 19 US two-digit industries and for manufacturing as a whole were supplied by the US Bureau of Labour Statistics. The data comprised estimates of nominal values of output, labour input, capital services, energy inputs, materials inputs, and purchased services, for the industries between 1949 and 1991.[14] In addition there were complementary data on price indices, indices of real output and inputs, and indices of total factor productivity.

Table 1 shows levels of Japanese Total Factor Productivity relative to the US (with the USA=100), for the eleven industries that are comparable and for manufacturing as a whole. The data show that in 1955, total factor productivity in total Japanese manufacturing was around fifty percent of that in the US, and that by 1980, most of that gap had been eliminated.[15] This suggests a fairly high rate of unconditional 'catch-up'. Figure 1 shows the relative productivity level of total manufacturing over the entire period, and suggests that from around 1980 onward, Japanese productivity has been growing at broadly the same rate as that of the US.[16]

Table 1
Relative TFP Level of Japanese Industry (US=100)

	1955	**1973**	**1980**	**1989**
Total	**52.9**	**79.8**	**90.0**	**91.3**
Chemicals	81.4	90.0	108.0	122.6
Primary Metals	57.2	99.1	124.0	122.0
Electricals	56.4	93.7	117.9	119.9
Paper	63.8	95.9	102.2	112.4
Machinery	19.4	82.4	101.0	90.7
Metal Products	42.0	75.8	72.5	78.9
Minerals	38.6	81.5	78.5	85.3
Transport	42.3	79.1	89.4	83.0
Food	77.9	83.4	82.7	73.9
Textiles	55.0	71.6	79.0	68.9
Instruments	42.4	74.8	75.6	66.2

13 Under Cobb-Douglas assumptions, the theoretically correct way to calculate the aggregate figure from the industry data is to weight each industry's relative TFP level by its share of inputs (weighted by their exponents in the production function), see Bernard and Jones (1996b). However, since the two-digit data on intermediate inputs and gross output are on a net sector basis (i.e. include inputs from, and outputs to, other manufacturing sectors), they cannot be aggregated to the total manufacturing level without an unknown amount of double-counting. Therefore, the aggregate figure in Table 1 is calculated by using value added weights, which leads to a slightly lower figure than by using a simple average or using weights based on gross output shares (because the high TFP industries have a lower share of weighted inputs than they do of output, by definition). The time profile in each case is very similar, with a mean difference between the value added input weighted aggregate and the gross output weighted aggregate of 0.075 with a standard deviation of 0.015, and a similar difference from the simple average figure. Note that none of the regression results in the paper are affected by this, since they are only based on the industry level data.

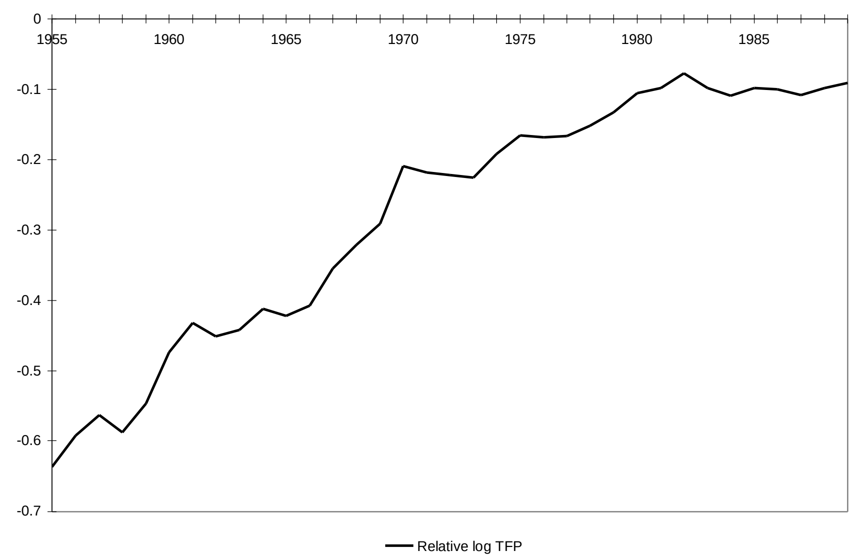
14 Note that the US data breaks the intermediate input category down into three components - energy, materials, and purchased services. The sum of these components is equivalent to the material category of Japanese inputs.

15 Note the estimates in table 1 are equivalent to A_A/A_B in equation 11, while figure 1 presents $log(A_A/A_B)$.

16 Note that to the extent that the two countries' business cycles are not synchronized, relative TFP may change due to changes in relative capacity utilisation.

As mentioned earlier, Dollar & Wolff (1994) and Kuroda (1996) also calculate estimates of Japanese manufacturing TFP relative to the US. Kuroda's estimates are constructed on a similar basis to those in this paper, but extend only to 1985. Dollar & Wolff's estimates use a value-added production function with labour and capital as the only inputs, and use a final expenditure PPP to convert Japanese prices into US prices, rather than the industry and factor specific PPPs used by Kuroda and in this paper (the PPP estimates used in this paper are taken from Kuroda; however, output and input data are taken from Tokutsu, 1994). Pilat (1996) constructs estimates of relative manufacturing TFP for the OECD economies in 1987 using a value-added production function, the final expenditure PPP, and constant factor shares.

