# Stylized Facts and Parables of Economic Growth: The Emerging Role of Intangible Capital

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## I. Introduction

This paper is about "the business of growth," to borrow a phrase from Edmund Phelps' Nobel essay on macroeconomics and modern economies (2007). The theory of economic growth that evolved beginning in the 1950s and 1960s rests on the conceptual foundation provided by an aggregate production function that links inputs to output via a "technology." This production function is part of the larger neoclassical growth paradigm that has focussed on explaining physical capital accumulation and investment while "technology" remains exogenous and costless. Despite this limitation, the simple elegance of the basic neoclassical growth model has led to many insights about the logical nature of economic growth.

That said, modeling the sources of the increases in "technology"—often on the basis of research (R&D) activity and advances in human knowledge—has been a major concern of growth theory and analysis (eg., Griliches 1979, Romer 1986, Lucas 1988). The purpose of this paper is to place what has come to be called *the knowledge capital of the firm*, or intangible business capital, in this larger picture.

The knowledge capital of the firm is the result of an "expanded" view of business investment. This view gathers *all* outlays that businesses make for innovation and capacity expansion and treats them as part of the output and capital measures used to measure productivity. Following a literature whose early contributors[1] termed business spending to develop new products, new processes, and new economic competencies "spending on intangibles," Corrado, Hulten, and Sichel (2005, 2006) demonstrated the significance of recognizing such spending as business investment in the national and

[1] Brynjolfsson and Yang (1997), OECD (OECD Secretariat 1998; Kahn 2001), Nakamura (1999, 2001), Lev (2001, 2003), and Blair and Wallman (2001).

growth accounts of the United States. Intangible investment was found to be the largest portion of private business investment since the late 1990s and capital deepening including intangibles the dominant source of U.S. productivity growth since the early 1970s, the starting period of the study.

This paper begins its empirical analysis of U.S. productivity growth more than a decade earlier (1959 to be precise) and extends it to 2007 (another 4 years). Throughout, the view is from 30,000 feet. While this aggregate nature of standard growth analysis draws some criticism, a plausible defense long has been that growth theory was meant as a parable, not as an exact description of the growth process (Samuelson 1962). Parables are simple stories from which a lesson can be drawn, and in the context of economic growth, they provide insights into the dynamics of a growing economy and are consistent with its stylized facts.[2] The relative constancy of labor's share is one such "fact" that has been widely used in both the theory and empirics of macroeconomic growth (e.g., Mankiw, *et. al.* 1992). Another is the investment and saving rates of an economy tend to rise with economic development, but are rather constant in a mature economy such as in the United States.[3]

But, while parables are useful, even necessary, for macroeconomic research, the use of stylized facts and theory can also problematic. The decision as to which data to collect and how they should coalesce into stylized facts necessarily proceeds from some "primitive" theoretical point of view, albeit one that is not always explicit, and the data and theory evolve together. Suppose that this primitive theoretical world-view and the

[2] The famous paper by Nicholas Kaldor (1961) gave economics the idea of "stylized facts" as an acceptable methodological approach to understanding aggregate economic growth.
[3] This tendency for saving and investment to rise with development is confirmed for the U.S. experience only when dated from the late nineteenth century (Maddison 1992).

resulting development miss something important as the structure of the economy changes? What, then, of the stylized facts and the subsequent theorizing?

When the neoclassical growth paradigm is used to model capital accumulation resulting from innovative investments and knowledge appropriation by firms, the result is a more general notion of the supply-side of the economy in which new "facts" emerge. As shown in our earlier work with Sichel, the income share of labor compensation is not constant and the U.S. investment rate rises with the increase in intangible investments by business. Strikingly similar results are obtained for the U.K. economy (Marrano and Haskel 2006), while the findings for Japan are less like those for the U.S. and the U.K (Fukao, *et. al.* 2007).

The foregoing strongly suggests a central role for context (comparative, institutional, etc.) as well as theory in the study of economic growth. As a result, we examine the neoclassical growth paradigm and some of its notable extensions in light of both the context in which they were developed and the new "facts" as expanded to allow for intangibles. In the following sections of this paper, we review the standard theory and underscore the need to include investments in business knowledge capital (broadly defined) as part of economic activity. We then develop a correspondence between those investments and business knowledge appropriation and conclude that treating business spending on intangibles as investment expands the way in which human capital enters the standard production function.

