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New technologies and long-run growth

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NEW TECHNOLOGIES AND LONG-RUN GROWTH

Senior Honors Thesis

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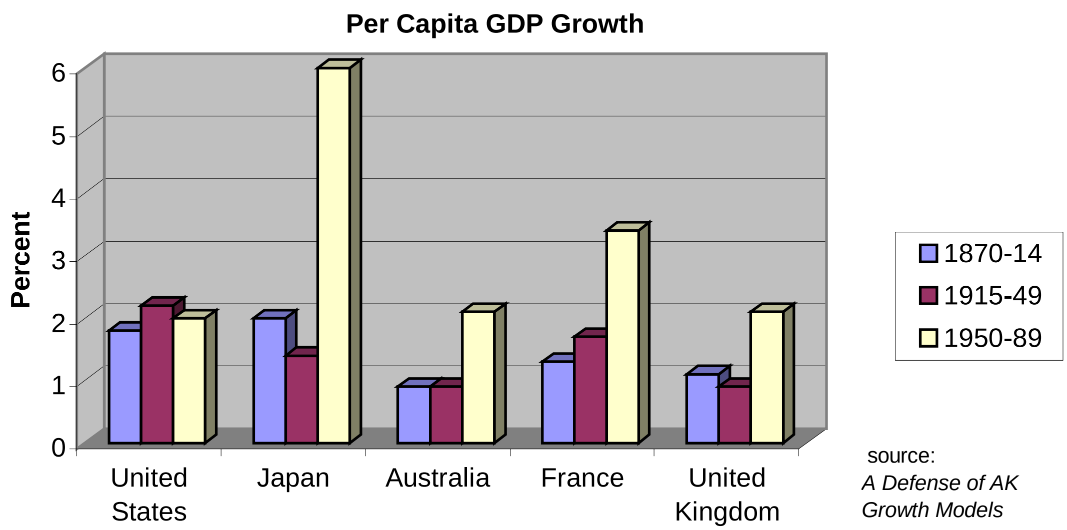
Abstract

Have new technologies fundamentally changed the way we look at economic growth? The neoclassical growth model, one of the most prominent growth theories of the past, states that the economy eventually reaches a steady state where per capita output remains constant. However, some economists are now starting to disagree with this claim and instead believe that a new economy is emerging in which computing power and other technologies enable the economy to grow indefinitely. One recent theory of economic growth, the AK growth model, explains how this 'new economy' functions. This project shows why the AK growth model is a more accurate representation of the economy than the neoclassical growth model and then uses a computer simulation to illustrate the differences between the two theories.

Is it possible for an economy to grow forever? Economists of the past would say no—the economy must eventually reach a steady state where output grows at the same rate as the population. However, many individuals are starting to question these old economic growth theories. Long-term trends from the United States' economy and other countries indicate that per capita output has been growing for hundreds of years. The graph below shows that per capita GDP growth rates to not seem to be approaching zero.



On the contrary, Japan's per capita GDP grew a whopping six percent between 1950 and 1989. Other data shows that the median standard of living for Americans will rise by three percent each year.[1] Why have the world's economies been consistently growing? Furthermore, can economic growth theories of the past explain the persistent growth that these economies are currently experiencing, or will new growth theories replace the old ones?

More than ever before, technology is playing a more and more vital role in today's economy. Approximately 200 million computers are currently active in the world, providing processing power that averages approximately 100,000,000 instructions per second. In just 40 years, processing power has increased a million-fold.[2] The availability of this enormous amount of computing power enables firms to perform tasks much more efficiently than in the past. Rather than relying on human memory, firms can now use computers to calculate, search, sort, and organize information. Technology can be used in almost any task involving information processing, organization, or communication, which is practically every activity.