Figure 1 Log Relative TFP Level (Japan - US)



How do these other estimates of relative Japanese TFP compare with those in table 1? Let us consider 1970, a year for which all three estimates are available.[17] In 1970, Kuroda estimates a relative Japanese TFP level of 0.81, compared with a Dollar & Wolff estimate of 0.92 and this paper's estimate of 0.81. By the end of the 1970s the estimates had diverged further, with a Kuroda estimate of 0.85 for 1980, compared with this paper's estimate of 0.90 and a Dollar and Wolff estimate for 1979 of 0.77. By 1985, Kuroda estimates a relative TFP level of 0.84 while this paper estimates 0.91. The latest estimate in Dollar & Wolff is 0.88 for 1982. Pilat (1996) estimates a relative Japanese TFP level in manufacturing of 0.74, rather lower than this paper's 1987 estimate of 0.90. In general, the estimates in this paper are slightly higher than those of Kuroda and Dollar & Wolff. However, the latter are likely to be biased because they use a single deflator and also appear excessively cyclical - in 1970 Dollar & Wolff estimates a relative TFP level of 0.92, compared with 0.77 in 1979 and 0.88 in 1982. It seems unlikely both that there

[17] Kuroda (1996) does not provide an aggregate manufacturing estimate, so the figures in this paragraph have been constructed from his individual industry estimates using the same value added weights as were applied in Table 1.

was relative technological regress in Japan between 1970 and 1979, and also that there was such a sharp burst of catch-up between 1979 and 1982.[18]

Turning back to the Kuroda estimates, they are generally lower than those contained in this paper but both sets peak in around 1980 and both estimates suggest that Japanese TFP was stable relative to that of the US after 1980. In 1980, table 1 suggests that five Japanese industries had overtaken or had achieved parity with US TFP levels, namely the paper, chemicals, primary metals, machinery, and electricals industries. Kuroda also estimates that the Japanese chemicals and electricals industries had overtaken the US by 1980, and that paper, primary metals and machinery were almost at parity. Overall, the simple mean difference between Kuroda's industry-level estimates of 1980 relative TFP and those in table 1 is 0.036, with a standard deviation of 0.15.

The aggregate data shown in Figure 1 and Table 1 suggest that the Japanese productivity growth slowdown started in the 1980s rather than the 1970s. However, the aggregate data conceal some important industry trends. In terms of the catch-up process, it is possible to divide the Japanese industries into three groups. The leading industries, chemicals, primary metals, paper, and electrical machinery caught up with the US quickly and have tended to move ahead since the early 1980s. The middling industries, machinery, minerals, transport[19], and metal products, have not caught up to the same extent and have generally maintained their positions against the US since the early 1970s. The lagging industries, food, textiles, and instruments, also appear to have stopped converging by the early 1970s, but the productivity gap remains substantial. It appears that the leading industries continued to perform well enough relative to the US in the 1970s, and this disguised the slowdown in the middling and lagging sectors that appeared in the early 1970s.

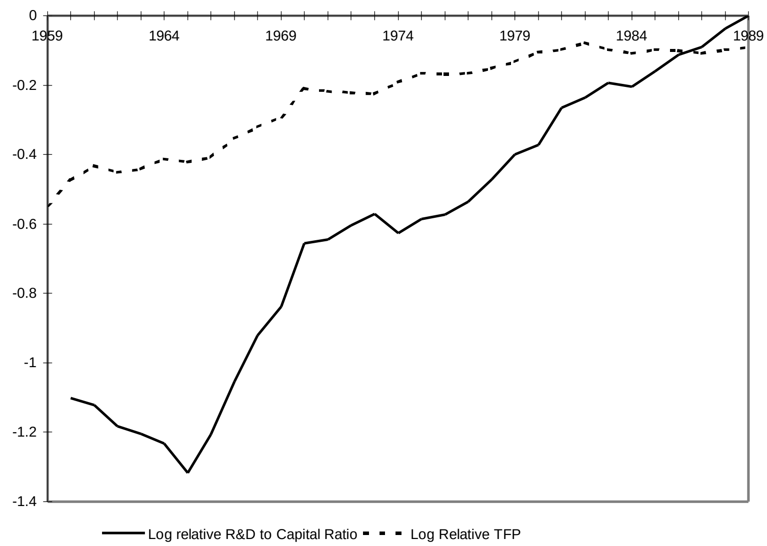
Finally for this section, figure 2 shows the log of US total factor productivity relative to Japan and the log of the Japanese R&D capital to physical capital ratio relative to the US. Between 1960 and 1969, Japanese R&D efforts increased relative to those of the US by around 50 per cent. Between 1969 and 1975, Japanese R&D efforts stagnated relative to those of the US. Between 1975 and 1989, they improved by around 60 per cent, such that by 1989, the countries had roughly similar R&D capital to physical capital ratios. Over the entire period, Japanese total factor productivity catches up considerably on the US as well, but as in figure 1, the majority of this catch-up is completed by the mid 1970s. Despite the relative lack of Japanese progress on total factor productivity levels since the mid 1970s, their R&D capital to

18 Estimates taken from a value-added production function are typically more volatile than from a gross-output production function.