## II. Production and Growth

The modern aggregate production function can be traced to the circular flow model (CFM) of the economy advanced by Frank Knight (Patinkin 1973). The CFM traces the flow of goods and payments between consumers and producers, as they pass through (and are valued in) markets. The CFM shown in Figure 1 illustrates this process for a vector of labor and capital inputs, *X*, and a single output *Q*. Consumers are the source of the inputs, from which they derive income, and producers are the users who transform the inputs into the output. This transformation occurs via the aggregate production function, one of the key structural features of the CFM:

$$Q_t = F(K_t, L_t, t) \quad . \tag{1}$$

Time subscripts are added to allow for change over time (that is, for successive annual CFM representations. Time is included as an explicit variable to capture the possibility of differences (over time or between countries) in the productivity with which labor and capital are used. Under constant returns to scale in production and competitive pricing, the production function yields the familiar GDP identity, $P_t^Q Q_t = P_t^K K_t + P_t^L L_t$, where the *P*'s are the prices that correspond to the inputs and output.

The production function is a major determinant of how an economy evolves over time. The growth in output, $\dot{Q}_t$, must conform to the production function, and must therefore be related to the growth rate of the inputs, $\dot{K}_t$ and $\dot{L}_t$, and to the rate of productivity change, the shift in $F$ denoted by $\mu_t$,

$$\dot{Q}_t = \mu_t + \alpha_t \dot{K}_t + \beta_t \dot{L}_t \quad . \tag{2}$$

The variables $\alpha_t$ and $\beta_t$ are the output elasticities of capital and labor (variable except in the case of the Cobb-Douglas production function). This is also the basis for the Solow (1957) residual model that distinguishes between shift in the production function and movements along the function due to the weighted rates of change in capital and labor inputs. Under the assumption of competitive pricing, the output elasticities are equal to their corresponding factor shares, $s_t^K$ and $s_t^L$ , and the latter then can be measured from data on prices and quantities, and the shift in the production function can be estimated as a residual.

The growth equation (2) is but one part of the dynamic structural model relations that determines the rate of growth. Some explanation must be given for the evolution of the variables on the right-hand side of the production function. Neoclassical growth theory typically assumes that the rate of growth of labor is an exogenously determined constant given by $\eta$. The rate of productivity change $(\mu)$ is also treated as an exogenous constant in some versions of growth theory, that is, as "Manna from Heaven" that falls costless into the production function. However, in more recent variants of the theory, productivity change is associated with spillovers from the stock of capital and is thereby endogenized (of which more below).

The growth in capital is typically assumed to be an endogenous function of past investments, adjusted for physical depreciation and retirement. This process is captured by the recursive accumulation equation

(3) $$K_t = I_t + (1-\delta)K_{t-1} \quad .$$

in which $K_t$ is the stock in any year left over after the depreciation of the preceding year's stock, plus new investment. The accumulation equation can be expressed in an alternative form

(4) $$\dot{K} = (\sigma / \upsilon) - \delta$$

that links the dynamics of capital accumulation to consumers' decision to save.

In the standard one-sector model, output can be used for consumption or investment, thus $Q_t = C_t + I_t$ . The split between $C_t$ and $I_t$ is determined by the implied rate of saving, $\sigma_t = P_t^Q I_t / P_t^Q Q_t$ , which is assumed to be constant in the Solow (1956) version of the model of growth and to depend on the relation between the rate of time preference $\theta$ and the marginal product in the Cass-Koopmans version of optimal growth. The parameter $\upsilon$ is the capital-output ratio, so the rate of growth of capital in equation (4) can be interpreted as the balance between the amount that is added via saving and the amount that is needed to replace the existing stock lost to depreciation.

The dynamics of the one-sector neoclassical growth model are fully characterized by the parameters $(\sigma, \eta, \delta, \mu)$ in the case of the Solow growth model, or $(\theta, \eta, \delta, \mu)$ in Cass-Koopmans theory.[4] Given a functional form for the production function, the structural system can in principle be solved for a dynamic reduced form in which capital and output are endogenous left-hand side variables and these parameters are on the right. Mankiw, Romer, and Weil (1992) produced an explicit reduced form system for the Cobb-Douglas functional form.

## III. Extensions

The neoclassical growth model has an elegant simplicity to it, as befitting a good parable, but as previously noted, technical change is assumed to occur without cost or effort in the conventional form of the model. Costless innovation may occur from autonomous inspiration and tinkering (Newton's apple), or when technology diffuses from the original innovator to other users. Economists long have associated education and human capital with the autonomous technical change of the business sector, while Nelson and Phelps (1966) conjectured that technological diffusion was related to the quantity of a society's

[4] The productivity parameter $\mu$ is usually replaced with the Harrodian labor-saving rate of productivity change $\mu / \beta$.

human capital with the argument that managers need to be educated in order to embrace innovation and evaluate risks.

