Human Capital and Growth in Japan: Converging to the Steady State in a 1% World

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Abstract

Annual growth in GDP/adult in Japan has declined from over 10% in 1969 to an average of 1% since the financial crisis in 1991. I show that a dynamic Solow growth model, augmented with human capital, weekly labor-hours, and oil prices, explains Japan’s annual growth rates from 1969 to 2007 as conditional convergence to a steady-state rate of 1%/year. Each additional year of average adult schooling attainment raised GDP/adult directly and indirectly by 20 percent, and weekly hours worked had an output elasticity of 0.5. The marginal product of schooling was double the marginal product of physical capital.

JEL Codes: I25, O41, O53

Key Words: Japan; Human Capital; Schooling; Productivity; Economic Growth; Convergence

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I. Introduction

After World War II Japan entered a period of rapid economic growth that continued until it experienced a financial crisis in 1991. As shown in Figure 1, from 1960 to 1991 Japan’s average annual rate of growth of GDP/adult was five percent. Since that time it has grown at a much slower rate, averaging only one percent.¹

Figure 1

Annual Growth of GDP/Adult in Japan 1960-2010

Economists have proposed various hypotheses to explain the lower growth rates since 1991. All of these hypotheses are based on the premise that the lower growth rates are an aberration, which must be due to suboptimal policies of some kind. Hayashi and Prescott [2002] identify the cause as a slowdown in total factor productivity (TFP) growth. They estimate that

¹ The growth rates for 1960-2007 are calculated from data on real income per capita (rgdpch) and population (pop) in Penn World Table (PWT) 6.3 [Heston, Summers, and Aten, 2009] and data on the Japanese population age 15 to 64 [Statistics Bureau, 2011]. Data for 2008-2010 are estimated from other sources.
TFP grew 2.4% per year over 1983-1991, but only 0.2%/year over 1991-2000. They attribute part of decline in TFP to the decline in weekly hours worked that followed the government’s reduction of the hours in the standard workweek, but they are unable to identify the cause of the rest of the decline.

A number of economists have examined the hypothesis that TFP declined due to suboptimal policies in the financial sector. Caballero, Hoshi, and Kashyap [2009] hypothesize that Japanese banks supported unproductive “zombie” firms during the 1990s, instead of reallocating their funds to more productive firms. Their argument is that the banks renewed loans to unproductive firms, a process called “evergreening,” to avoid recognizing losses.

This hypothesis is popular, but Griffin and Odaki [2009] dispute its validity. They agree that Japanese banks supported unproductive firms during the 1990s, but they show that this was a continuation of earlier practices. They present evidence that the misallocation of resources within existing firms was worse during earlier periods. Fukuda and Nakamura [2011] also dispute the validity of the zombie hypothesis. They observe that most of the so-called “zombie” firms restructured and then recovered financially in the first half of the 2000s.

Regardless, it is not obvious that banks could have made loans to alternative, more productive firms. Fukao and Kwon [2006] find that the manufacturing firms that went out of business in the 1990s had higher TFP than those that continued to operate. They suggest that the high-TFP firms reduced their operations in Japan to relocate to more profitable locations.

Leigh [2010] examines whether the low growth in the 1990s was due to suboptimal monetary policy. He observes that the Bank of Japan pursued an expansive monetary policy in a sustained effort to stimulate the economy. He concludes that a more expansive policy could only have increased growth temporarily and that monetary policy was not the primary cause of the
low growth rates. Canova and Menz [2010] concur with Leigh. They argue that restrictive monetary policy was not the principal cause of the low growth, but that it depressed output more than necessary for a few years after 1997.

The perception that Japan’s growth rate has been abnormally low since 1991 is based on the presumption that countries should grow at rates above 1%/year. But Breton [2013a] presents evidence that the world steady-state growth rate over 1910-2000 was 1%/year. This finding indicates that growth rates above 1% are not sustainable indefinitely because they require continual increases in the share of GDP allocated to investment in either physical or human capital.

The implication of Breton’s finding and the trend in growth rates in Figure 1 is that over the 1960 to 2010 period, Japan may have been converging to the world steady-state rate of growth. If this is the case, then the convergence process was temporarily interrupted by the speculative real estate bubble that developed in the late 1980s, but then accelerated after the financial crisis in 1991.

In this paper I present a statistical test of the hypothesis that the decline in growth rates between 1969 and 2007 was due to changes in real factors of production and conditional convergence to a world steady-state rate of 1%/year. My neoclassical methodology is related conceptually to Hayashi and Prescott’s approach, but it differs in several important respects. Most importantly, I include the effects of human capital and oil prices in the analysis, which explain the decline in productivity that they observed. Secondly, I estimate the effect of changes in weekly labor-hours on output, rather than assume it had a proportional effect. Third, I assume that the steady-state annual growth rate applicable to Japan is one percent rather than two
percent. Fourth, I estimate the parameters of my model using the 1969-2007 period, while Hayashi and Prescott estimated the parameters of their model using the 1984-1989 period.

I perform my analysis using an annual version of a dynamic augmented Solow growth model. I show that this model explains Japan’s annual growth rates quite well, including the rates over 10%/year at the beginning of the period and the low rates averaging about 1%/year after 1991. The estimated coefficient on schooling in the model is consistent with estimates of the effect of schooling in recent cross-country studies. Average schooling attainment increased in Japan during 1969-2007, but at a declining rate. The model’s results indicate that this decline reduced Japan’s annual growth rate directly, and indirectly through its effect on the marginal product of physical capital, by 1.2% over this period. The remaining decline in growth rates is explained by the stabilization of the rate of investment in physical capital relative to a shrinking labor force, the decline in weekly labor-hours worked, rising oil prices, and the process of convergence to the world steady-state growth rate.