However, there has been some debate as to how much technology has really improved productivity. Statistics show that productivity growth has actually slowed every decade since the 1960s while investments in information technology have grown dramatically. This "productivity paradox" can be partially attributed to difficulties in accurately measuring productivity. For example, in the past, accountants did not count computer software as capital. Productivity has actually grown over one percent per year for the past thirty years for sectors that have invested heavily in computers. MIT economists showed that in the 1990s, computers significantly contributed to firm-level output and productivity. In addition, computing technologies are often characterized by a "network effect"—the more individuals that use these technologies, such as the Internet, the more value they will provide for users. Once this occurs, the productivity paradox could give way to a productivity boom.[3]

Unfortunately, the benefits of computing do not come without costs. More so than with technologies of the past, computing has created a significant learning curve for firms that implement information technology. Adopting these technologies involves a significant cost in terms of learning.[4] For example, if a firm decides to implement a new database, many employees will need to be trained to use it. However, the longer the employees work with the

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[1] Cohen, Stephen S., Bradford DeLong, and John Zysman. "An E-conomy?"
[2] Cohen, Stephen S., Bradford DeLong, and John Zysman. "An E-conomy?"
[3] "Explaining The Productivity Paradox." http://www.neweconomyindex.org/productivity.html

technology, the more efficiently they learn to use it. In fact, a large share of technological advances has come from "learning by doing." For some products, such as software, important operating characteristics are only revealed after intensive use.[5] The more the workers use the technology, the more knowledge that is gained about it. Not only does learning-by-doing make the initial learner more productive, but because others are able to copy the worker, other workers become more productive as well. However, the law of diminishing returns states the contrary—it states that the marginal physical product of a variable declines as more of it is employed with a given quantity of other fixed inputs. Rather, the knowledge spillovers that occur can actually eliminate the diminishing returns.[6] Thus, the concept of diminishing returns is less applicable when dealing with computing technology.

Because of the large amount of knowledge that can be gained from using computing technologies, it is often beneficial for firms to give their employees experience in using these systems. By doing this, the firms are investing in human capital—the accumulated value of an individual's intellect, knowledge, experience, and potential.[7] In fact, increases in productivity have come with the increase in human capital from on-the-job training.[8] Thus, investing in learning today increases output tomorrow, just as investing in physical capital does.[9]

Thus, computing technologies differ from previous economic theories about capital and productivity. However, has technology also affected the economic growth theories of the past as well? Previous growth theories did take technology into account but in a much different manner

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[4] Greenwood, Jeremy and Mehmet Yorukoglu. "1974."
[5] Greenwood, Jeremy. "The Third Industrial Revolution: Technology, Productivity, and Income Inequality."
[6] "Economic Growth." http://fhss.byu.edu/econ/Spencer/Econ581/Chapter%207%20-%20W99.pdf.
[7] http://www.knowledgeworkers.com/index.asp?get=humanCapitalSol.html
[8] DeLong, Bradford. "What Do We Really Know About Economic Growth?"
[9] Greenwood, Jeremy and Mehmet Yorukoglu. "1974."

than the newly emerging economic growth theories. Which model is a better representation of today's economy?

The neoclassical growth theory is one of the most popular economic growth theories of the past. These models take full employment of all resources to be the natural state of the economy when prices and wages are flexible.[10] Robert Solow and Trevor Swan developed one of the more commonly used neoclassical growth models in the 1950s. Their model involves growth in the capital stock, growth in the labor force, and technological progress as leading an economy to equilibrium.

The production function used in Solow's model is the Cobb-Douglas production function, which is listed below[11]:

$$Y_t = A\, K_t^{\alpha}\; N^{1-\alpha} \qquad 0 < \alpha < 1$$

where Y_t = total national product during year t

K_t = the capital stock at the beginning of the year

N_t = the size of the productive labor force available during the year

A = scaling constant that measures the level of technology in the economy. It converts the physical labor and capital units on the right to the units in which national product is measured. (e.g. from man-hours and machine-hours to dollars of national product)

For simplicity, 'A' does not have a time subscript, meaning that the technology is constant and unchanging.