The standard-bearer aggregate growth model with human capital is due to Uzawa-Lucas in which business output production is neoclassical and uses both human capital and physical capital. The production of human capital occurs in a separate sector (the education sector) and involves no physical capital (Uzawa 1965, Lucas 1988). The two-sector feature of the model implies that the resource constraint for business output production does not include the direct cost of producing human capital.

When production is Cobb-Douglas, the business sector's production function and resource constraint is as follows (ignoring time subscripts):

$$Q = C + I_K = AK^{\alpha} L^{\beta} \tag{5}$$

where $\alpha + \beta = 1$, and $L$ is labor input measured as the services from human capital $uH$. In the Uzawa-Lucas model, the variable $H$ is the economy's total quantity of human capital, and $u$ is the fraction used in the production of business output. We ignore the parameter $u$ in our subsequent analysis and use the variable $H$ to refer to human capital as a factor of production in the business sector.

In aggregate productivity analysis, a common way of thinking about human capital as a factor of production is to regard $H$ as the product of the hourly labor input of all workers $Hours$ and an index of the human capital of the typical worker $h$,

$$H = Hours \bullet h \; . \tag{6}$$

Following Griliches and Jorgenson (1967), $H$ can be built as the weighted sum of growth rates of hours by *type* of worker $i$ where the weights are shares in overall labor cost $\omega_i$.

Aggregate labor input is therefore constructed as $\left(\prod_{i}^{\tau_L} Hours_i^{\omega_i}\right)$ and $h$ becomes an index of labor composition, in which educational attainment is captured by the relative wage differentials between different types of workers.

If the growth in human capital of the typical worker $\dot{h}$ is not accounted for in the calculation of the productivity residual via equation (2), the result is a productivity measure that includes the contribution of $\dot{h}$ along with increases in technical change:

(7) $$\mu_t = \dot{Q} - \alpha \dot{K} - \beta \dot{Hours} = \dot{A} + \beta \dot{h} \quad .$$

This model is instructive in that it suggests that accounting for increases in the human capital of workers is among the more important tasks of "getting productivity measures right" (Kendrick 1976). The model also only *seems* to imply that productivity gains calculated via equation (2) are costless after accounting for increases in the human capital of the typical worker. Business output production is part of a larger model in which education-induced increases in economic growth (e.g., Nelson-Phelps managers), along with measured increases in educational attainment, are not costless to society overall.

Much real world product and process innovation is the result of systematic efforts *within* business organizations, however, through R&D programs, market research, and other design and development activities. Some of these systematic efforts are associated with IT spending (which includes the firm's own production of software), but many are not and most are far from costless, as data on R&D performed by business reveal (nearly $250 billion in 2006). The importance of R&D for productivity analysis has long been recognized, and efforts to estimate the return to R&D spending and put a stock of R&D

capital into empirical growth accounts, mainly for manufacturing, go back decades (for example, see the collected papers in Griliches 1988).

Griliches (1979), Romer (1986), and Lucas (1988) made important steps forward with the linking of knowledge capital—in various forms, but commonly R&D—to spillover externalities. The return to R&D capital is not fully appropriable by the owner of the capital, and the total marginal product of the capital exceeds the direct private product on which private profit maximization is based. The total "social" output elasticity thus exceeds the direct private elasticity, and the wedge between the two, the spillover externality, is suppressed into the Solow residual in the growth accounting model (Barro 1999, Hulten 2001). If these externalities were the only factors contributing to the residual, productivity growth would effectively be endogenized.

A production function for business output including the R&D stock and the possibility of increasing returns can be used to summarize the aggregate implications of this literature,

(8) $$Q = C + I_K = AK^{\alpha_1} L^{\alpha_2} R^{\beta}$$

where $\alpha_1 + \alpha_2 + \beta \geq 1$ and $R$ is the R&D stock, whose determinants are ignored for now. With no direct estimates available for the coefficient $\beta$, computing the Solow residual in the standard way yields:

(9) $$\mu = \dot{Q} - \alpha_1 \dot{K} - \alpha_2 \dot{L} = \dot{A} + \beta \dot{R} \quad .$$

Equation (9) indicates that measured productivity change includes effects from spillovers and increasing returns, represented in this model by the impact of changes in the R&D stock on productivity growth. This result could just as easily pertain to physical capital if $K$ were the source of the increasing returns (i.e., with $AK^{\alpha_1+\beta} L^{\alpha_2}$), or to $H$ from the foregoing model under similar conditions; this symmetry is discussed in Barro and Sala-i-Martin (2004, p. 445-7).[5]

The model in which R&D is the factor $R$ that is source of the increasing returns contains a major loose-end, namely accounting for the production and accumulation of $R$. Research generation shares much in common with education (factors used in production; location and funding to a lesser extent) but the R&D investment to be accounted for occurs largely *within* business organizations, as previously indicated. Therefore, modeling the accumulation of $R$ in a separate sector (a "research" sector) as done with $H$ is not appropriate. Rather, $R$ must be viewed as produced within the sector along with $K$.