19 The gap in transport equipment may appear surprising, but this may reflect some cyclical mis-measurement, and also the different output compositions of the industries in the two countries. The transport sector includes automobiles, ships, railway engines and carriages, aerospace, motorcycles, and buses. While the US has a large aerospace sector, Japan has had little aerospace manufacturing until recently. See Fuss and Waverman (1990, p. 85), and Denny et al. (1992) for discussion on this point.

physical capital ratio has continued to rise faster than that of the US, suggesting that higher levels of R&D effort were necessary after the virtual elimination of the productivity gap in the mid 1970s.

Figure 2 Log Relative TFP and Log Relative R&D to Capital Ratio
Japan relative to the USA 1959 to 1989



4. Econometric Method and Results

4.1 Method

The model of growth through imitation and research presented in section 2 readily lends itself to econometric estimation as a dynamic panel data regression such as:

$$\textbf{(12)}\ \Delta \log A_{i,t} = -f \log(A_{i,t-1} / A^{us}_{i,t-1}) + \mathbf{Z}_i y \ \log(A_{i,t-1} / A^{us}_{i,t-1}) + \mathbf{?}_i b + \sum_{j=1}^{p-1} l_j \Delta \log A_{i,t-j} + \sum_{j=0}^{q-1} \Delta \mathbf{?}_{i,t-j} d_{i,j} + m_i + e_{i,t}$$

where A_i is an index constructed from equation (10) and $\log(A_{i,t-1} / A^{us}_{i,t-1})$ is the log level of Japanese TFP in industry i minus the log level of US TFP industry i and is set to zero if the Japanese level is above that of the USA. $\mathbf{?}_i$ is a matrix of regressors that vary both across industries and time periods, including R_i/K_i, the ratio of the R&D capital stock to the physical capital stock, and H_i/L_i, the ratio of non-production to total workers. $\mathbf{Z}_i$ is a matrix of industry interaction terms explained in the next sub-section (the capital to labour ratio; the energy to capital ratio; the ratio of non-production to total workers; the ratio of R&D capital to physical capital; exports divided by output; and imports divided by home sales). These are interacted with the productivity gap, $\log(A_{i,t-1} / A^{us}_{i,t-1})$, in order to allow the effect of the productivity gap to vary across industries. In practice, the contemporaneous values of $\mathbf{?}_i$ and $\mathbf{Z}_i$ are omitted to rule out any contemporaneous correlation with the error term, and use their first lags instead.

The regressions that follow deal with a panel of eleven industries observed over 27 years (1963 to 1989). The nature of this panel is rather unusual, since most panels encountered in econometrics consist of either many units and few observations, or many observations and few units. Pesaran, Shin and Smith (1999) have recently discussed estimation with panels where T and N are quite large. The usual approach is to either estimate N separate regressions and to calculate the coefficient means, the Mean Group (MG) estimator, or to pool the data and restrict the slope coefficients and error variances to be the same, the Fixed Effects (FE) estimator. Instead, Pesaran et al. propose an intermediate method, called the Pooled Mean Group (PMG) estimator, which constrains the long run coefficients to be identical (since they are defined as $q_i = b_i / f_i$ where $q_i = q$), but allows the short run coefficients and error variances to differ across groups.

This paper is interested in the long-run heterogeneity of productivity gap, so it also adopts a dynamic panel framework that allows each industry to be treated as separately as possible while imposing restrictions across the panel (see Phillips and Moon, 1999, for a discussion of non-stationary panel data issues). In particular, a common-coefficient is imposed on the main variable of interest, the productivity gap. This restriction is then relaxed by the interaction of the gap variable with various industry characteristics. These characteristics can be seen as shifting the productivity gap coefficient up or down. Since each industry has its own speed of adjustment, this also implies that the long run coefficients on the $?_i$ variables differ by industry, since the long-run coefficients on $?_i$ are now defined as $q_i = b / f_i$. As is well known, the use of a lagged dependent variable in a panel data model can be a problem because of its correlation with the fixed effects. As Nickell (1981) shows, the fixed effects estimator is biased of order *O(1/T)* and its consistency relies upon T being large. However, since the time period examined is fairly long (T=27), the bias is likely to be fairly small (see Pesaran and Zhao, 1997, for discussion). In any case, the majority of regressions reported later use instrumental variables (see Anderson and Hsiao, 1982).

4.2 Data Description

Table 2 reports the interaction terms used in the panel regressions. There are six industry characteristics, each measured relative to the manufacturing average. Therefore a value of 0 for the log *K/L* ratio term means that the industry has the same capital to labour ratio as manufacturing as a whole. The interaction terms are the physical capital to labour ratio; the energy input to physical capital ratio; the ratio of non-production workers to total workers; the ratio of R&D capital to physical capital; the export to output ratio; and the import to output ratio. The aim of the interaction terms is to allow for industry heterogeneity in productivity responses and long-run coefficients in a parsimonious manner. They can be interpreted as follows: if the response to the productivity gap was estimated as 0.04 and the coefficient on the capital to labour ratio interacted with the gap was 0.05, then an industry with a capital to labour ratio ten per cent higher than manufacturing would have an effective productivity gap coefficient of 0.045 (i.e. 0.04 + 0.1*0.05).