I also examine the policy implications of the results. The augmented Solow model’s estimate of the marginal product of schooling in Japan is about twice its estimate of the marginal product of physical capital. This ratio indicates that an optimal growth policy would divert national resources from investment in physical capital to investment in human capital.

The paper provides three contributions to the literature. First, it presents a version of a dynamic augmented Solow model that simulates annual growth using the investment rate for physical capital and the stock of human capital. Second, it explains Japan’s annual growth rates over a 38-year period. Third, it provides additional evidence that in a market economy an additional year of schooling in the adult population raises GDP/adult directly or indirectly by about 20 percent.
The paper is organized as follows. Section II reviews the literature related to the steady-state growth rate and the validity of the augmented Solow growth model. Section III provides the specification for the annual growth model used in the analysis. Section IV presents the empirical results. Section V discusses the policy implications. Section VI concludes.

II. The Steady-State Growth Rate

Hayashi and Prescott [2002] begin their analysis by de-trending Japan’s growth rate using a 2% annual rate, which they say was the per capita average for the leader country over the previous century. Using this 2% benchmark, they conclude that the 1990s was “a lost decade” for Japan.

But the average growth rate for the leader country (the U.S.) is not necessarily an appropriate benchmark for Japan, since the U.S. and Japan had very different investment patterns over the 1960-2010 period. Jones [2002] argues that the 2% annual growth rate in the U.S. (over the 1950-93 period) was a balanced rate that exceeded the steady state rate due to rising U.S. educational attainment. Hayashi and Prescott provide no evidence that 2%/year was the world’s steady-state growth rate over the period they examined.

Figure 2 shows the ratio of the investment rate $s_k$ (the share of GDP invested in physical capital) to the sum of the rate of labor growth ($n$), the steady-state rate ($g$), and the physical capital depreciation rate ($\delta_k$) for the U.S. and Japan.\footnote{Calculated from data in PWT 6.3} According to the Solow model, when this ratio is constant, an economy either grows at the steady-state rate or is converging to this rate. This ratio has been stable for Japan since the late 1960s, but it has been increasing for the U.S. since the mid-1970s. The implication is that during the 1980s and 1990s the U.S. growth rate was above the steady-state rate, while Japan’s growth rate was converging to the steady state.
Hayashi and Prescott [2002] evaluate Japan’s growth experience using a traditional neoclassical model, so the effect of rising schooling attainment is included in the residual TFP growth rate. If rising human capital is included as a factor of production, the residual rate of TFP growth and the associated steady-state growth rate are lower. Breton [2013a] shows that over the 1910-2000 period, if the effect of human capital is excluded, the residual steady-state growth rate in 29 countries, including Japan, was about 1%/year.

Figure 2

Solow Model Investment Ratios for Physical Capital in the U.S. and Japan

The steady state is a phenomenon that characterizes the growth process if total factor productivity rises at a constant rate and investment in capital has diminishing returns [Romer, 2012]. Endogenous growth models do not have a steady state rate, so an analysis of whether Japan may be converging to such a rate can only be performed within the context of a
neoclassical growth model, such as the Solow model, which predicts convergence to the steady state.

The basic Solow growth model includes only physical capital, but numerous recent studies provide considerable evidence that human capital also has a large effect on growth. Ding and Knight [2011], Hanushek and Woessmann [2012], and Gennaioli, La Porta, Lopez-de-Silanes, and Shleifer [2013] use unstructured income and growth models to show human capital’s effects. Cohen and Soto [2007], Ding and Knight [2009], and Breton [2011, 2013a, and 2013b] use a Solow model augmented with human capital to show its effect.

A Solow model augmented with human capital may or may not exhibit diminishing returns to investment and convergence to a steady state, depending on the model’s parameters. In Mankiw, Romer, and Weil’s (hereafter MRW) [1992] version of this model, the production function is:

1) \[ Y_t = K_t^\alpha H_t^\beta (A_t L_t)^{1-\alpha-\beta} \]

where \( Y \) is output, \( K \) is physical capital, \( H \) is human capital, \( L \) is labor, and \( A \) is labor-augmenting, total factor productivity (TFP). In this model if \( \alpha + \beta < 1 \), then a nation’s total investment in capital has diminishing returns. Romer [2012] summarizes the empirical evidence on the returns to investment, and he finds clear evidence that investment in physical capital exhibits diminishing returns. But the empirical evidence for the return on the sum of investment in physical capital and human capital \((\alpha + \beta)\) is not as clear.

Bernanke and Guykarnak [2001] provide evidence that \( \alpha \approx 0.35 \) across countries, but conclusive evidence that \( \beta < 0.65 \) has been lacking. Most national measures of human capital, such as average schooling attainment or average test scores, are non-linear proxies for human
capital, so when they are used to represent human capital in the augmented Solow model, it is not evident how their effect on income or growth is related to $\beta$ in this model.

Breton [2013b] presents explicit evidence that $\beta \approx 0.35$, which indicates that a nation’s total investment in capital (physical capital + human capital) has diminishing returns. He estimates the MRW model using data for the financial stock of human capital, calculated from prior investment in schooling. Since this estimate of human capital is based on the standard OECD [2001] methodology for estimating a capital stock, the estimate of the effect of this stock in the MRW model is $\beta$ by definition. While Breton’s estimates of human capital only include investment in schooling, for most countries this investment is the principal investment in human capital. Breton [2013b] provides additional empirical support for the validity of the MRW model by showing that its estimate of the effect of investment in schooling on workers’ incomes is consistent with independent estimates in 36 countries.

