e-Capital: The Link between the Stock Market and the Labor Market in the 1990s

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Abstract

In the 1990s, the stock market rose dramatically. Firms employing or producing new technologies, especially relating to software, computers, and communication, rose the most. In the labor market, college graduates enjoyed pay increase substantially larger than other workers. These increases occurred in the face of a large shift of labor supply toward college graduates. I attempt an integrated explanation of these phenomena based on a new factor of production, e-capital. The stock market records the value of plant, equipment, and e-capital. I infer the quantity of e-capital from the excess of the market value of firms over the reproduction cost of their plant and equipment. I test the resulting view within standard production economics using non-parametric methods.

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I. Introduction

Important changes occurred in the U.S. economy over the past decade. New technologies based on computer software began to transform the production and distribution of goods and to form the basis of new goods. The value of the stock market rose tremendously, with the largest increases occurring among firms practicing the new technologies. Figure 1 depicts the increase in relation to the value of the plant, equipment, and inventories of corporations. The stock market as of 1999 viewed corporations as owning intangibles worth more than their tangible capital. Internet companies are valued almost exclusively for their intangibles: Yahoo! has a value of $67 billion with $20 million of physical capital.

The workers who develop and use the new technologies are mostly college graduates. Both the number of college-educated workers and their relative earnings rose remarkably. The ratio of the total dollars paid to college graduates to the dollars paid to other workers rose from 0.59 to 0.75 from 1990 to 1998. Figure 2 shows the increase in constant-dollar earnings by education from 1991 to 1998. College graduates and people with graduate training enjoyed much larger increases than those with less education.

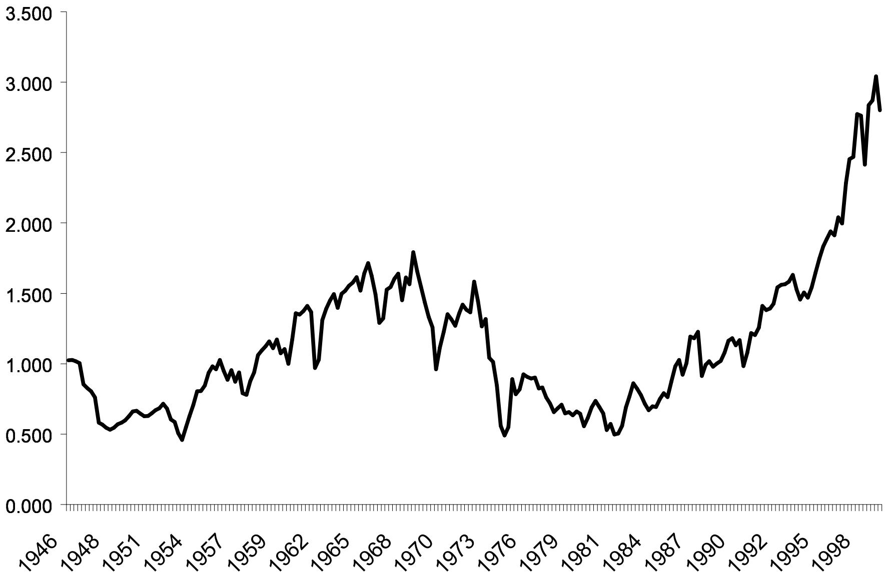

Figure 1. Ratio of the Market Value of Non-Farm, Non-Financial Corporations to Reproduction Cost of Their Physical Capital, 1990-1998
Source: Hall [2000]