Table 2
Interaction Terms

1.	$\log(\frac{K_i}{L_i}) - \log(\frac{K}{L})$	Physical Capital/ Labour
2.	$\log(\frac{E_i}{K_i}) - \log(\frac{E}{K})$	Energy/ Physical Capital
3.	$\log(\frac{H_i}{L_i}) - \log(\frac{H}{L})$	Non-Production workers/Total workers
4.	$\log(\frac{R_i}{K_i}) - \log(\frac{R}{K})$	R&D Capital/Physical Capital
5.	$\log(\frac{X_i}{Q_i}) - \log(\frac{X}{Q})$	Exports/Output
6.	$\log(\frac{M_i}{Q_i + M_i - X_i}) - \log(\frac{M}{Q + M - X})$	Imports/Home Sales

Note: *For an industry with the same value of the characteristic as total manufacturing, the value of the log interaction term will be zero.*

Table 3 reports the relative values of the industry characteristics for the eleven industries for the year 1985. The first column also reports the actual values of $(A_{i,t-1} / A^{us}_{i,t-1})$ in 1985 (TFP in Japan relative to the US) for the industries concerned and is comparable with the data in table 1. For the capital to labour ratio, paper & pulp, chemicals, and primary metals stand out as especially capital intensive. These industries, along with minerals, are also the most energy intensive. There is surprisingly little variation in the ratio of non-production to production workers, with chemicals, machinery, electricals and instruments having the highest ratio. As for the ratio of R&D capital to physical capital, the most intensive industries are chemicals, electricals, transport, and instruments. Cameron, Proudman and Redding (1999) show that for the UK, export to output and import to output ratios are highly correlated across industries. This is not the case for Japan. The pattern of relative export to output ratios finds that electricals, transport, and instruments have high ratios, while food exports are very low. In contrast, food, textiles, and chemicals, as well as instruments have high import to output ratios. Electricals and transport have low relative import to output ratios.

Table 3
Relative Industry Characteristics for Japanese Manufacturing in 1985

	A/A^{us}	K/L	E/K	H/L	R/K	X/Q	M/HS
Total	0.98	1.00	1.00	1.00	1.00	1.00	1.00
Food	0.74	0.63	0.69	1.00	0.53	0.06	1.20
Textiles	0.71	0.54	0.68	0.70	0.53	0.96	3.25
Paper&Pulp	1.04	1.31	1.61	0.86	0.44	0.22	0.87
Chemicals	1.13	4.35	3.73	1.79	2.18	0.91	3.38
Minerals	0.85	0.98	1.37	0.85	0.58	0.37	0.27
Metals	1.14	4.06	2.17	0.83	0.58	0.59	0.71
Metal Prod.	0.79	0.66	0.64	0.85	0.49	0.64	0.31
Machinery	0.98	0.63	0.78	1.17	0.93	0.87	0.35
Electricals	1.22	0.57	0.85	1.18	8.50	1.64	0.55
Transport	0.86	0.84	0.58	0.98	1.59	2.14	0.42
Instruments	0.75	0.66	0.49	1.12	1.77	1.82	1.40

Notes:		*Actual data for manufacturing in 1985*
K/L	*Capital to Labour Ratio*	*17.92*
E/K	*Energy to Capital Ratio*	*0.06*
H/L	*Non-production to total workers*	*0.36*
R/K	*Ratio of R&D Capital to Physical Capital*	*0.24*
X/Q	*Ratio of Exports to Output*	*0.17*
M/HS	*Ratio of Imports to Home Sales*	*0.06*

The low correlation between Japanese export intensive and import intensive industries deserves further examination. Table 4 reports simple correlations between the industry characteristics. The table confirms the low correlation between exports and imports. Furthermore it suggests that import ratios are not especially correlated with any of the other characteristics except for the ratio of non-production to production workers. Of the other correlations, the capital to labour ratio is highly correlated with the energy to capital ratio as noted above in the discussion of table 3. High capital to labour ratios are exhibited by the traditional heavy industries, such as chemicals and primary metals.

Table 4
Correlation Matrix for industry characteristics

	K/L	**E/K**	**H/L**	**R/K**	**X/Q**	**M/HS**
K/L	1.00					
E/K	0.84	1.00				
H/L	0.24	0.13	1.00			
R/K	-0.13	-0.17	0.61	1.00		
X/Q	-0.21	-0.37	0.09	0.50	1.00	
M/HS	0.33	0.12	0.63	0.30	0.36	1.00

4.3 Dynamic Panel Data Results

First, Table 5 estimates simple TFP convergence regressions. The dependent variable is the change in log Total Factor Productivity, regressed against the first lag of Japanese TFP relative to the USA, $\log(A_{i,t-1} / A_{i,t-1}^{us})$. Regression 1 shows a significant and negative productivity gap term as predicted by the theory, estimated using Ordinary Least Squares without fixed effects. The speed of adjustment is fairly low at 3.6 per cent. Adding fixed effects in regression 2 raises the catch-up effect to just over 6.3 per cent. Regression 3 weights the observations by the real gross output levels of the industries and gives a catch-up effect of about 6.7 per cent. Regression 4 adds year dummies and the catch-up effect falls to about 4.1 per cent. Finally, regression 5 instruments the first lag of the productivity gap with its second lag in order to allow for potential endogeneity and estimates a catch-up effect of about 5.3 per cent. Recall from equation (7) that such a catch-up rate implies that, for every 1 percentage point that the Japanese rate of domestic innovation is slower than the US rate, the steady-state productivity gap will be about nineteen per cent (since $\log(A_{i,t} / A_{i,t}^{us})^{*} = (g_i^{US} - g_i) / f_i$). Note that a Hausman test of regression 5 versus regression 4 has a value of 3.82, which is close to a rejection at the five per cent level of the exogeneity of the first lag of the productivity gap. Consequently, the next table uses the second lag as an instrument for the first lag in all but the first column.[20]