To fully reflect the treatment of private R&D as an asset, the concept of output must be broadened to reflect business investments in R&D, thereby according them the same status as investments in physical capital as in CHS (2005, 2006) and as required by the CFM. The left-hand side of equation (8) is restated as follows:

(10) $$Q^* = C + I_K + I_R \quad ,$$

which yields a resource constraint consistent with $R$ as another type of capital in the production function.

Owing to the nonrival nature of R&D, aggregate spillovers and excess returns still could be present, in which case the function is written as

(11) $$Q^* = AK^{\alpha_1} R^{\alpha_2+\beta} L^{1-\alpha_1-\alpha_2} \quad .$$

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[5] The model as written in equation (8) also reveals that obtaining the proper weights for physical capital for use in equation (9) is problematic when data for capital income are determined residually from total product and labor income (the usual case). In this situation, the income attributed to physical capital will include the returns to R&D (or a fraction of them when overall returns are increasing rather than constant).

The parameter $\beta$ captures the excess returns to R&D, and they continue to appear in the aggregate productivity residual as in equation (9).

Before we turn to assessing the empirical significance of estimated productivity contributions from $\dot{h}$ and $\dot{R}$, we note a certain ambiguity when associating $R$ with stocks of business R&D capital. These stocks can be built from data on R&D *funded* by the private business sector, or from R&D *performed* by the private business sector, a broader measure that would add in the R&D performed by private business but funded by nonprofit institutions and governments. The U.S. Bureau of Economic Analysis recently issued a satellite account for R&D investment that includes net stocks for all producing sectors (private business, nonprofits, and government) and selected industries (Robbins and Moylan 2007).

The BEA has used the ownership basis for capitalizing R&D as an asset in national accounts. They also produced estimates of R&D investment performed, but they did not issue corresponding net stocks. As an ingredient to economic growth, the performer basis has generally been preferred although the R&D literature is not clearly dispositive (Sveikauskas 2007). Material differences between business R&D funded and business R&D performed took place the 1950s and 1960s, but the differences in later periods are relatively minor. In our earlier analysis of productivity with Sichel, we used the performer data mainly because this measure seemed better aligned with the notion of self-generated production; in any event, the issue was a relatively minor one for that analysis, because its start period was 1973. We retain the use of R&D capital input on a performer basis in the productivity calculations that follow, but we show BEA's total net stock to illustrate the trend in R&D overall.

**Table 1**
**Rates of change in human capital per worker hour and real R&D net stock**
(average annual percent change)

| | 1959 to 2007[1] | 1959 to 1973 | 1973 to 1995 | 1995 to 2007[1] |
|---|---|---|---|---|
| 1. Labor composition index | 0.33 | 0.12 | 0.40 | 0.47 |
| 2. Real R&D net stock, total | 5.50 | 7.44 | 3.49 | 7.41 |
| *Contribution to NFB OPH growth (percentage points):* | | | | |
| 3. Labor composition | 0.22 | 0.08 | 0.27 | 0.31 |
| 4. R&D capital deepening, business, performer basis | 0.14 | 0.15 | 0.08 | 0.22 |
| 5. IT capital deepening[2] | 0.36 | 0.17 | 0.38 | 0.55 |
| *Memo:* | | | | |
| 6. (3)+(4) as a percent of the change in NFB OPH | 6.5 | 8.0 | 23.8 | 8.7 |

Source—Data, BLS (labor composition index) and BEA (Real R&D net stocks). Contribution to growth, BLS (labor composition) and authors' estimates (R&D capital input). Authors' estimates of R&D capital input use BEA's R&D investment data and the "output" deflator from its preliminary R&D satellite account.
NFB OPH = output per hour, nonfarm business sector.
1. BEA's data for R&D (line 2) end in 2004.
2. Removes the R&D software investment double-count (see BEA R&D article).