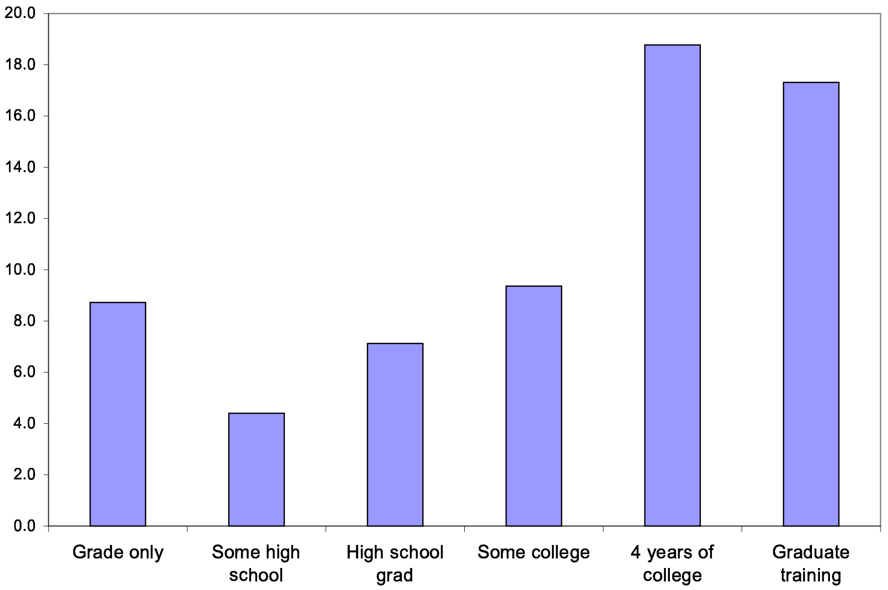

Figure 2. Percent Increase in Earnings, by Education, 1991-1998, in Constant Dollars
Source: Current Population Survey, deflated by the implicit deflator for private GDP

Despite the stock market's view that corporations have accumulated valuable technology resources apart from their physical capital, and the huge increase in demand for college graduates derived from the new technology, productivity growth rose only a little in the 90s. The data I use in this paper show a Solow residual or total factor productivity growth of 1.5 percent per year from 1990 to 1998. This figure—similar to the findings of other recent studies—suggests that the idea of a technology revolution in the United States is overblown. Skeptics about the importance of new technology tend to view the high valuation of American corporations in the stock market as an irrational bubble.

This paper pursues the idea developed in Hall [2000] that the stock market should be taken seriously as a measure of resources owned by corporations. I introduce a new kind of capital—e-capital—to characterize the resources. I view the production of goods and services as employing the services of e-capital along with machines, college-graduate workers (c-workers), and workers who have not graduated from college (h-workers). I use the standard tools of production economics to understand changes in factor intensities and factor prices, without invoking significant changes over time in the production function for goods and services.

Of course, something must be changing to induce the sharp changes observed in the economy over the decade. I model the change as fairly rapid improvement in the technology for producing e-capital. The technology is simple: c-workers by themselves make e-capital. No other factors are required. There is a 10-percent annual improvement in the productivity of c-workers in making e-capital.

Earlier discussions of the declining economic positions of lower-skilled or less-trained workers have invoked the concept of skill-biased technical change. With an essentially stationary production function and a large increase in the fraction of workers with college educations, the dramatic rise in the relative earnings of college graduates would call for a large skill bias in the limited amount of technical change that occurred. I calculate the amount of that change. The explanation I offer, on the other hand, invokes capital accumulation as well as skill bias. The demand for college graduates is increased both by the skill bias and by the fact that college graduates are the only factor of production used to make e-capital. I model the skill bias in a two-sector setup, where there is growth in the productivity of college graduates in making e-capital.

The e-capital model explains the low level of measured productivity growth despite the strong evidence in the stock market and in the earnings of college graduates that a technology revolution is underway. The standard Solow residual treats all c-workers as working to make goods and services. Total factor input to goods and services is overstated by the amount of the services of c-workers actually used to make e-capital. To date, this overstatement is offset by the failure to include e-capital as an input in standard productivity calculations. Thus the standard calculation of 1.5 percent per year productivity growth is not much different from the view adopted here, that there is little productivity growth in goods and services once e-capital is treated as an input.

During the transition, as resources are used to build a stock of e-capital, the standard productivity calculation overlooks the benefits the economy is enjoying. If the accumulation of e-capital fell to steady-state replacement levels, c-workers would move back to making goods and services, and the standard calculation would reveal a large increase in productivity. Because e-capital is an intermediate product, the standard calculation is not completely inappropriate in the long run, but it misses capital accumulation in the short run. The theory of Divisia aggregation teaches that the overall rate of growth of total factor productivity in an economy with two forms of output is the weighted average of the rates of growth of productivity in the two sectors, with weights based on the relative market values of the two kinds of output. That weighted average growth is 2.5

percent per year—not a spectacular level, but considerably above rates of productivity growth observed in most other eras of the U.S. economy and other economies.