[20] All regressions in this paper used TSP version 4.3a (Hall, 1995), including the Pooled Mean Group estimations, which were based on the GAUSS code discussed in Pesaran, Shin and Smith (1999).

Table 5

Impact of the Productivity Gap on Japanese TFP growth

Dlog(TFP)i,t	1	2	3	4	5
Obs	297	297	297	297	297
$\log(A_{i,t-1} / A^{us}_{i,t-1})$	0.036 *(0.010)*	0.064 *(0.015)*	0.067 *(0.015)*	0.041 *(0.026)*	0.053 *(0.025)*
Fixed Effects	no	yes	Yes	yes	yes
Year Dummies	no	no	No	yes	yes
Weighted	no	no	Yes	no	no
IV	no	no	No	no	yes
Robust SEs	yes	yes	Yes	yes	yes
R^2	0.0414	0.1274	0.1225	0.2987	0.2981
s.e.	0.0301	0.0292	0.0293	0.0275	0.0275
LMbar	13.2	13.4	13.3	13.5	13.4
AR	3.09 [0.00]	0.90 [0.56]	0.93 [0.53]	0.84 [0.62]	0.75 [0.71]
HS	0.98 [0.47]	0.97 [0.48]	0.99 [0.46]	1.66 [0.07]	1.68 [0.06]
RESET	2.38 [0.00]	0.52 [0.91]	0.89 [0.56]	0.04 [0.99]	0.03 [0.99]

Notes:

Sample Period 1963 to 1989. Heteroscedasticity-consistent standard-errors in parentheses. Dependent Variable is the change in log Total Factor Productivity. $\log(A_{i,t-1} / A^{us}_{i,t-1})$ *is the productivity gap.*

LMbar	*Test for non-stationary residuals based on Im, Pesaran and Shin (1997).*
AR	*F-test for 1st and 2nd order serial correlation, Breusch-Pagan (1980).*
HS	*F-test for heteroscedasticity, White (1980).*
RESET	*F-version of the RESET test for j powers, Ramsey (1969).*

Table 6 examines the effect on the TFP growth rate of the productivity gap, R&D, and human capital (as measured by the ratio of non-production to total workers). One possibility is that the R&D capital to physical capital ratio and the human capital ratio should enter in first differences. Therefore an increase in the rate of growth of either R&D capital or human capital leads to a rise in the rate of growth of TFP. An alternative view might be that these variables should enter as levels effects, so that a rise in the level of R&D capital or human capital would lead to a rise in the rate of growth of measured TFP. Such a rise in the growth rate is in the spirit of the Benhabib & Spiegel (1994) view of human capital. In addition the productivity gap is also interacted with the various industry characteristics discussed in the previous section. Recall from the methodological discussion that this allows the speed of adjustment and long-run coefficients to differ across industries. In addition, the regressions in table 5 also include a number of cyclical terms based on capacity utilisation in aggregate Japanese manufacturing, as well as growth in world trade and US real government spending.

Regression 6 estimates a productivity gap effect of around 4.5 per cent, and an R&D elasticity (*log* R/K) of 0.034 both of which are significant, while the human capital effect is insignificant in both levels and differences. The pattern of the interaction terms is interesting. Recall that a positive coefficient on an interaction term implies that a higher value of the interaction raises the catch-up rate and that a negative coefficient implies that a higher value of the interaction lowers the catch-up rate. The capital to labour ratio, energy to capital ratio, the human capital ratio and the import ratio have negative but insignificant coefficients. The R&D capital to capital ratio and export to output ratio interactions have positive and significant, implying that industries with more R&D capital and higher export ratios catch-up faster to US levels of TFP.

Table 6

Impact of Productivity Gap and Interactions on Japanese TFP growth in Dynamic Fixed Effects Models