[10] Miller, Merton H. and Charles W. Upton. *Macroeconomics: A Neoclassical Introduction.*
[11] Miller, Merton H. and Charles W. Upton. *Macroeconomics: A Neoclassical Introduction.*

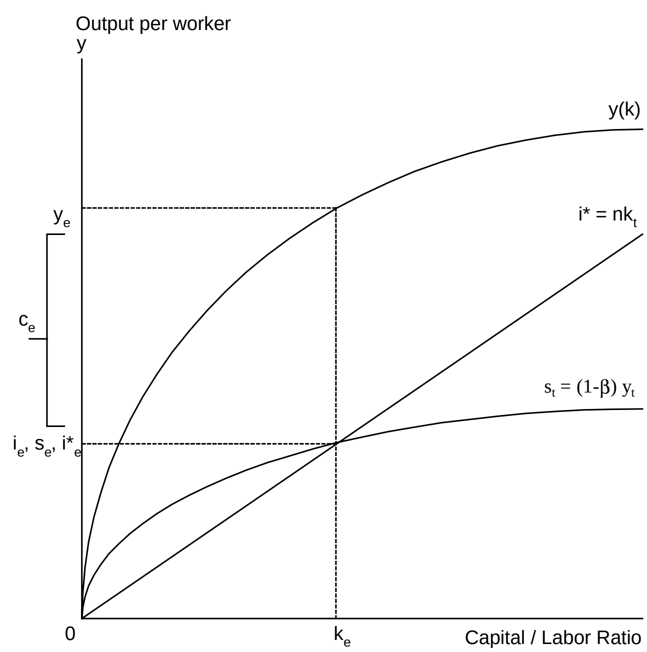
Note that the Cobb-Douglas function implies that the firms in the economy experiences diminishing returns. The function can be rewritten in per capita terms as follows:[12]

$$\frac{Y_t}{Nt} = y_t = A\,\frac{K_t}{Nt} \cdot N_t^{1-\alpha} = Ak_t^{\alpha}$$

Even if both labor and capital are increased but capital is increased by a smaller proportion than labor, the capital/labor ratio will fall, and so will the average output per worker.

The equilibrium condition, or steady state, of the neoclassical growth model occurs when the capital widening level of investment equals the per capita savings. The capital widening level, i*, refers to the level where the capital stock is growing just fast enough to equip any new workers entering the labor force with the same amount of capital equipment per worker as available to the existing work force.

The graph below shows the Solow growth model equilibrium condition:



[12] Miller, Merton H. and Charles W. Upton. *Macroeconomics: A Neoclassical Introduction.*

k_e is the equilibrium capital/labor ratio and y_e, s_e, and c_e are the corresponding equilibrium values of output (and income) per capita, of saving (and investment) per capita and of consumption per capita. When an economy is in equilibrium, all per capita magnitudes are constant. Thus, the total national product grows at the same rate as the population.

The model also assumes a constant average propensity to consume. By some process, a certain fraction of per capita income βy_t is used for immediate consumption and the remainder $(1- \beta)\ y_t$ is used for savings and investment. However, an individual aiming to maximize his lifetime utility will not consume a constant fraction of his income. Instead, he will consume a portion of his income based on his rate of time preference, which measures how much he values consumption now versus consumption later. For example, if the market interest rate is greater than the consumer's rate of time preference, the consumer feels that the market is giving him a greater return than he needs. Thus, the consumer will save for more future consumption. Consequently, an individual who is saving optimally produces different results than the neoclassical model suggests: the more patient the consumer, the more the consumer saves, thus leading to more growth in the economy.

In order to satisfy the equilibrium condition of Solow's model, growth can only be transitory as the economy moves from an initial to a higher steady state. For example, if the savings rate increases, the savings curve (s_t) shifts upward. The new steady state capital/labor ratio and per capita output will be higher than in the initial equilibrium. However, once the economy reaches this new equilibrium, the per capita output remains constant and the economy stops growing as a consequence of the diminishing returns from the production function. Thus, growth is not continuous—it only occurs until the economy reaches its equilibrium.

Even when technological improvements are considered in the model, growth remains transitory. For example, a one-shot technological improvement shifts the production curve and savings curve upward. Once again, the steady state capital/labor ratio and per capita output increase, but the growth stops once these new levels are reached.