Measures of $\dot{h}$ and $\dot{R}$ are shown in the table above. The human capital measure is the BLS labor composition index (line 1), and the entry for $R$ on line 2 is the BEA total net stock of U.S.-funded R&D. These measures are strikingly different. The available index of human capital per hour worked increases about 15 percent over the period shown (see chart 1) whereas the total R&D capital stock balloons more than tenfold; see chart 2, which also shows separate results for private business and public R&D stocks. After restating the changes on lines 1 and 2 in terms of contributions to the growth in nonfarm business output per hour (which subtracts the growth in hours from the growth in private business R&D capital and accounts for a sizeable difference in factor income shares), the difference in the two variables narrows greatly (compare lines 3 and 4).[6]

Both human capital and private business R&D capital have made sizeable percentage point contributions to the growth in output per hour according to these measures. [Note: results in line 4 using the BEA output deflator are preliminary and those for line 5 use author's estimates for recent years and may be incorrect owing to the magnitudes involved.] Indeed, their sum is essentially equal to the contribution from IT capital, a significant magnitude to be sure.

But is that all there is to the impact of human knowledge and research capital on productivity? The increases in these quantities explain only 6-1/2 percent of the overall gain in labor productivity from 1959 on (line 6), leaving the remainder to be explained by the deepening of physical capital and shifts in the production function. And, after accounting for a significant portion of the increases in NFB OPH from 1973 to 1995 (a period of lackluster growth overall), the measured contribution of human knowledge and research activity fell back to its pre-1973 fraction from 1995 on. Can this be correct?

## IV. Intangibles and Knowledge Appropriation in Growth Theory and Empirics

Capital stocks do not appear spontaneously, but are the result of systematic investments that require resources to produce as the CFM and equation (10) make clear. Whether it is the construction of a piece of tangible equipment, or a "bit" of knowledge, consumers must be willing to defer current consumption in order to build up resources that they expect will increase future consumption.

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[6] Labor share averaged .667 versus an estimated .096 for R&D capital input over the same period. The derivation of the estimate for R&D capital input follows standard procedures, as explained in CHS 2006.

On the firm side, the resources set aside for future capacity expansion are increasingly being built by business knowledge appropriation, a process whereby financial or commercial value is obtained from the intellectual property accumulated in the "work done" by employed scientists and engineers, product developers, market researchers, managers and executives, etc. Relative to the "research" view, interpreted narrowly as the view that R&D is the genesis of innovation in business (high rates of returns and spillovers are widely documented), the focus on intangible capital recognizes a broader system of product design and development (including services products), marketing, and management as contributing to modern economic growth capitalist economies.[7] [insert discussion of implications for wages; discussion of training]

The $R$ from before therefore must be expanded to include all of the costs associated with commercializing new products and services and with developing and maintaining organizational capabilities, an expansion that greatly increases the potential for a paradigm shift, and along with it, the stylized facts. To illustrate the potential for such a shift, assume that the economy's workforce is composed *entirely* of "knowledge workers," as is currently the case for much of the high tech sector in the United States.[8] The economy's resource constraint is then a simple one-sector model with two capital goods, physical capital and knowledge capital. Assuming the resource constraint has

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[7] With regard to the estimated high rates of return, in a recent literature review, Sveikauskas (2007, p 17) opines "the high returns firms apparently earn on research expenditures may partially reflect returns to such complementary investments." He further notes, as did Mansfield and others long ago, that R&D returns could reflect a substantial risk premium owing, at least in part, to the uncertain nature of expected commercial returns (Mansfield *et. al.* 1971).

[8] [Include comment about modularity in production and globalization. Berger.] As Mandel (2006) observes, while the Apple iPod is made in China, "Where the gizmo is made is immaterial to its popularity. It is great design, technical innovation, and savvy marketing that have helped Apple Computer sell more than 40 million iPods." In this view, the pure production of a "gizmo" is no longer the key activity in many high technology industries, and the transformation of input into output must be seen as a far more complex process involving product development, management, and marketing.

been duly expanded on "both sides" according to the CFM and equation (10), and if production is Cobb-Douglas with constant returns, the aggregate production function reduces to the so-called $AK$ model of endogenous growth (for proof, see Barro and Sala-i-Martin 2004, pp. 240-242).

Though the above example is unrealistic for the economy as a whole, as just noted, the stylized business model *is* an accurate depiction of many IT firms now (Apple, Cisco, Nvidia and other "fabless" semiconductor companies) and may indicate the direction where many others are heading. We therefore turn to the assumptions used in our central proposition: Let $R$ in fact be the product of many assets that enter the more general production function (11) as $\left(\prod_{i}^{\tau_N} R_i^{\omega_i}\right)^{\alpha_2+\beta}$ where the summation over $i$ from 1 to $\tau_N$ represents the expansion of knowledge capital from investments based on the "work done" by scientists and engineers (R&D) to a larger number of investments based on the "work done" by a broader list of workers. The parameter $\beta$ represents all manner of spillovers not otherwise captured by the standard growth computations for R&D and human capital. Other parameters are the usual elasticities.