Dlog(TFP)i,t	6	7	8	9	10
Obs	297	297	297	297	297
$\log(A_{i,t-1} / A^{us}_{i,t-1})$	0.045	0.069	0.065	0.059	0.066
	(0.021)	*(0.023)*	*(0.034)*	*(0.016)*	*(0.019)*
$\Delta\log(R/K)_{i,t-1}$	-0.003	-0.004	-0.020		
	(0.052)	*(0.048)*	*(0.048)*		
$\log(R/K)_{i,t-1}$	0.034	0.034	0.034	0.037	0.039
	(0.17)	*(0.16)*	*(0.16)*	*(0.18)*	*(0.17)*
$\Delta\log(H/L)_{i,t-1}$	-0.074	-0.070	-0.116		
	(0.055)	*(0.052)*	*(0.062)*		
$\log(H/L)_{i,t-1}$	0.004	0.011	0.015		
	(0.048)	*(0.045)*	*(0.046)*		
Interactions:					
K/L	-0.015	-0.013	-0.011	-0.010	
	(0.022)	*(0.021)*	*(0.020)*	*(0.022)*	
E/K	-0.017	-0.019	-0.026	-0.013	
	(0.032)	*(0.029)*	*(0.027)*	*(0.030)*	
H/L	-0.115	-0.158	-0.171	-0.062	
	(0.147)	*(0.130)*	*(0.113)*	*(0.103)*	
R/K	0.022	0.016	0.015	0.026	0.033
	(0.011)	*(0.008)*	*(0.007)*	*(0.022)*	*(0.017)*
X/Q	0.048	0.042	0.046	0.067	0.072
	(0.023)	*(0.023)*	*(0.022)*	*(0.023)*	*(0.029)*
M/HS	-0.004	-0.008	-0.004	-0.017	
	(0.041)	*(0.038)*	*(0.039)*	*(0.037)*	
Fixed Effects	yes	yes	yes	yes	Yes
Capacity Utilisation	yes	yes	yes	yes	Yes
Year Dummies	no	no	no	no	no
Weighted	no	no	no	no	no
IV	no	yes	yes	yes	yes
Robust SEs	yes	yes	yes	yes	yes
$\mathbf{R^2}$	0.2553	0.2535	0.2625	0.2389	0.2325
s.e.	0.0280	0.0280	0.0279	0.0281	0.0280
LMbar	13.7	13.5	13.6	13.7	13.4
AR	1.11 [0.35]	0.99 [0.46]	0.91 [0.54]	0.89 [0.56]	0.88 [0.58]
HS	1.43 [0.15]	1.47 [0.13]	1.35 [0.18]	1.13 [0.33]	1.15 [0.31]
RESET	0.43 [0.95]	0.55 [0.89]	0.03 [1.00]	0.18 [0.99]	0.12 [0.99]

Key to Interaction Terms (interacted with $\log(A_{i,t-1} / A^{us}_{i,t-1})$ *, the productivity gap):*

K/L *Capital to labour ratio.*
E/K *Energy input to physical capital ratio.*
H/L *Ratio of non-production workers to total workers.*
R/K *Ratio of BERD capital to physical capital.*
X/Q *Exports divided by output.*
M/HS *Imports divided by home sales.*

Notes:

Sample Period 1963 to 1989. Heteroscedasticity-consistent standard-errors in parentheses. Dependent Variable is the change in log Total Factor Productivity. $\log(A_{i,t-1} / A^{us}_{i,t-1})$ *is the productivity gap. R/K is the ratio of the stock of R&D capital to the physical capital stock. H/L is the ratio of non-production workers to total workers. All equations include industry fixed effects.*

LMbar *Test for non-stationary residuals based on Im, Pesaran and Shin (1997).*
AR *F-test for 1st and 2nd order serial correlation, Breusch-Pagan (1980).*
HS *F-test for heteroscedasticity, White (1980).*
RESET *F-version of the RESET test for j powers, Ramsey (1969).*

Regression 7 instruments the first lag of the productivity gap with its second lag and estimates a catch-up effect of nearly seven per cent. Once again only the level of the R&D capital stock variable is significant, along with the interactions on the R&D capital stock and the export ratio. A Hausman test of regression 7 against regression 6 has a value of 4.54, which rejects exogeneity at the five per cent level. Of course, if the potential endogeneity of the first lag of the productivity gap is a problem when it enters of its own account, it may also be a problem for the interaction terms (which are set up as the first lag of the industry characteristic multiplied by the first lag of the productivity gap). Therefore, regressions 8-10 use interaction terms which are lagged twice. Reassuringly, the results in regression 8 are very similar to those in regression 7, the only potential worry being that the lagged change in the human capital variable is nearly significant.

Regressions 9 and 10 show the progressive deletion of, respectively, the insignificant levels and differences of human capital and R&D capital, and of the insignificant interaction terms. Taken together, the results in table 6 and in particular, regression 10, suggest that the productivity gap and the level of R&D capital relative to physical capital have a significant effect on TFP growth in Japanese manufacturing. Interestingly, human capital appears to have no significant effect, either as a levels effect or in differences (the ratio of non-production workers to total workers is a rather imprecise measure of human capital). Furthermore, the human capital interaction term is also negative and insignificant. The interaction terms suggest that industries with more R&D capital and higher export ratios tend to catch up faster.

Table 7 investigates a number of alternative panel estimators. The basic specification looks at just the effect of the productivity gap and the level of R&D capital on the rate of growth of Japanese TFP. Four estimators are reported. First, the standard Dynamic Fixed Effects (DFE) estimator. Second, the Seemingly Unrelated Regression (SUR) estimator which allows error variances to differ across industries and offers potential efficiency gains if disturbances are highly correlated across industries and/or the less correlation there is between the independent variables for each industry (see Zellner, 1962). Third, the Mean Group (MG) estimator, where each industry regression is run separately and then the coefficients are averaged to produce the estimator. Lastly, the Pooled Mean Group (PMG) estimator, proposed by Pesaran, Shin and Smith (1999), where short-run coefficients and error variances are allowed to differ across groups but the long-run coefficients are constrained to be identical. Regressions 11 and 12 present the results produced by the DFE and SUR estimators, with identical R&D capital effects and almost identical productivity gap effects. The MG estimator finds a rather faster rate of catch-up and a rather lower R&D capital effect, while the PMG estimator produces a catch-up rate of around 7.3 per cent and an R&D capital effect of around 0.021.