If world technological progress raises TFP uniformly across countries, according to the relationship $A_t = A_0e^{\alpha t}$, then the MRW model with $\alpha + \beta < 1$ has a steady-state growth rate:

$$g = \Delta \text{TFP/year}/(1-\alpha-\beta)$$

Breton [2013a] estimates the parameters of the MRW model from data for 42 market economies over the 1910-2000 period, using average schooling attainment as a proxy for human capital. By relating the effect of schooling attainment to the total effect of the stock of human capital and physical capital in 2000, he estimates that the residual average annual TFP growth was 0.3%/year and that the associated steady-state rate ($g$) was 1.0%/year.

II. Specification of a Japanese Growth Model

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3 Since this investment does not include expenditures on private tutoring, it underestimates investment in human capital in some countries, particularly in Asia [See Dang and Rogers, 2008].

4 Breton [2013b] shows that the MRW model has two external effects, one on the marginal product of physical capital and one on the marginal product of (unschooled) labor, so only part of the effect of human capital on national income accrues to workers.
MRW [1992] specify a dynamic version of the augmented Solow model in (1) that simulates an economy’s process of convergence to the steady state growth rate. They define output/effective worker \( y_t = \frac{Y_t}{A_tL_t} = y^* \) when output/worker \( (Y/L)_t \) rises at a constant rate \( g \). They model the change in log(\( y_t \)) in each period \( t \) as a process of partial adjustment between log(\( y_{t-1} \)) and log(\( y^* \)):

3) \[
\ln(y_t) - \ln(y_{t-1}) = \lambda \ln(y^*) - (1-\lambda) \ln(y_{t-1})
\]

They show that if output is determined as in (1), then:

4) \[
\ln(y^*) = \frac{\alpha}{1-\alpha} \left[ sk/(n+g+\delta_k) \right] + \beta/(1-\alpha) \ln(h^*)
\]

where \( s_k \) is the constant share of output invested in physical capital \( (I_k/Y) \), \( n \) is the constant labor growth rate, \( \delta_k \) is the rate of depreciation of physical capital, and \( h_t = H_t/A_tL_t = h^* \). MRW’s model in (4) is static, but I convert it to a dynamic model by making \( y^* \), \( s_k \), \( n \), and \( h^* \) a function of time. In this model \( y^* \) is different in each period \( t \).

Estimation of this model requires time series data for \( h \). Human capital/worker has been estimated in various ways in the literature, but due to data availability the most common approach is to use a nation’s average schooling attainment as a proxy for its level of human capital/worker.

Hanushek and Woessmann [2012] argue that average schooling attainment is a poor proxy for human capital because it does not account for cross-country differences in schooling quality. While their argument is technically correct, when average schooling attainment is used as a proxy for human capital in a log-linear framework, the estimated coefficient on average attainment implicitly accounts for the higher average quality of schooling in countries with higher average schooling attainment (e.g., the average quality in countries with 13 years of schooling, like Japan, versus the average quality in countries with five years of schooling, like
Breton [2013b] shows that across 58 countries Cohen and Soto’s [2007] estimate of average schooling attainment for the population age 15 to 64 has a highly-correlated, log-linear relationship with a country’s financial stock of human capital/adult (H/L):

5) \[ \ln(H/L) = 0.32 \text{ attainment} + 7.3 \]

Combining this relationship with the definition of \( h \) yields:

6) \[ \ln(h_t) = 0.32 \text{ attainment}_t – gt + 7.3 – \ln A_0 \]

Substituting this relationship into (4) creates a dynamic model for \( y^* \):

7) \[ \ln (y^*_t) = \frac{\alpha}{1-\alpha} \ln \left( \frac{sk_t}{nt+g+\delta_k} \right) + \frac{\beta}{1-\alpha} [0.32 \text{ attainment}_t – gt] + c \]

An examination of the two components of \( \ln(y^*_t) \) in Japan during 1960-2007 provides an indication of whether Japan was departing from or converging to the steady state over this period. Figure 3 shows the data for these components using the population ages 15 to 64 as a proxy for workers.\(^5\) As shown earlier, the physical capital investment ratio was rising until 1969 and then was stable over 1969-2007. With this trend the basic Solow model predicts that the growth rate would increase until 1969 and then would begin converging to the steady-state rate. By 2007 after 38 years of convergence, the growth rate would be approaching the steady state.\(^6\)

The data also show that human capital/effective worker (h) was rising throughout the period, but at a declining rate, which in 2007 was only slightly above Breton’s [2013a] estimate of the steady-state growth rate of 1%/year. In the aggregate with these two investment trends,

\(^5\) The log of the capital investment ratio in Figure 3 is based on Japanese data for the population age 15 to 64, so it differs slightly from the ratio in Figure 2, which was calculated from PWT 6.3 data for the adult population.

\(^6\) With a depreciation rate of 0.06, the convergence process for investment of physical capital is relatively rapid. If the model were specified with investment in human capital, the convergence process would be much slower, since human capital has a much lower depreciation rate [See Breton, 2013b].
the augmented Solow model predicts that growth rates would be substantially above the steady-state rate in 1969 and would be approaching the steady state rate (from above) in 2007.

**Figure 3**

Japanese Investment Rate and Human Capital/Effective Worker 1960-2007

The model in (7) can be augmented to include factors, other than world technological progress, that affect the level of national productivity and output/worker in the steady state. I include two factors that had substantial effects on Japanese productivity during the 1960-2010 period: weekly labor hours worked and oil prices. As mentioned earlier, Hayashi and Prescott included the effect of labor-hours worked in their analysis, but they did not include the effect of human capital and oil prices.

In 1987 the Japanese government reduced the standard work week from 48 to 40 hours, specified an industry-specific timetable to phase in the requirement, and required companies to
provide overtime pay for hours exceeding the standard week [Kawaguchi, Naito, and Yokoyama, 2008]. Figure 4 shows Kawaguchi, et. al.’s estimates of the average legal work week for each year during the transition and my estimates of actual hours worked per week during these years. I estimated weekly hours worked from Statistics Bureau of Japan [2011] data on total weekly hours worked and the number of workers employed from 1968 to 2007. The weekly hours worked do not appear to be constrained by the standard hours in the figure because these hours are an average that include part-time workers, but the standard hours were constraining for many full-time workers.