Research on trends in the labor market in the 1990s and earlier decades have gravitated toward the hypothesis of skill-biased technical change, particularly because other ideas—such as competition from low-wage workers in other countries—have been shown to have little role in these trends. I show that rates of growth of skill bias around two percent per year are consistent with the trends in relative wages and relative employment levels. For this hypothesis to make sense, the elasticity of substitution between college and non-college workers must be well above one. The hypothesis is a close relative of the view developed in the paper, based on the idea that e-capital was accumulated during the 1990s. The advantage of the version of the skill-bias explanation based on e-capital is that it provides a unitary explanation of events in the stock market and the labor market.

The methods used here are relentlessly non-parametric. The Solow residual is the primary tool. In addition, I test the implications of the e-capital model against the Weak Axiom of Cost Minimization—in effect, asking why e-capital was not used before 1990 even though it was practical to produce it. I also use a non-parametric approach to measuring skill bias.

Brynjolfsson and Yang [1999] provide supporting evidence about e-capital. They demonstrate that firms with higher levels of observed investment in information technology—a likely correlate of e-capital—have much higher valuations than other firms. In the framework of this paper, their results suggest that there is about $9 of e-capital in the typical firm for each $1 of observed IT capital.

II. A Four-Factor Model

Define the following notation:

k_t	quantity of e-capital
m_t	quantity of physical capital (machines)
c_t	labor input of c-workers (college graduates)
h_t	labor input of h-workers (not college graduates)
q_t	output
r_t^k	rental price of e-capital
r_t^m	rental price of physical capital
w_t^c	wage rate for c-workers
w_t^h	wage rate for h-workers
p_t^q	price of output
p_t^k	price of e-capital
p_t^m	price of physical capital
A_t	index of Hicks-neutral or output-augmenting technical change

I assume constant returns to scale. Let the technology for producing q be

$$q_t = A_t f(k_t, m_t, c_t^q, h_t). \tag{2.1}$$

I assume constant returns and perform the standard Solow-Divisia exercise on the production function (take time derivatives of both sides, replace the derivatives of the production function with the corresponding factor prices, and approximate the time derivatives of the form $\frac{\dot{x}}{x}$ with the discrete approximation $\Delta \log x$):

$$
\begin{aligned}
\Delta \log q_t \doteq \Delta \log A_t + \frac{r_t^k k_t}{p_t^q q_t} \Delta \log k_t + \\
\frac{r_t^m m_t}{p_t^q q_t} \Delta \log m_t + \frac{w_t^c c_t^q}{p_t^q q_t} \Delta \log c_t^q + \frac{w_t^h h_t}{p_t^q q_t} \Delta \log h_t
\end{aligned}
\quad . \qquad (2.2)
$$

That is, the observed rate of change of output is the rate of productivity growth plus the weighted average of the rates of change of the factor inputs, with cost shares serving as weights. Here c_t^q is the amount of c-labor used as an input to goods production. In actual use, the shares are measured as the equally-weighted average of the shares in t-1 and t, so I actually use the superlative index of total factor input. The Solow residual or total factor productivity growth, $\Delta \log A_t$, measures the shift of the production function.[1]

I take the technology governing e-capital to be

$$
k_{t+1} = e^{\lambda t} c_t^k + \left(1 - \delta^k\right) k_t . \qquad (2.3)
$$

δ^k is the rate of deterioration of e-capital. λ is the rate of growth of productivity in the production of e-capital and is the primary driving force of the changes described in this paper. An immediate implication is that the price paid at the end of period t to form a unit of e-capital starting in period t+1 is $p_t^k = e^{-\lambda t} w_t^c$. In addition, the price for renting a unit of e-capital during period t is

$$
r_t^k = \left(1 + r_t^{f,k}\right) p_{t-1}^k - \left(1 - \delta^k\right) p_t^k . \qquad (2.4)
$$

[1] The standard formula for the Solow residual appears to break down when there is a zero level of an input. This is an illusion associated with dividing and multiplying by the input level in the derivation. The underlying logic of the Solow residual rests on a linear approximation to the production function, which encounters no problems when an input is at zero. In that case, the contribution of a factor needs to be calculated as, for example, $\dfrac{r^k \Delta k}{p^q q}$.