If the economy experiences continuous technological progress, the economy will still arrive at an equilibrium level, and the growth will not continue.[13] Technological progress makes each unit of labor more effective and serves to increase the effective labor supply in much the same way that population growth increases the actual labor supply.[14] The amount of capital required needs to increase in order to keep up with the increase in the effective labor supply. The capital widening curve becomes $(n + g)k_t$, where g is rate of technological progress. Thus, the slope of the capital-widening curve (i*) increases, which results in a lower capital/effective labor ratio and per effective worker output but higher standard of living (c_e). Even with continuous technological progress, the economy still does not experience the continuous growth that has been observed in today's economy.[15]

Solow's model has several other limitations as well. The model assumes that technological progress and its implementation are both free. Implementation often requires the purchase of new machines and new human capital, neither of which are taken into account when 'A', the constant representing the level of technology, increases.[16] Furthermore, the capital stock does not include human capital or intangible capital, both of which are vital elements of an economy that is driven by technology.

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[13] "Economic Growth." http://fhss.byu.edu/econ/Spencer/Econ581/Chapter%207%20-%20W99.pdf.
[14] Miller, Merton H. and Charles W. Upton. *Macroeconomics: A Neoclassical Introduction*
[15] Kurz, Heinz D. and Neri Salvadori. "The 'New' Growth Theory: Old Wine in New Goatskins."

In order to address these limitations of the neoclassical growth model, new economic growth theories were created. One of the models that are currently gaining popularity is the AK growth model. The model has the following production function[17]:

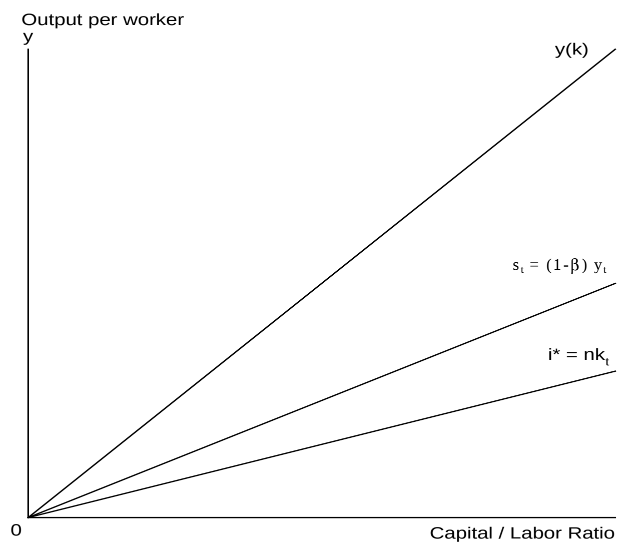
$$Y_t = AK_t$$

where Y_t = total national product during year t

K_t = the capital stock at the beginning of the year

A = scaling constant that measures the level of technology in the economy

Like the neoclassical model, the AK growth model also assumes a constant average propensity to consume. However, unlike Solow's model, the AK growth model does not have an equilibrium condition. Because effective labor units are not incorporated into the production function, the rate of technological change is no longer exogenous, which also differs from Solow's model. As shown in the graph below, the economy will grow forever:



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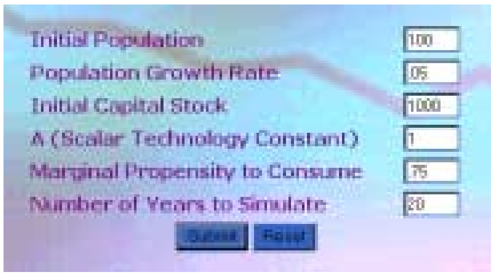
[16] Greenwood, Jeremy and Boyan Jovanovic. "Accounting for Growth."
[17] McGrattan, Ellen R. "A Defense of AK Growth Models."

The AK model departs from Solow's model is many other ways as well. Unlike Solow's model, the economy in the AK model does not experience diminishing returns. The absence of diminishing returns is reflected in the linear savings curve.[18] Thus, an increase in capital yields the same percentage increase in output.