**Figure 4**

Average Hours Worked per Week in Japan 1968-2007

The patterns in the two data sets indicate that the legislation affected hours worked per week, but they also indicate that the actual number of hours worked was endogenous. Prior to 1988 when the economy was growing strongly, the annual average number of hours worked per
week is increasing. After 1997 when the economy was not growing strongly, the annual average number of hours worked per week is decreasing.

Labor (L) in Y/L could be defined to include hours worked, but reductions in average hours worked per week do not necessarily reduce labor productivity in a linear fashion. When firms reduce an employee’s weekly hours, productivity in the remaining hours is likely to increase. To permit the data to determine the marginal relationship between weekly hours worked and output, I include the log of weekly hours worked as a separate variable in the growth model. The coefficient on this variable is expected to be positive and less than one.

Japan is almost entirely dependent on imports of petroleum and natural gas to meet its requirements for these fuels, and historically its prices for imported natural gas (LNG) have been contractually linked to oil prices. As a consequence, when the price of imported oil rises, Japanese productivity falls. The change in oil prices impacts Japan’s annual rate of growth if the change is substantial from one year to the next [Jiménez-Rodríguez and Sánchez, 2012].

Figure 5 shows the relationship between annual rates of economic growth and oil prices. The patterns in the data suggest that large changes in oil prices have a substantial effect on annual growth rates. I include the log of oil prices as a separate variable in the growth model. The coefficient on this variable is expected to be negative.

Adding these two factors to (7) yields the following dynamic model of steady-state output/effective worker:

8) \( \ln(y_t^*) = \theta \ln(\text{oilpr}_t) + \phi \ln(\text{hrs}_t) + \beta/(1-\alpha)[0.32 \ln(r_t - g_t) + \alpha/(1-\alpha) \ln(s_{kt}/(n_t + g + \delta_k))] + c \)

The model in (8) cannot be inserted directly into the partial adjustment model in (3) because the first three terms in this model affect \( \ln(y_t) \) immediately, while the investment rate for physical capital affects \( \ln(y_t) \) through a partial adjustment process. The convergence effect \( \lambda \) in (1) is the
average effect of all four terms in the model of $\ln(y^*_t)$. Since the effect of the first three terms is larger than $\lambda$, the effect of the fourth term is smaller than $\lambda$. As a consequence, substitution of (8) into (3) yields the following growth model:

$$\ln(y_t) - \ln(y_{t-1}) = \theta \ln(oil_{pt}) + \varphi \ln(hrs_t) + \beta/(1-\alpha)[0.32 \text{ attain}_t - \text{ gt}] + \gamma \lambda \alpha/(1-\alpha) \ln[s_{kt}/(n_t+g+\delta_t)] - (1-\lambda) \ln(y_{t-1})$$

In this model, $\gamma < 1$, and $\alpha$ and $\beta$ are not identified.

**Figure 5**

**Annual Growth Rate vs. Oil Price 1960-2007**

In the MRW model the coefficient $\beta/(1-\alpha)$ on the human capital variable $0.32 \text{ attain}_t - \text{ gt}$ includes the direct effect of human capital on growth ($\beta$) and the indirect effect human capital has through its effect on the marginal product of physical capital ($\alpha\beta/(1-\alpha)$). This can be shown by deriving the marginal product of physical capital in (1):
10) \[ \text{MPK} = \frac{\partial Y}{\partial K} = \alpha \left( \frac{K}{L} \right)^{\alpha-1} \left( \frac{H}{L} \right)^{\beta} A^{1-\alpha-\beta} \]

Solving for \( \frac{K}{L} \) in a market economy, in which MPK equals the financial market return \( (r_k) \), physical capital/worker \( \left( \frac{K}{L} \right) \) is a function of human capital/worker \( \left( \frac{H}{L} \right) \):

11) \[ \frac{K}{L} = \left( \frac{\alpha}{r_k} \right)^{1/1-\alpha} \left( A_0 \right)^{(1-\alpha-\beta)/(1-\alpha)} \left( \frac{H}{L_{it}} \right)^{\beta/(1-\alpha)} \]

Substituting (12) into (1) shows that the total effect of changes in \( \log \left( \frac{H}{L} \right) \) on \( \log \left( \frac{Y}{L} \right) \) is \( \beta(1-\alpha) \):

12) \[ \frac{Y}{L} = \left( \frac{\alpha}{r_k} \right)^{\alpha/(1-\alpha)} \left( A_0 \right)^{(1-\alpha-\beta)/(1-\alpha)} \left( \frac{H}{L_{it}} \right)^{\beta/(1-\alpha)} \]

If \( \alpha \) is \( 1/3 \), the total effect of changes in human capital on output is 50% larger than the direct effect. It is this total direct and indirect effect of human capital that is estimated in (9).

The dependent variable in (9) can be rewritten as:

13) \[ \ln(y_t) - \ln(y_{t-1}) = \ln \left( \frac{Y}{L} \right) - \ln \left( \frac{Y}{L} \right) - g \]

Substituting (13) into (9) and rearranging yields the following annual growth model for estimation:

14) \[ \ln \left( \frac{Y}{L} \right)_t - \ln \left( \frac{Y}{L} \right)_{t-1} = c + \theta \ln(oilp_t) + \varphi \ln(hrs_t) + \beta/(1-\alpha) \left( 0.32 \text{ attain}_t - g_t \right) \]
\[ + \gamma \lambda \alpha/(1-\alpha) \ln \left[ \frac{s_k}{(n_t+g+\delta_k)} \right] - (1-\lambda) \left[ \ln \left( \frac{Y}{L} \right)_{t-1} - g(t-1) \right] + \epsilon_t \]

III. Data Used to Estimate the Model

I obtained the data for estimation of the model from numerous sources. National output is calculated from GDP/capita (rgdpch) and population (pop) from Penn World Table (PWT) 6.3 [Heston, Summers, and Aten, 2009]. The rate of investment in physical capital \( (s_k) \) is the series ci in this data set.