Here $r_t^{f,k}$ is the financial return required by the market, adjusted for the risk associated with holding a unit of e-capital during period t (see Hall and Jorgenson [2000]). In this formula, I assume that the costs of producing e-capital are deductible for tax purposes as they are incurred.

For physical capital, I assume that one unit of capital can be formed from $\frac{p_t^q}{p_t^m}$ unit of goods output. The rental price for physical capital is

$$r_t^m = \frac{1-\tau z}{1-\tau}\left[\left(1+r_t^{f,m}\right)p_{t-1}^m - \left(1-\delta^m\right)p_t^m\right]. \tag{2.5}$$

Here $r_t^{f,m}$ is the risk-adjusted interest rate for physical capital, δ^m is the deterioration rate, τ is the corporate tax rate, and z is the present discounted value of tax deductions associated with physical capital (see Hall and Jorgenson [1967]).

Securities markets reveal the combined value of e-capital and physical capital:

$$v_t = p_t^k k_t + p_t^m m_t. \tag{2.6}$$

where v_t is the net value of all financial claims on firms. Thus the quantity of e-capital can be recovered from observables according to the equation:

$$k_t = \frac{e^{\lambda t}}{w_t^c}\left(v_t - p_t^m m_t\right). \tag{2.7}$$

The value of newly produced e-capital is

$$p_t^k\left[k_t - (1-\delta)k_{t-1}\right] = e^{-\lambda t} w_t^c\left[k_t - \left(1-\delta^k\right)k_{t-1}\right], \tag{2.8}$$

so employment of c-workers making e-capital is

$$c_t^e = e^{-\lambda t}\left[k_t - \left(1-\delta^k\right)k_{t-1}\right]. \tag{2.9}$$

The remainder, $c_t^q = c_t - c_t^e$, are employed in the goods sector.

III. Data

Data for the stock of physical capital and the value of securities are taken from Hall [2000]. Data for earnings by education are from the Current Population Survey, Table P-18: *Mean Income by Educational Attainment and Sex, People 25 Years Old and over.* These numbers match the employee compensation numbers from the NIPA reasonably closely. The exclusion of young workers and benefits just offsets the inclusion of government workers.

Figure 3 shows the calculated quantity of e-capital over the period.

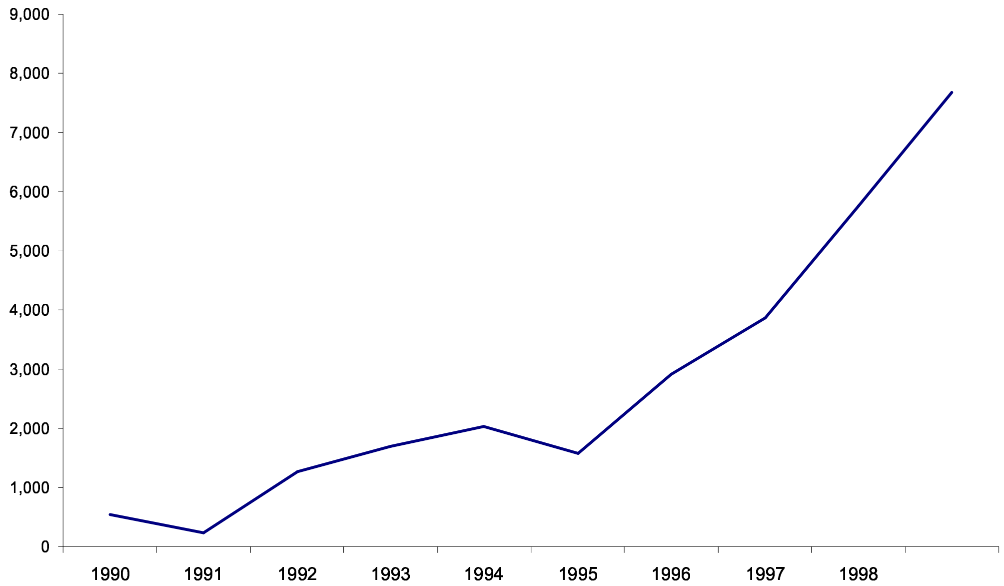

Figure 3. e-Capital in billions of 1998 dollars

The level of employment of c-workers in producing e-capital, stated as a fraction of all c-workers, from equation (2.10), is 60 percent. Because noise from the stock market introduces randomness into the derived measure of e-capital employment and production, I have smoothed the data by imputing e-capital employment as 60 percent of the total number of c-workers each year.