One of the other important differences between the AK model and the neoclassical growth model is that in the AK model, the capital stock includes both human and intangible capital, while in Solow's model, only physical capital is accounted for. As a result, the engine of growth in the AK model is actually the advance of economically useful knowledge rather than just the purchase of physical capital.

Another key difference between the two models is the way they deal with growth and technological improvements. In the AK model, a one-shot improvement in technology implies a higher percentage growth rate whereas in Solow's model, the one-shot improvement does not affect the economy's long-run rate of growth. In fact, unlike Solow's model, the AK model's economy may experience a positive long-run growth rate without any technological progress.

A computer simulation was created to numerically show the differences between the two models. The following values were entered into the simulation:



[18] "Economic Growth." http://fhss.byu.edu/econ/Spencer/Econ581/Chapter%207%20-%20W99.pdf.

These values, along with a value of 0.5 for α, were used to generate the following snapshots of a neoclassical economy and an AK economy:

Neoclassical Growth Model

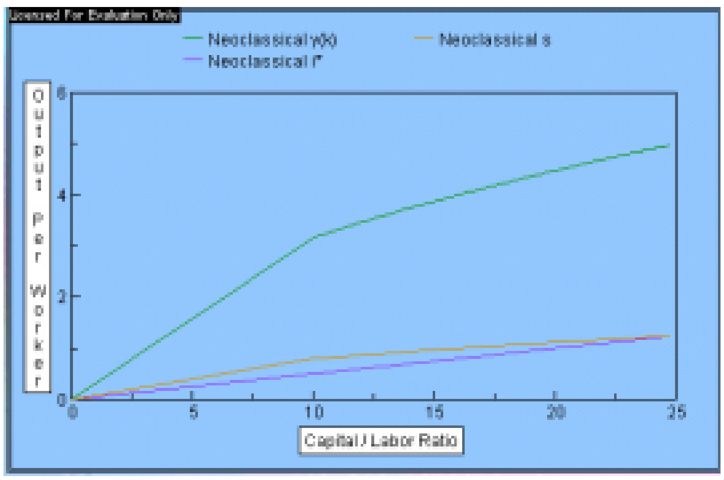
Year	Population	Capital Stock	National Product	Savings & Investment	Capital Widening Investment	Capital/ Labor Ratio	Output Per Worker	Average Standard Of Living
0	100.00	1,000.00	316.23	79.06	50.00	10.00	3.16	2.37
1	105.00	1,079.06	336.60	84.15	53.95	10.28	3.21	2.40
2	110.25	1,163.21	358.11	89.53	58.16	10.55	3.25	2.44
3	115.76	1,252.74	380.81	95.20	62.64	10.82	3.29	2.47
4	121.55	1,347.94	404.78	101.19	67.40	11.09	3.33	2.50
5	127.63	1,449.13	430.06	107.51	72.46	11.35	3.37	2.53
6	134.01	1,556.65	456.73	114.18	77.83	11.62	3.41	2.56
7	140.71	1,670.83	484.87	121.22	83.54	11.87	3.45	2.58
8	147.75	1,792.05	514.56	128.64	89.60	12.13	3.48	2.61
9	155.13	1,920.69	545.86	136.46	96.03	12.38	3.52	2.64
10	162.89	2,057.15	578.87	144.72	102.86	12.63	3.55	2.67
11	171.03	2,201.87	613.67	153.42	110.09	12.87	3.59	2.69
12	179.59	2,355.29	650.37	162.59	117.76	13.12	3.62	2.72
13	188.56	2,517.88	689.05	172.26	125.89	13.35	3.65	2.74
14	197.99	2,690.14	729.81	182.45	134.51	13.59	3.69	2.76
15	207.89	2,872.59	772.78	193.20	143.63	13.82	3.72	2.79
16	218.29	3,065.79	818.08	204.52	153.29	14.04	3.75	2.81
17	229.20	3,270.31	865.77	216.44	163.52	14.27	3.78	2.83
18	240.66	3,486.75	916.04	229.01	174.34	14.49	3.81	2.85
19	252.70	3,715.76	969.00	242.25	185.79	14.70	3.83	2.88
20	265.33	3,958.01	1,024.78	256.20	197.90	14.92	3.86	2.90