The Statistics Bureau of Japan [2008 and 2011] provides data on the number of hours worked, beginning in 1968, and on the population ages 15 to 64, beginning much earlier. For most estimates of the model, I use the adult population ages 15 to 64 to represent the labor force, calculating the labor growth rate \( (n) \) and the economic growth rate \( (\Delta \ln(Y/L)) \) using these data.
However, I calculated the weekly hours worked from the Statistics Bureau’s data on total weekly hours worked and the size of the Japanese work force, since these data are likely to have been created from information collected in the same surveys.

Figure 6 shows the annual growth in workers and in the population ages 15 to 64 from 1969 to 2007. While the overall trend in these two data sets is similar, the annual variation is much larger for the number of workers than for the population, and the variation in the number of workers seems suspect in certain years. For example, there is a very large increase in workers in 1973 (2.4%) followed by a huge decline in 1974 (3.0%). While the decline in 1974 could be due to the oil price shock, it seems unlikely that the number of workers could have increased by 2.4% the prior year. As another example, the data show a large increase in the work force during the financial crisis in 1991 and during the Asian crisis in 1997.
Even if the large variations in the annual growth of workers are correct, they are due in part to shocks to the economy and to economic cycles that are not estimated by the MRW model. These variations affect both the growth rate per worker and the ratio $s_k/(n+g+\delta_k)$, so they increase the unexplained variance in the regressions and if incorrect, may bias the estimated coefficients. The advantage of using the population age 15 to 64 as the proxy for the work force is that annual changes in these data capture the trend in the size of the work force, while excluding changes related to shocks and economic cycles or to estimation error. In addition, since the average schooling attainment estimates are based on the population ages 15 to 64, the use of these same population data for the other variables is consistent with the attainment data.

The disadvantage of using the population data rather than the workers data is that the growth rates are likely to be less correlated with the weekly hours worked. I examine the effect of using data on workers rather than the adult population in the complete model to determine whether the model’s results are robust to changes in these data.

The oil price is the average U.S. refiner imported crude oil acquisition cost from EIA [2011], converted to 2007 U.S. dollars using a GDP deflator from UNData [2011] and converted to constant yen using the Japanese exchange rate and the price index (p) for Japan relative to the U.S. in PWT 6.3.

The assumed value of $g = 0.01$ is Breton’s [2013a] estimate of this rate for the 1910 to 2000 period, as described earlier. The assumed value of $\delta_k = 0.06$ is from Caselli [2004]. I estimated annual average schooling attainment from Morrisson and Murtin’s [2009] data. Since these data are critical to the estimated effect of human capital in the model, I describe the process for creating these data in detail.
A country’s human capital stock changes very slowly, as students move through the educational system and the population ages. The actual human capital of the work force also varies due to changes in employment during economic shocks and cycles, but this effect is not captured in the model. The effect of changes in the economic cycle on growth rates is captured in the model in the labor-hours worked and in the physical capital investment ratio.

There are two key requirements for the human capital data in the annual growth model in (14). The first is that they correctly replicate the trend over time, so this effect can be distinguished from the trend in weekly labor-hours worked. The second is that the annual differences in human capital be due to the trend, not to data error. As described later, the model is estimated in differences to control for the non-stationarity of the data. If there is considerable random error in the annual data, differencing will exacerbate this error and cause bias in the estimate of the effect of human capital on growth [Krueger and Lindahl, 2001].

My approach to maintain the trend free of measurement error is to fit a cubic equation to Morrisson and Murtin’s [2009] decadal data for Japanese average schooling attainment for the population age 15 to 64 and use the predicted annual data from this equation in the model. A cubic equation captures the changing trend over time and creates annual data without exacerbating the measurement error in the decadal data:

15) \[ \text{Attainment} = (0.000022685 \times \text{year}^3) - (0.136063 \times \text{year}^2) + (272.088 \times \text{year}) - 181391.48 \]

This equation has an \( R^2 = 0.999 \).

Morrison and Murtin’s decadal data are particularly accurate because they created them using census data by age cohort that are adjusted using education-specific and age-specific mortality rates. By using the data in all of the censuses and OECD surveys to simultaneously estimate average attainment in all periods, their methodology reduces the measurement error in
individual censuses and surveys and provides a relatively accurate estimate in years that lack census data. Using this approach they reduced Cohen and Soto’s [2007] estimate of average schooling attainment in Japan in 1960 from 9.48 years to 8.90 years.

Godo [2011] has created annual schooling attainment data for Japan from gross enrollment data. These data have a magnitude that is similar to Morrisson and Murtin’s data, but they have some annual variation and a different trend over the 1960-2000 period. Godo’s data are not matched to the census and OECD survey data, so they provide a less accurate measure of the trend in average attainment than the interpolated data. Gross enrollments do not account for students that repeat grades or for those that drop out during the year. Neither do they account accurately for the effect of education-specific mortality rates on the average schooling attainment of the adult population over time.