IV. Productivity Calculations

Table 1 shows the two productivity calculations for the goods and services sector. The upper panel applies the ideas of this paper by adding e-capital as an input and removing the fraction of c-workers employed in the production of e-capital. The lower panel reports standard calculations. The weights reported in the table are averages, but the calculations are made yearly, and the contributions are the sums of the annual contributions (price changes multiplied by weights). As a result, the contributions in the table are not precisely the products of the reported input changes and weights.

Productivity calculations with e-capital					
	k, e-capital	*m, machines*	*C^q, college grads*	*h, not college grads*	*Total*
		Input changes			
	2.911	0.281	0.094	0.080	
		Weights			
	0.075	0.132	0.164	0.629	
		Contributions			
	0.218	0.037	0.016	0.052	0.323
				Output growth	0.374
				Residual	0.052
				Annual rate	0.006
Standard productivity calculations without e-capital					
		m, machines	*c, college grads*	*h, not college grads*	*Total*
			Input changes		
		0.281	0.094	0.080	
			Weights		
		0.112	0.352	0.535	
			Contributions		
		0.032	0.079	0.044	0.154
				Output growth	0.272
				Residual	0.117
				Annual rate	0.015

Table 1. Productivity Calculations with and without e-Capital

The upper panel, referring to the e-capital calculations, shows that the input of e-capital rose substantially (this measurement uses the method discussed in footnote 1), though the average weight given to e-capital is only 7.5 percent. Employment of c-workers grew about 9 percent over the period, but the share given to them here is only 16 percent, because 60 percent of c-workers were not employed in this sector, but rather were making e-capital. More than half of the cost of goods and services comes from h-workers. Productivity grew about 5 percent over the 8 years, or about 0.6 percent per year.

The lower panel reports standard productivity calculations. e-Capital does not play a role, and all c-workers are treated as employed in the goods and services sector. Because the addition of more c-workers does not completely offset the removal of e-capital, the growth of total factor input and of the productivity residual is somewhat higher.[2]

The e-capital model has two productive sectors—goods and services and the flow of new e-capital. Economy-wide productivity growth can be stated as the Divisia index of growth in the two sectors. As calculated in the top panel of Table 1, goods and services production had productivity growth of 0.6 percent per year in the e-capital framework. The sector's share of the value of total output averaged 79 percent. Productivity growth in making e-capital was 9.5 percent per year. The average of the two growth rates, with weights of 79 and 21 percent, is 2.5 percent per year. The e-capital view results in a higher overall rate of productivity growth than the conventional view because it considers the accumulation of e-capital as another form of production. In a later section, I will compare the two views in more detail and observe that the standard approach can be seen as treating e-capital as an intermediate input.

[2] Note that the rate of growth of output is lower in the conventional calculations. In this version, I have calculated output for the non-financial non-farm corporate sector as the sum of factor costs divided by the price of private GDP. That is, I have imposed the assumptions of constant returns and competition and used the resulting condition of zero pure profit. But, because total factor costs are different in the e-capital calculations than in the conventional calculations, the resulting rate of growth of output is different. Work in progress will attempt to measure output growth in the sector directly and overcome this anomaly.

V. Consistency with Production Theory

Is the story of this paper consistent with standard production theory? A basic property of the theory is the Weak Axiom of Cost Minimization (Varian [1984]). Table 2 applies the WACM to data for the beginning and ending years of my analysis, 1990 and 1998.