A few comments on the robustness of these results may be appropriate at this point. A number of checks were conducted. First, all regressions report heteroscedasticity-consistent standard-errors, and there is no evidence of problems with autocorrelation or heteroscedasticity except in the simple OLS estimate of regression 1. Using the LMbar test for unit roots proposed by Im, Pesaran and Shin (1997), the restriction that the residuals of all the regressions are I(0) cannot be rejected. Second, the results are not sensitive to the inclusion of particular industries. Any individual industry can be omitted from the panel without a significant effect, that is, no variable of interest changes by more than one standard error and usually by much less. This suggests that the results are not being driven by outliers in any particular industry.

Third, although the R&D capital variables are all deflated by the physical capital stock, this normalisation is not important. For example, in regression 10, the log of the R&D capital stock divided by the physical capital stock can be replaced by the log of the R&D capital stock and its coefficient falls only slightly to 0.028, although it is less precisely estimated. A fourth check on the robustness of the results was performed by the inclusion of interaction terms with the R&D capital variable as well as with the productivity gap. None of the former interactions has any significant effect. Fifth, although the estimates of the productivity gap use the industry-specific Purchasing Power Parities of Kuroda (1996), the results are not sensitive to the use of the Unit Value Ratios of van Ark (1996).

Sixth, it has often been argued that there was a major structural break in Japanese growth in 1973 (see Denny et al., 1992, for example). In order to test this hypothesis, regression 10 was modified to include break terms for 1973 for both the productivity gap and R&D capital. The change in both the productivity gap effect and in the R&D effect is negative but insignificant. The joint hypothesis of no structural break in these two variables cannot be rejected (F(2,274)=0.22 [P=0.80]). Seventh, it might be argued that the pattern of export openness is endogenous to the pattern of TFP levels in the industries. Consequently, Japanese export openness (Japanese trade with the rest of the world) was instrumented with OECD export openness (OECD exports to the OECD), which might reasonably be expected to be exogenous and reflect progress in world trade opening. There were no significant changes to a regression like regression 10. Lastly, the results do not change significantly if the restriction that there is no productivity bonus for the US if the Japanese TFP level is higher than the US level is relaxed.

Table 7

Alternative Panel Estimators of the Impact of the Productivity Gap on Japanese TFP growth

	DFE	SUR	MG	PMG
Dlog(TFP)i,t	11	12	13	14
Obs	297	297	297	297
$\log(A_{i,t-1} / A^{us}_{i,t-1})$	-0.044	-0.051	-0.108	-0.073
	(0.021)	*(0.015)*	*(0.030)*	*(0.032)*
$\log(R/K)_{i,t-1}$	0.026	0.027	0.017	0.021
	(0.14)	*(0.009)*	*(0.009)*	*(0.010)*
Fixed Effects	yes	yes	no	yes
Year Dummies	no	no	no	no
Weighted	no	no	no	no
IV	no	no	no	no
Robust SEs	yes	yes	yes	yes
R^2	0.2138	0.2187	0.2132	0.2103
s.e.	0.0283	0.0275	0.0276	0.0276
LMbar	13.6	13.6	13.5	13.5
AR	0.97 [0.48]	0.95 [0.50]	1.12 [0.34]	1.04 [0.41]
HS	1.13 [0.33]	1.04 [0.41]	1.09 [0.36]	1.11 [0.35]
RESET	0.12 [0.99]	0.14 [0.99]	0.28 [0.99]	0.35 [0.98]

Notes:

Sample Period 1963 to 1989. Heteroscedasticity-consistent standard-errors in parentheses. Dependent Variable is the change in log Total Factor Productivity. $\log(A_{i,t-1} / A^{us}_{i,t-1})$ *is the productivity gap. R/K is the ratio of the stock of R&D capital to the physical capital stock. d73 is a dummy variable taking the value zero before 1973 and 1 thereafter. DFE is the Dynamic Fixed Effects estimator, SUR is the Seemingly Unrelated Regression estimator, MG is the Mean Group estimator, PMG is the Pooled Mean Group Estimator.*

LMbar — *Test for non-stationary residuals based on Im, Pesaran and Shin (1997).*
AR — *F-test for 1st and 2nd order serial correlation, Breusch-Pagan (1980).*
HS — *F-test for heteroscedasticity, White (1980).*
RESET — *F-version of the RESET test for j powers, Ramsey (1969).*

5. Conclusion

This paper has argued that the process of economic growth is very different for a follower than it is for a leader. A follower is able to use technology transfer to import foreign technology, machinery, and work practices and consequently able to grow more rapidly than the leader. However, as the follower's productivity level approaches that of the leader, these imitative gains become more and more difficult. Eventually the follower has to undertake significant amounts of R&D in order to raise productivity levels.