The central proposition is as follows: As $i$ increases from 1 to $\tau_N$, the aggregate increasing returns parameter approaches 0, thereby restoring the "utility" of the standard neoclassical production function and paradigm for explaining modern economic growth. With this interpretation, the shift in paradigm is in the context, not the theory, of economic growth. Intangible capital, as IT/computer capital before it, begs a paraphrase of the famous quip by Robert Solow (1987): you see the knowledge economy everywhere but in the productivity data. The emerging role of intangible capital is a composition effect, but the effect is not readily apparent from available data because many important asset types are not currently capitalized in national accounts.[9]

To build the required capital and productivity data, we rely on the framework and data for intangible investments developed in our earlier work with Sichel. In the one-sector neoclassical macro growth model, the creation of the new productivity and capital data occurs as follows: The addition of intangible capital, $R_t$ , to the input list in (1) means including real intangible investment, $N_t$ , in real output:

(12) $$Q_t = C_t + I_t + N_t$$

and rewriting the nominal GDP accounting identity as

(13) $$P_t^Q Q_t = P_t^Q C_t + P_t^Q I_t + P_t^Q N_t = P_t^L L_t + P_t^K K_t + P_t^R R_t \quad .$$

Given time series for intangible investments, starting values for capital and depreciation rates, two capital accumulation equations can now be evaluated:

(14) $$K_t = I_t + (1-\delta_K)K_{t-1} \text{ and } R_t = N_t + (1-\delta_R)R_{t-1} \quad .$$

New $P^K$ and $P^R$ variables can be calculated by solving for the *ex post* rate of return $r$ that satisfies equation (13), a procedure established by Jorgenson and Griliches (1967), and which yields

(15) $$P_K = (r+\delta_K)P_Q \text{ and } P_R = (r+\delta_R)P_Q \quad .$$ [10]

In this expanded framework, the factor shares change, and are recomputed as:

(16) $$s_t^L = P_t^L L_t / P_t^Q Q_t \ , \ s_t^K = P_t^K K_t / P_t^Q Q_t \ , \ s_t^R = P_t^R R_t / P_t^Q Q_t \quad .$$

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[9] In terms of R&D, the proposition implies only that *aggregate* excess returns to private R&D vanish once all relevant costs are taken into account. The well-documented transfer of R&D across firms within industries remains an important underlying factor in the diffusion of technology appearing as a costless shift in the production function.

[10] This entire formulation is more plausibly presented as a three sector model, with separate production functions and separate prices for the three components of aggregate demand. In our empirics, we assume that the price for newly produced intangible assets is the same as the overall nonfarm business output price (except R&D), so the above exposition is actually not that far off the mark.

Finally, the contributions to growth are determined in the usual way. Although much more complexity inheres in the actual data system (taxes, multiple asset types for physical capital, and the like), these equations generally summarize the basic steps involved in expanding a productivity and capital dataset to include additional types of capital.

The table below reports the results of assessing the contribution of business knowledge appropriation to the growth in nonfarm business output per hour. Nonfarm output is adjusted to include intangibles, and results are shown beginning in 1959.

**Table 2**
**Contribution to the growth output per hour from intangible and human capital deepening**
(average annual change, in percentage points)

| | 1959 to 2007 | 1959 to 1973 | 1973 to 1995 | 1995 to 2007 |
|---|---|---|---|---|
| 1. Intangible capital deepening, (expanded $\dot{R}$ per hour) | .47 | .34 | .39 | .74 |
| 2. Computerized information[1] | .07 | .02 | .07 | .12 |
| 3. Intellectual property | .23 | .19 | .17 | .35 |
| 4. Economic competencies | .17 | .12 | .15 | .27 |
| 5. Human capital per hour ($\dot{h}$) | .22 | .08 | .27 | .31 |
| *Memos:* | | | | |
| 5. New CHS | .37 | .30 | .28 | .58 |
| 6. New CHS, excl. R&D | .23 | .15 | .20 | .35 |
| 7. (1)+(5) as percent of the change in NFB OPH | 20.7 | 11.6 | 24.5 | 26.6 |

Note—All calculations are for the nonfarm business sector.
Source—Intangible capital, authors' estimates; human capital per hour is the BLS labor composition index. R&D contribution uses BEA's R&D performer investment data from 1959-2004, authors' estimates both before and after, and, as of this writing, preliminary results using the BEA R&D "output" deflator as the investment price.
1. Removes the R&D software investment double-count (see BEA R&D article).