	e-Capital	*Machines*	*College graduates*	*Not college graduates*	*Total*
Inputs, 1990	0.000	0.871	0.389	0.598	
Inputs, 1998	1.198	1.225	0.030	0.663	
Prices, 1990	0.245	0.152	0.823	0.915	
Prices, 1998	0.119	0.134	1.000	1.000	
Compare 1998 inputs to 1990 inputs at 1990 prices:					
1990 cost	0.000	0.132	0.320	0.548	1.000
1998 cost	0.294	0.186	0.025	0.607	1.111
Difference	-0.294	-0.054	0.296	-0.060	-0.111
Compare 1990 inputs to 1998 inputs at 1998 prices					
1998 cost	0.142	0.164	0.030	0.663	1.000
1990 cost	0.000	0.117	0.389	0.598	1.104
Difference	0.142	0.047	-0.359	0.065	-0.104

Table 2. Calculations for the Weak Axiom of Cost Minimization

The two rows showing the inputs are normalized by the amount of output (actually, the Divisia index of input, to offset the small amount of productivity growth in the data). The goods and services sector used much more e-capital in 1998 than in 1990, somewhat more machines, much less c-labor, and somewhat more h-labor. To understand the growth of h-labor, it is important to consider that the measure is a Divisia index of the four lower education categories. The number of people with no college declined during the 90s, but the growth of those who had some college without graduating made up for that decline. Further, because the Divisia index weights by relative wages, it gives more weight to the some-college category.

Relative factor prices moved in accord with these changes in factor intensities. The services of e-capital became much cheaper, thanks to the rapid decreases in the amount of c-labor needed to make a unit of e-capital. Other factors became somewhat more expensive.

Table 2 shows that the e-capital view of the 1990s does satisfy the basic rationality condition of production economics. The essential question is why the economy waited until the 1990s to begin to accumulate e-capital. The e-capital view would fail if the 1998 factor input bundle—containing quite a bit of e-capital services—could have produced the 1990 level of output more cheaply (at 1990 prices) than the bundle actually chosen. The answer, in the middle panel of Table 2, is that the 1990 input bundle was actually cheaper. The adoption of e-capital during the 1990s occurred because e-capital became so much cheaper. For the same reason, it would not have been economical to use the 1990 input bundle to produce the 1998 level of output.

VI. Skill-Biased Technical Change

Previous research on the combination of rising relative wages and rising relative employment levels of more-skilled or more-educated workers has gravitated toward the idea of skill-biased technical change. Other explanations—notably rising competition from low-wage workers in other parts of the world—have received little support. The e-capital model developed in this paper is an extension of the idea of skill bias, not a replacement for it. If e-capital were not durable—if it were a standard intermediate product—then the two-sector e-capital model could be rewritten as a one-sector model relating output of goods and services to inputs of primary factors. What I portray as productivity growth in the two-sector model would appear, equivalently, as skill-biased change in the rewritten model.

The durability of e-capital improves the explanatory power of skill-biased technical change in two ways: First, it eliminates what are otherwise somewhat extreme implications of the skill bias view. It helps align rapid rates of wage growth for college graduates with low rates of total factor productivity growth. Accumulation of e-capital fills in the difference, as explained earlier in this paper. Second, the e-capital model accounts for the rise in the stock market, a factor not previously considered in the skill bias literature.

Consider the technology,

$$q = Af(m, xc, h). \tag{2.10}$$

where x is an index of c-worker-augmenting technical change and A is an index of output-augmenting or Hicks-neutral technical change. The wage of c-workers per efficiency unit is $\frac{w^c}{x}$. The elasticity of substitution between c-workers and h-workers is

$$\sigma = -\frac{\Delta \log\left(\frac{xc}{h}\right)}{\Delta \log\left(\frac{w^c}{xw^h}\right)}. \tag{2.11}$$

Given a value for the elasticity, one can infer the bias in technical change from observable data according to

$$\Delta \log x = \frac{\sigma}{\sigma - 1}\Delta \log \frac{w^c}{w^h} + \frac{1}{\sigma - 1}\Delta \log \frac{c}{h}. \tag{2.12}$$

The formula reflects the well-known proposition that the bias of technical change is not defined when the elasticity of substitution is unity, as in the Cobb-Douglas technology. Notice that the bias would go in the wrong direction—contradicting the observed increase in relative wages and increase in relative employment rates for c-workers—if the elasticity of substitution were less than one. With an elasticity not too much higher than one, the bias will be a high multiple of the relative wage increase and of the relative employment increase.