This paper has applied these ideas to the post-war experience of Japan. In 1955, it estimates that total factor productivity in Japan was about fifty per cent of the US level, but that by 1980 it had reached around ninety per cent of that of the USA. As the technological gap narrowed, particularly after 1973, Japan began to devote substantial sums to R&D. While Japan may previously have undertaken research in order to adapt foreign technologies, much of this informal research would not be captured by the R&D data. It is only when formal R&D facilities begin to be developed that the R&D data begin to capture the full R&D effort of Japan, and this is the stage at which genuinely innovative research begins to occur.

The productivity performances of the two countries are similar in two ways. First, there was a dramatic productivity growth slowdown in the 1970s, followed by a speed-up in the 1980s. Second, there appear to be greater similarities between the performance of the same industries in the different countries than between different industries in the same countries - for example, electrical engineering and instruments have performed well in both countries, whereas minerals, primary metals, and food have performed less well. The countries differ in at least one important way. Japanese productivity growth in the 1980s does not appear to have returned to its 1955 to 1973 rate, but has settled at broadly the same rate as that of the US. This would be consistent with the argument that relative Japanese and US productivity *levels* are now broadly at their steady-state, and that Japan can no longer exploit rapid catch-up effects.

This paper has used four different panel data approaches, namely, dynamic fixed effects, mean groups, pooled mean groups, as well as interactions with the productivity gap. The econometric results presented in this paper suggest that the productivity gap with the USA had a significant effect on TFP growth in Japanese manufacturing. This effect has both a direct element and a indirect element mediated by the industry interaction effects. Regression 10 suggests that the direct effect has a coefficient of around 0.066 meaning that 6.6 per cent of any productivity gap disappears each year. The indirect effects mean that industries with higher ratios of R&D capital to physical capital and higher ratios of exports to output, catch up faster. Industries with higher ratios of non-production workers to total workers catch up more slowly.

These effects can be used to estimate implied catch-up effects that vary across the industries. These estimates suggest that the highest catch-up effects occur in electricals, textiles and instruments. In contrast, paper and food do not appear to significantly benefit from catch-up effects. Note that, from equation (7), this implies that electrical, textiles and instruments can be thought of as usually being close to their steady-states, while paper and food do not appear to have stable steady-states relative to the US (this is the result of $\phi=0$ in equation (7)).

The paper also examined the role played by the R&D capital and human capital. The results presented above suggested that the *level* of R&D capital (as opposed to the *change* in R&D capital) was a significant influence on the rate of domestic innovation in Japanese industries but that the measure of human capital had little effect on TFP growth in Japanese manufacturing over the period studied.

Appendix 1 Data Sources

Japan

Data on Japanese outputs and inputs were supplied by Ichiro Tokutsu (see Tokutsu, 1994). These consisted of data on gross output and labour, energy, material, and capital inputs, in current and constant prices for the years 1955 to 1989:

- Gross output at market prices and 1985 constant prices.
- Intermediate input at market prices and 1985 constant prices.
- Aggregated energy input at market prices and 1985 constant prices.
- Capital income at market prices and gross capital stock at 1985 constant prices.
- Compensation of employees and persons engaged.

The following data were supplied by the Japanese Ministry of Labour, the Economic Planning Agency and MITI:

- Percentage of workers who are operatives.
- Normal and overtime hours worked.

Purchasing Power Parities

Data on Japan-US Purchasing Power Parities in 1970 were supplied by Masahiro Kuroda (see Kuroda, 1996).

USA

Data on US output and inputs were supplied by the Bureau of Labour Statistics for the years 1948 to 1992.

- Gross output at market prices and 1980 constant prices.
- Intermediate input at market prices and 1980 constant prices.
- Aggregated energy input at market prices and 1980 constant prices.
- Capital services at market prices and gross capital stock at 1980 constant prices.
- Compensation of employees and labour hours.

Panel Data Unit Root Tests

Table A1 reports LMbar statistics for heterogeneous panel data unit root tests based on Im, Pesaran and Shin (1997). The hypothesis that they are I(0) can be rejected for all the levels variables, but cannot be rejected for their first differences (which, of course, includes the dependent variable, $\Delta\log(A)$). It is interesting that the productivity gap terms do not test as being I(0), given that one strand of the convergence literature regards this as a test of convergence (see Bernard and Jones, 1996b, for example, and Ben-David, Lumsdaine and Papell, 1999, for discussion).

Table A1

Dynamic Panel Data Unit Root Tests

	Levels	**Differences**
Log(A)	3.63	12.67
Log(R/K)	3.90	7.86
Log(H/L)	3.41	15.1
$\text{Log}(A_{i,t-1} / A^{us}_{i,t-1})$	4.37	12.75

Notes:

Critical value with time trend (approx.): 4.41. Critical value without time trend (approx.): 2.98 from Im, Pesaran and Shin (1997). Constant and Trend included in levels, and Constant only in Differences. Sample Period is 1960 to 1989. Log(A) is the level of Japanese log total factor productivity. Log(R/K) is the log ratio of R&D capital to physical capital. Log(H/L) is log ratio of non-production workers to total workers. $\text{Log}(A_{i,t-1}/A^{us}_{i,t-1})$ *is the log of Japanese total factor productivity relative to the US.*

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