Jumping to the bottom line, the combined contribution of intangible capital deepening and increases in human capital per worker hour accounts for more than 20 percent of the overall gains in output per hour (line 7) for the period shown. Compared with the results shown in table 1, the stronger contribution stems from the rapid rate of intangible capital deepening in more recent years (1995 to 2007).

The results on capital contribution stem from the divergent behavior of what are now two rates of saving (investment) in the expanded framework:

$$\sigma_t^I = P_t^Q I_t / P_t^Q Q_t \quad \text{and} \quad \sigma_t^N = P_t^Q N_t / P_t^Q Q \ . \tag{17}$$

These investment rates are shown in the upper panel of chart 3 and hint at the potential for the change that plays out in the growth computations: the intangible investment rate moves up noticeably through 2000. While we estimate that the rate of intangible investment has been stable post-2000, the tangible investment rate continues a downward trend that apparently began in the early-/mid-1980s. This shift in composition has an impact on the aggregate investment rate, illustrated in the bottom panel by comparing rates from systems of data with and without the capitalization of intangibles. As may be seen, the divergence is large enough to affect the aggregate picture: Whereas the rate of private business investment previously began to slide down in the mid-1980s, the rate including intangible investment drifts up.

The emerging role of intangible capital is also shown in chart 4, whose upper panel shows nominal shares of tangible and intangible capital with the expected pattern. When looking at overall income shares we obtain one of our most striking results, that capital's share rises steadily over the entire period we study. Of course, the context here is especially important. For example, the growth of R&D was very strong in the early years and prior to the start of this study but experienced a long lackluster period before gaining again with the onset of the IT revolution. During that middle period, the climb of intangible investment and capital likely was related, at least in part, with the rapid expansion of the managerial workforce in the United States (chart 5).

The technology revolution appears in this expanded framework in the IT capital component of tangible capital, and in the relation between intangible investment (which includes software) and the corresponding stock. Jorgenson (1966) showed that the two exactly balance under Golden Rule steady-state growth, so the inclusion or omission of a type of capital from the model does not affect the dynamics of growth.[11] However, a steady-state growth model is not well-suited to the task of describing a shift from one technological era to another. The IT revolution involves new types of capital, major changes in the composition of existing types, as well as shifts in the production function. In the early stages of the transition, the growth in new investment will typically outstrip the growth in the corresponding stock. The growth rates of the two will not cancel, and will instead affect the dynamics of the model. Something similar may be going on with intangible capital, though the developments are not necessarily technological/scientific in their fundamental nature, even if some are complementary with IT and/or R&D.

When the full range of business investments in intangibles are capitalized in macroeconomic data, the result is a picture of the transformation of input into output that better summarizes the complex technological, environmental, and cultural factors that shape value creation in modern economies. We think this is especially true relative to the view that increases in human knowledge enter the production function as they do in the standard data via the augmentation of labor input. When you look at these standard data, you have to ask, where is the Knowledge Economy? The knowledge held, nurtured, and

[11] Capital and output (and their components) are endogenous in the steady state model, and grow at a common rate determine by labor force growth, the rate of depreciation, and the Harrodian rate of technical change. The levels also depend on the rate of saving.

developed *within* business organizations is one of the most important inputs to production in the business world of today, and we need better and richer micro and macro data to improve our understanding of modern production processes.

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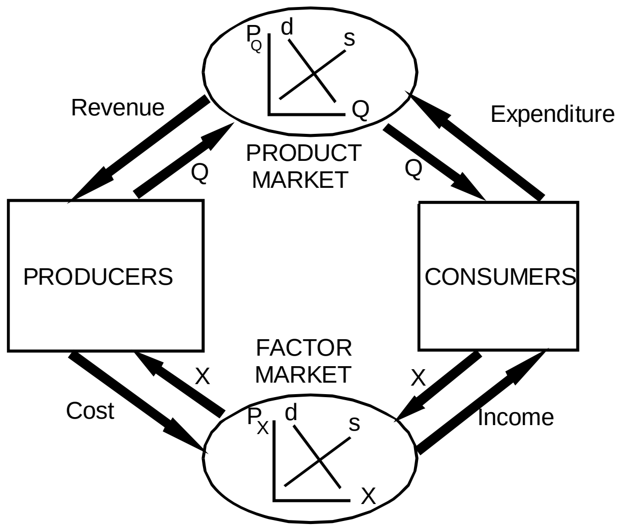
Figure 1