Another restriction on an interpretation based on biased technical change is that it should not involve technical regress—both the index of c-worker augmentation, x, and the index of output augmentation, A, should rise over time. The Solow residual for this technology is $\Delta \log A + s^c \Delta \log x$, where s^c is the share of c-workers. The condition for non-negative output augmentation is that $\Delta \log x$ not exceed the Solow residual divided by the factor share of c-workers, s^c. Figure 4 shows the results of these calculations, with the elasticity of substitution on the horizontal axis.

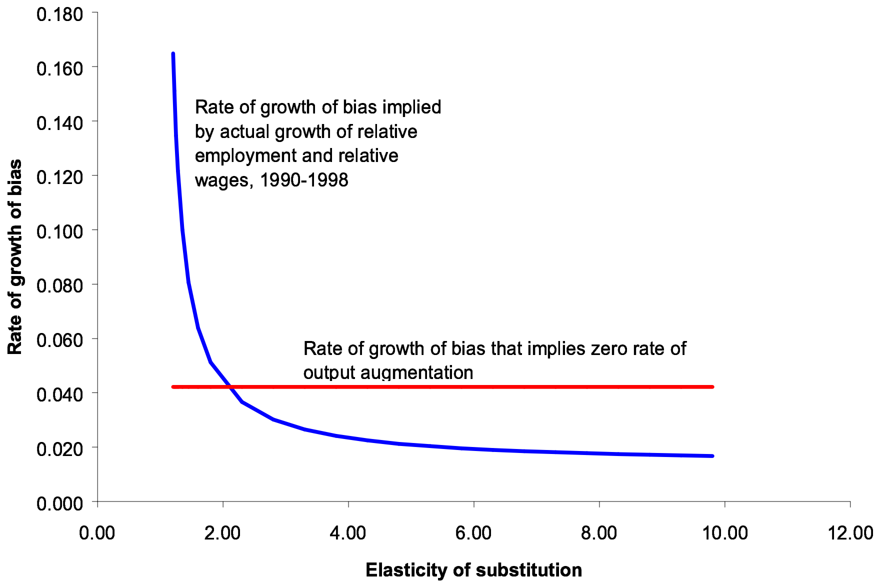

Figure 4. Rate of growth of bias favoring college-educated workers, as a function of the elasticity of substitution

For values of the elasticity of substitution above about 2, the hypothesis of skill-biased technical change is internally consistent. For example, if the elasticity of substitution between c-workers and h-workers is 4, bias growth is about 2.3

percent per year, which would account for 0.8 percent per year growth in the Solow residual, a little over half of the total growth of 1.5 percent per year.

These calculations demonstrate that the hypothesis of growth of the skill bias of the technology is capable of explaining the striking facts about the growth of the relative wages of college-educated workers in the face of rapid growth of employment of college-educated workers relative to those without college. The model developed earlier in the paper is mainly an elaboration of the idea of skill bias. Rather than placing the skill bias directly in the single aggregate production function, the model considers rapid growth in productivity in a second sector, producing e-capital. The one-sector model considered in this section is, roughly speaking, a reduced form of the two-sector model, in which the intermediate product, e-capital, is solved out. If e-capital were a flow intermediate product rather than a stock, the reduced form would be rigorous. The two-sector model is able to reconcile another important fact about the economy of the 1990s—the rise in the stock market—by the accumulation of stocks of e-capital.

VII. Concluding Remarks

The 1990s saw two remarkable changes in the American economy. One was the huge increase in the stock market. The other was the rapid growth of the earnings of college graduates at the same time that they became a substantially higher fraction of the labor force. The natural explanations for these phenomena invoke productivity growth. But the actual growth of recorded productivity in the decade was only a little above the two preceding decades and well below the 1950s and 1960s.

This paper has developed a view consistent with all of these facts. I stress that the view is consistent and is not yet compelled by the facts. We may learn in coming years (for example, by a stock-market crash) that the high stock market was a mistake and corporations had not accumulated capital of corresponding value. And skill bias standing alone is a plausible view of the sharp growth in the earnings of college graduates.

Nonetheless, I find it more satisfactory to link the two phenomena through the concept of e-capital. It replaces the twist of the production function implicit in the skill bias view with a new factor of production. It is the rising comparative advantage of college graduates in making e-capital that has driven up their wages, not an arbitrary change in the production function.

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