AK Growth Model

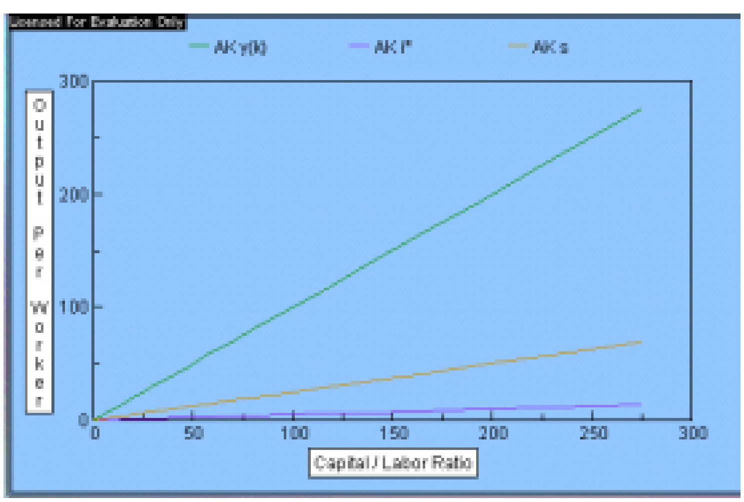
Year	Population	Capital Stock	National Product	Savings & Investment	Capital Widening Investment	Capital/ Labor Ratio	Output Per Worker	Average Standard Of Living
0	100.00	1,000.00	1,000.00	250.00	50.00	10.00	10.00	7.50
1	105.00	1,250.00	1,250.00	312.50	62.50	11.90	11.90	8.93
2	110.25	1,562.50	1,562.50	390.63	78.13	14.17	14.17	10.63
3	115.76	1,953.13	1,953.13	488.28	97.66	16.87	16.87	12.65
4	121.55	2,441.41	2,441.41	610.35	122.07	20.09	20.09	15.06
5	127.63	3,051.76	3,051.76	762.94	152.59	23.91	23.91	17.93
6	134.01	3,814.70	3,814.70	953.67	190.73	28.47	28.47	21.35
7	140.71	4,768.37	4,768.37	1,192.09	238.42	33.89	33.89	25.42
8	147.75	5,960.46	5,960.46	1,490.12	298.02	40.34	40.34	30.26
9	155.13	7,450.58	7,450.58	1,862.65	372.53	48.03	48.03	36.02
10	162.89	9,313.23	9,313.23	2,328.31	465.66	57.18	57.18	42.88
11	171.03	11,641.53	11,641.53	2,910.38	582.08	68.07	68.07	51.05
12	179.59	14,551.92	14,551.92	3,637.98	727.60	81.03	81.03	60.77
13	188.56	18,189.89	18,189.89	4,547.47	909.49	96.46	96.46	72.35
14	197.99	22,737.37	22,737.37	5,684.34	1,136.87	114.84	114.84	86.13
15	207.89	28,421.71	28,421.71	7,105.43	1,421.09	136.71	136.71	102.53
16	218.29	35,527.14	35,527.14	8,881.78	1,776.36	162.75	162.75	122.07
17	229.20	44,408.92	44,408.92	11,102.23	2,220.45	193.75	193.75	145.32
18	240.66	55,511.15	55,511.15	13,877.79	2,775.56	230.66	230.66	173.00
19	252.70	69,388.94	69,388.94	17,347.23	3,469.45	274.60	274.60	205.95
20	265.33	86,736.17	86,736.17	21,684.04	4,336.81	326.90	326.90	245.17

The table clearly shows how much faster the economy using the AK model grows—all of the per capita magnitudes are much higher in the AK model. At year 20, the output per worker in the neoclassical model is only 3.86, while the output per worker in the AK model is 326.90. The standard of living is much higher in the AK model as well: 245.17 compared to 2.90 in the neoclassical model. In addition, the capital/labor ratio in the AK model is 326.90, whereas the capital/labor ratio in the neoclassical model is only 14.92.