Average schooling attainment is potentially endogenous in the growth model. As national income levels rise, countries are likely to allocate more resources to schooling. Since the trend in the growth rate in the Japanese data is inversely related to the trend in the level of income, an OLS estimate of the effect of schooling may be biased.7

I use average schooling attainment in the United States as an instrument for average schooling attainment in Japan. These two measures are highly correlated because Japan and the U.S. have similar average levels of schooling and both are facing diminishing returns to investment. Since U.S. and Japanese economic growth rates are not highly correlated, U.S. average schooling attainment should not be affected by Japanese growth rates. Growth rates in GDP/adult in the U.S. have not followed the declining trend in Japan and were not affected by

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7 When the population data are used to proxy for workers, there is no conceptual reason to expect that the physical capital investment ratio is endogenous.
the Japanese financial crisis in 1991, so U.S. schooling attainment should be exogenous relative to Japanese economic growth rates.

I created annual U.S. average schooling attainment data from Morrisson and Murtin’s data using another cubic equation:

\[ \text{U.S. attainment} = 0.000001759349 \times \text{year}^3 - 0.011100 \times \text{year}^2 + 23.33549 \times \text{year} - 16332.6 \]

This equation has an \( R^2 = 0.994 \).

Figure 7 shows the decadal data and the annual data for average schooling attainment in Japan and the U.S. and the Godo data. Changes in U.S. schooling attainment since 1968 are correlated with changes in Japanese schooling attainment \( (\rho = 0.80) \), but they are not correlated with changes in Japanese economic growth rates \( (\rho = -0.05) \).

Figure 7

Average Schooling Attainment in Japan and the U.S. 1960-2010
IV. Model Estimation and Results

A visual review of correlograms and the results from Dickey Fuller tests revealed that most of the data are serially correlated and that none of the data series are stationary. The use of interpolated data for average schooling attainment does not create any particular statistical problems, but these data are not stationary even in differences. Over the 1968-2007 period, the data for $\Delta \ln(Y/L)_t$, $\ln[s_{kt}/(n_t+g+\delta_k)]$, $\ln(oilprice_t)$, $\ln(hrs_t)$, and $\ln(Y/L)_{t-1} - g(t-1)$ are I(1). The data for $[0.32*attain_{t-2} - g_t]$ for Japan are I(2).

I estimated the growth model in differences using GMM to control for non-stationarity and serial correlation. When the model in (14) is estimated in differences, the lagged income variable $[\ln(Y/L)_{t-1} - g(t-1)]$ is correlated with the error term, which could bias the estimated coefficient.$^8$ I control for this problem by using two instruments for lagged income; the lagged value of this variable and the lagged rate of investment $[L*\ln(s_{kt})/(n_t+g+\delta_k)]$.

Table 1 presents the estimates of the annual growth model for the period 1969-2007. The period commences in 1969 because, as mentioned, the data for labor hours worked are not available prior to 1968 and the first year of data is used in the differencing process. Column 1 presents the estimates for the basic Solow model. Column 2 presents the results for this model, with a variable added for weekly labor hours. This model includes the variables Hayashi and Prescott used in their analysis, and the estimated coefficient on weekly hours (0.97) is consistent with their assumption that changes in this variable affected output with a unitary elasticity. The negative estimated coefficient on lagged GDP/adult is consistent with the conditional convergence assumed in the Solow growth model.

But as discussed earlier, weekly labor hours appear to be endogenous. Column 3 presents the results for the same model, using average standardized legal hours as an instrument for labor

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$^8$ The estimated coefficients in the model are substantially different if lagged income is not instrumented.
hours worked. With this instrument the estimated elasticity of labor hours worked declines to 0.63, and it is not statistically significant.

Columns 4 and 5 present estimates of the model augmented with average schooling attainment. The results indicate that Japanese average schooling attainment may be endogenous, since the effect of schooling attainment is smaller in column 5 when U.S. schooling attainment is used as an instrument. Average attainment is statistically significant at the 1% level in both models.

| Table 1 |
|-------------------|---|---|---|---|---|---|
| **GMM Estimates of Annual Growth Rates/Adult in Japan 1969-2007** |
| [Dependent Variable is $D.\left(\ln(Y/L)_{t-1} - \ln(Y/L)_{t-2}\right)$] |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8** |
| Instrumented | | | | | | | |
| $\ln(y_{t-1})$ | $\ln(y_{t-1})$ | $\ln(y_{t-1})$ | $\ln(y_{t-1})$ | $\ln(y_{t-1})$ | $\ln(y_{t-1})$ | $\ln(y_{t-1})$ |
| $D.\left(\ln(s_{t}\gamma/n_{t} + g + \delta_{t})\right)$ | 0.29* | 0.27* | 0.28 | 0.21* | 0.21* | 0.22 | 0.23* | 0.12 |
| | (.08) | (.07) | (.12) | (.04) | (.04) | (.09) | (.08) |
| $D.\ln(Y/L_{t-1}) - g(t-1)$ | -0.50* | -0.46* | -0.40 | -0.54* | -0.47* | -0.59* | -0.59* | -0.57* |
| | (.14) | (.12) | (.16) | (.14) | (.12) | (.17) | (.12) |
| $D.\left(0.32*\text{attain} - gt\right)$ | | | | | | | | |
| $D.\ln(weeklyhours)$ | 0.97 | 0.63 | 0.36 | 0.64* | 0.69* | 0.64* | 0.51 |
| | (.44) | (.66) | (.32) | (.23) | (.21) | (.23) | (.29) |
| $D.\ln(oilprice)$ | | | | | | | | |
| | | | | | | | |
| *Significant at one percent level |
| **Dependent variable is annual growth of GDP/worker instead of GDP/adult** |

Column 6 presents estimates of the model that includes both average schooling attainment and weekly labor-hours, with instruments for both variables. In these results the effect of average schooling attainment is slightly larger and remains significant at the 1% level, and the effect of weekly hours worked is smaller and not statistically significant.
Figure 8 shows actual annual growth rates and the fitted prediction for the models in columns 3 and 6 for the 1969-2007 period. Both of these models use instruments for labor hours worked and average schooling attainment. The difference in the predictions is due to the addition of average schooling attainment. Since the models are estimated in differences, the empirical results do not include a constant. In the plot of the results, I include the constant for each model that makes the average growth rate in the model predictions equal to the actual average growth rate over the estimation period.