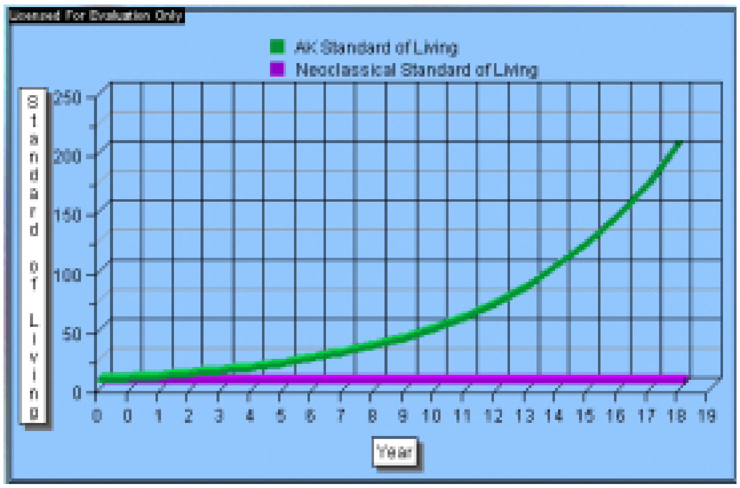
The graphs of both models also show how much faster the AK model grows compared to the neoclassical model. The neoclassical model below reaches its steady state at a capital/labor ratio of about 24 and a per capita output of about 5. Once the economy reaches this point, the economy will stop growing.



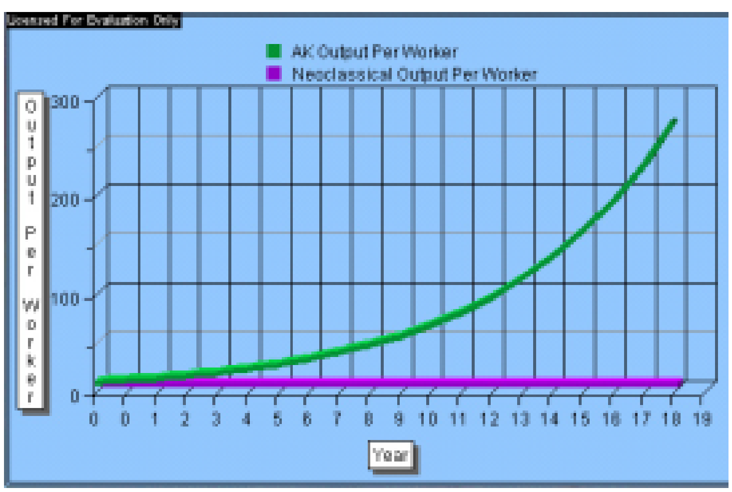
Meanwhile, the AK growth model does not approach a steady state condition and grows forever.



Time series graphs of the standard of living and per capita output of both economies further shows the differences between the two models. The following graphs use the data from the tables, and thus reflect the first 20 years of the economy. The graph shows that the standard of living in the AK model rises much more rapidly than in the neoclassical model. In fact, the neoclassical standard of living hardly rises at all.



Just like the standard of living graph, the output per worker graph shows the dramatic difference between the two models. The per capita output from the neoclassical model hardly increases and almost looks to be constant.



Thus, the AK growth model addresses all of the shortcomings of Solow's growth model. Computing has made diminishing returns less applicable, and it has also made human capital just as important as physical capital. However, the law of diminishing returns is the foundation of Solow's model, and human capital is not accounted for in the model. Its no surprise then that Solow's model fails to represent the continuous growth that the world's economies have been experiencing for hundreds of years. As Solow's model becomes more and more obsolete, perhaps the AK growth model will become widely accepted as the economic growth theory of the computing era.

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