**Figure 8**

*Actual Growth vs. Predictions of Solow and MRW Models: 1969-2007*

The plots in the figure show that the Solow model in column 3 that includes weekly labor hours does not provide an acceptable prediction of the trend in growth rates over the estimation period. It substantially overestimates growth rates prior to 1983 and underestimates them after
1991. Hayashi and Prescott did not encounter this problem because they began their analysis in 1984, after the period of high growth rates. The plots show that the addition of average schooling attainment to the model greatly improves the prediction of the trend in growth rates and reduces the serial correlation in the residuals. Average schooling attainment is implicitly an omitted variable in the basic Solow model. But the augmented model underestimates growth before 1974 and overestimates growth after 1997. The autocorrelation in the residuals indicates that the augmented model is still mis-specified.

Column 7 shows the results when labor hours worked and schooling attainment are instrumented and the oil price variable is included in the model. The inclusion of oil prices improves the statistical significance of several of the estimated coefficients. Importantly, the estimated coefficient on weekly labor hours increases to 0.5, and it is almost statistically significant at the five percent level.

Figure 9 shows the fitted prediction for this model. The model fits the actual data very well throughout the estimation period. The additional of the oil price variable enables the model to explain growth rates much better during the early 1970s, the early 1980s, and after 2000. As would be expected in a growth model based on real factors, the fitted prediction underestimates growth during the real estate bubble and overestimates growth during 1993-95 after the bubble collapsed. Implicitly the model prediction includes lower TFP growth prior to 1991 than in Hayashi and Prescott’s analysis and higher TFP growth after 1991.

The fitted prediction also underestimates growth in the years after the Plaza Accord and overestimates growth during the dotcom and Asian financial crises. All of these events constitute shocks that altered Japan’s growth rates relative to the underlying pattern due to the behavior of the fundamental factors that are included in the augmented Solow model.
Overall the model provides substantial evidence that Japan’s declining growth trajectory over the 1969 to 2007 period is consistent with the Solow model’s prediction that with constant rates of investment in physical and human capital, an economy’s growth rate converges to the world steady-state rate. There is no evidence in the model’s prediction that the low growth rates since 1991 are primarily due to suboptimal policies in the financial sector or at the Central Bank.

The estimated effect of schooling attainment in all the models is statistically significant at the one percent level. Importantly, the magnitude of this effect is robust to the inclusion of the additional variables. In the final model $\beta/1-\alpha = 0.64$, which indicates that each additional year of schooling raises national output/worker directly and indirectly by 20 percent.\footnote{0.64 * 0.32 = 0.20.} This estimate is
similar to the 2SLS estimates in Breton [2013a] in which an additional year of schooling raised output in 43 countries by 19 percent over the 1910-2000 period.

Gennaioli, La Porta, Lopez-de-Silanes, and Shleifer [2013] show that in 2005 an additional year of schooling is associated with a 26 percent increase in output across 1569 sub-national regions. Their estimate is larger than the estimated effect in this model, but their estimate does not control for endogeneity. Breton [2013a] obtains an OLS estimate similar to theirs (0.27) in 2000, but this estimate declines to 19 percent when he controls for endogeneity.

When the estimated effect of schooling is applied to the Japanese annual schooling data, it indicates that rising average schooling attainment increased Japan’s annual growth rate by 1.8% in 1969 and by 0.6% in 2007.\(^\text{10}\) In other words, the slowing growth in average schooling attainment reduced Japan’s annual economic growth rate by 1.2% over the 1969-2007 period.

Although \(\alpha\) is not identified in the model, it is typically about 0.35. Given the estimated coefficients on the lagged income variable and the investment variable, \(\gamma\) would have to equal 0.8 if \(\alpha\) were to equal 0.35. This is consistent with the conceptual requirement in the model that \(\gamma < 1\). If \(\alpha = 0.35\) and \(\beta/1-\alpha = 0.64\), the implied value of \(\beta = 0.41\). This value of \(\beta\) is similar to Breton’s [2013b] estimate of 0.36 across 61 countries in 1990.

Column 8 in Table 1 presents the results for the complete model, using growth in the log of GDP/worker rather than of GDP/adult as the dependent variable and using the annual growth in the number of workers as the estimate of \(n\) in the physical investment variable. The estimated effects and the statistical significance of all the variables, except weekly hours worked, are lower in this model. Nevertheless, these results are reassuring because the estimated effects of weekly labor hours and average schooling attainment are similar to the results in the model of GDP/adult.

\(^{10}\) In 1969 the increase is \(0.64*0.028 = 0.018\). In 2007 the increase is \(0.64*.009 = 0.006\).
and the estimated coefficient on labor hours worked is statistically significant. Although the output elasticity of weekly hours worked is slightly higher (0.62), it continues to be considerably less than one. And even though the effect of average schooling attainment is lower, it continues to be very substantial (0.51). Each additional year of average schooling attainment in this estimate of the model raises GDP/worker by 16 percent. These model results overall provide strong evidence that both average schooling attainment and weekly labor hours affected Japan’s economic growth rates over the 1969 to 2007 period.

V. Policy Implications

MRW’s augmented Solow model predicts that once investment rates stabilize at a constant share of GDP, growth rates will converge to the steady-state rate. This rate appears to be about 1%/year. Countries that are increasing the share of GDP invested, or that have been increasing this share, grow at a higher rate, but there is a practical limit to the share of GDP that a country can invest. In addition, since the marginal product of capital declines as the share of GDP invested rises, the sacrifice of current consumption to raise investment provides ever smaller future increases in GDP as the share of investment rises.

Japan has invested a higher share of GDP in physical capital than most other countries for a long time. As a consequence it has a higher capital/output (K/Y) ratio and a lower marginal product of physical capital (MPK) than most other countries. Figure 10 shows annual data for Japan’s share of GDP invested, the MPK in the U.S. and Japan, and the Bank of Japan’s real interest rate during 1980-2007. I estimated the values of MPK from its relationship in the MRW model (αY/K), using a value of α = 0.35 and values from Y and K calculated from PWT 6.3. I calculated the real interest rate from the Bank of Japan’s [2011] data on the basic discount rate and UNdata’s [2011] estimates of the GDP deflator.
The data in Figure 10 show that the share of GDP invested in physical capital has declined since the financial crisis, in conjunction with the decline in Japan’s MPK. The ratio $s_k/(n+g+\delta_k)$ has not declined (shown in Figure 3) because the growth in the adult population ($n$) also has declined and has actually been negative since 1995. Since the MPK in the MRW model (or the Solow model) is a function of labor ($L$), a rising labor force raises the MPK and encourages investment, while a falling labor force has the opposite effect. The implication is that the declining share of GDP invested in physical capital since the financial crisis is due primarily to the declining adult population.

Figure 10

Japan’s Investment Rate, MPK, and Interest Rate and U.S. MPK

![Graph showing GDP investment rate, MPK, and interest rate](image)

$11$ MPK = $\frac{\delta Y}{\delta K} = \alpha K^{\alpha-1} H^{\beta} (AL)^{1-\alpha-\beta}$
The Bank of Japan has maintained low real rates of interest since 1995 to encourage domestic investment, but the estimates of the MPK in the U.S. and Japan indicate that Japanese investors can obtain a better return on investment in physical capital outside Japan. The estimates of the MPK (real) in Japan show that it was about 8% in 2007 and only about 60% of U.S. MPK. A more expansive monetary policy cannot change this reality.

The high estimated effect of increased schooling on growth in Japan in the model’s results indicates that increased investment in post-secondary schooling could be an attractive growth strategy. Estimates of Japan’s MPK can be compared to estimates of its marginal product of human capital (MPH) by estimating the MRW model in equation (1) using cross-country financial data on historic investment in the human capital stock. Figure 11 shows the ratio of the MPH to MPK for 50 countries in 2005, taken from Breton [2013c]. These data show that Japan has a relatively low stock of human capital stock/adult compared to other high-income countries and a relatively high ratio of MPH/MPK of 2.2.

The human capital stock is relatively low in Japan in part because its school-age population is a lower share of the total population than in other counties. As a consequence, the share of GDP required to provide a high level of schooling to the school-age population is lower in Japan than elsewhere. Since the average schooling attainment of the school-age population across countries has been rising, even with the same average schooling for the school-age population, this leads to a lower average stock of human capital/adult in Japan than elsewhere.

The MPH/MPK ratio for Japan is slightly overestimated in the figure because Japan’s human capital stock is calculated from its expenditures on schooling and does not include its expenditures for private tutoring. Dang and Rogers [2008] report that Japan expended $14
billion annually on private tutoring in the mid-1990s. Data from PWT 6.1 [Heston, Summers, and Aten, 2002] indicate that these expenditures were approximately 0.5% of GDP in 1995.

Figure 11

Relative Returns to Increases in Human Capital and Physical Capital in 2005

Expenditures for schooling were approximately 4.2% of GDP in 1995 [Breton, 2010], so including tutoring would raise national expenditures for education by 11%. Assuming this relationship between tutoring and schooling expenditures was applicable historically, the adjusted human capital stock/adult in 2005 would be $85,000 and the MPH/MPK ratio in 2005 would be reduced from 2.2 to 2.0.

With this adjustment to Breton’s [2013c] estimate, Japan’s MPH in 2005 is 16.6 percent, compared to 8.3 percent for its MPK. The implication is that if Japan wishes to grow faster, policies to rebalance investment toward human capital (i.e., raise average schooling attainment)
and away from physical capital would be more cost-effective than a continuation of its emphasis on investment in physical capital.

VI. Conclusions

Recent empirical studies have provided considerable evidence that increases in human capital cause growth and that Mankiw, Romer, and Weil’s version of the augmented Solow model provides a valid representation of the growth process. This model predicts that if countries invest constant shares of GDP in physical and human capital, then their growth rate will converge to the steady state rate, which Breton [2013a] estimates to have been about 1%/year over the last century.

In this paper I examine whether a dynamic version of MRW’s model can explain Japan’s annual growth rates over the 1969-2007 period. I show that this model, with additional variables for weekly labor hours worked and oil prices and an assumed steady-state rate of 1%/year, explains the variation in growth rates over this period quite well, including the period of lower growth since 1991.

The empirical results indicate that Japan’s growth rate has declined due to slowing growth in human capital, the stabilization of the rate of investment in physical capital relative to a shrinking labor force, a decline in labor hours worked, higher oil prices, and convergence toward the steady state. The estimated coefficient in the model indicates that each additional year of average schooling attainment raised GDP in Japan by 20 percent and that slowing growth in schooling attainment reduced the annual growth rate by 1.2% between 1969 and 2007.

Given estimates of the financial stocks of physical and human capital, the MRW model provides estimates of the marginal products of both types of capital. These estimates indicate that in 2005 the MPH/MPK ratio in Japan was 2.0. This ratio is unusually high compared to
other high-income countries, which generally invest a higher share of GDP on schooling and a lower share on physical capital. This finding indicates that Japan could increase its growth rate more cost-effectively by rebalancing its rates of investment between human capital and physical capital to place more emphasis on investment in formal schooling and less on investment in physical capital.
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## Appendix

### Principal Data Used in the Analysis

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– Whole Japan and Population Age 15 to 64