P
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PRODUCT
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PRODUCERS
CONSUMERS
FACTOR
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Cost
Income
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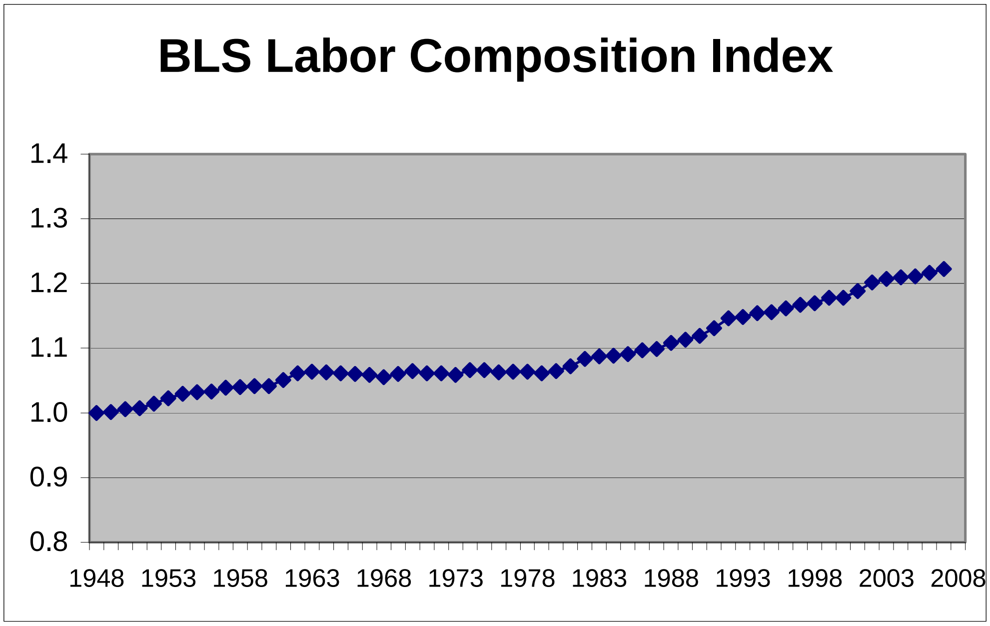
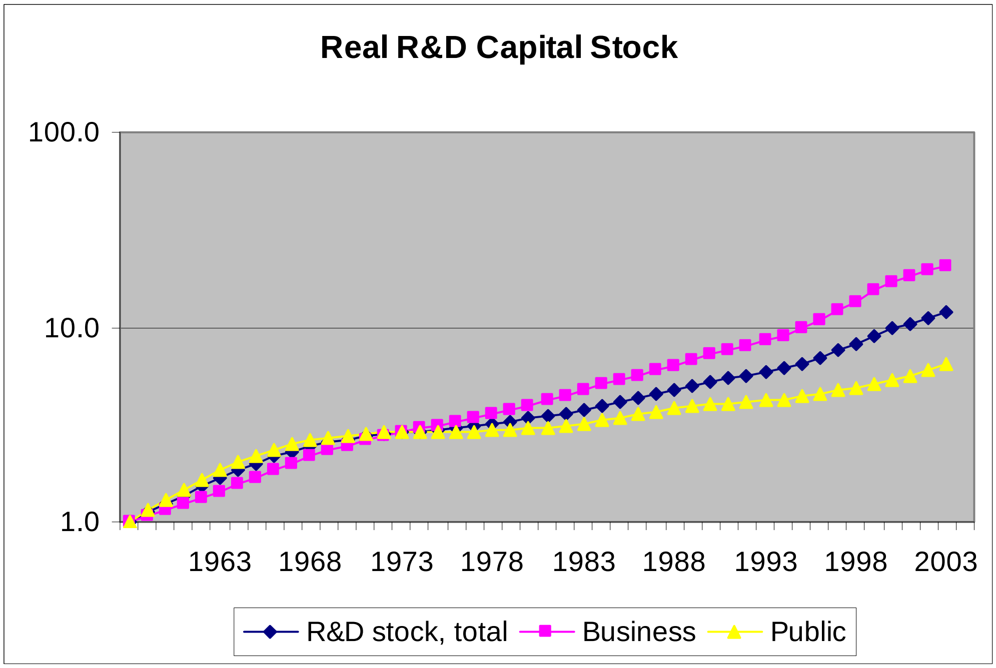
Chart 1



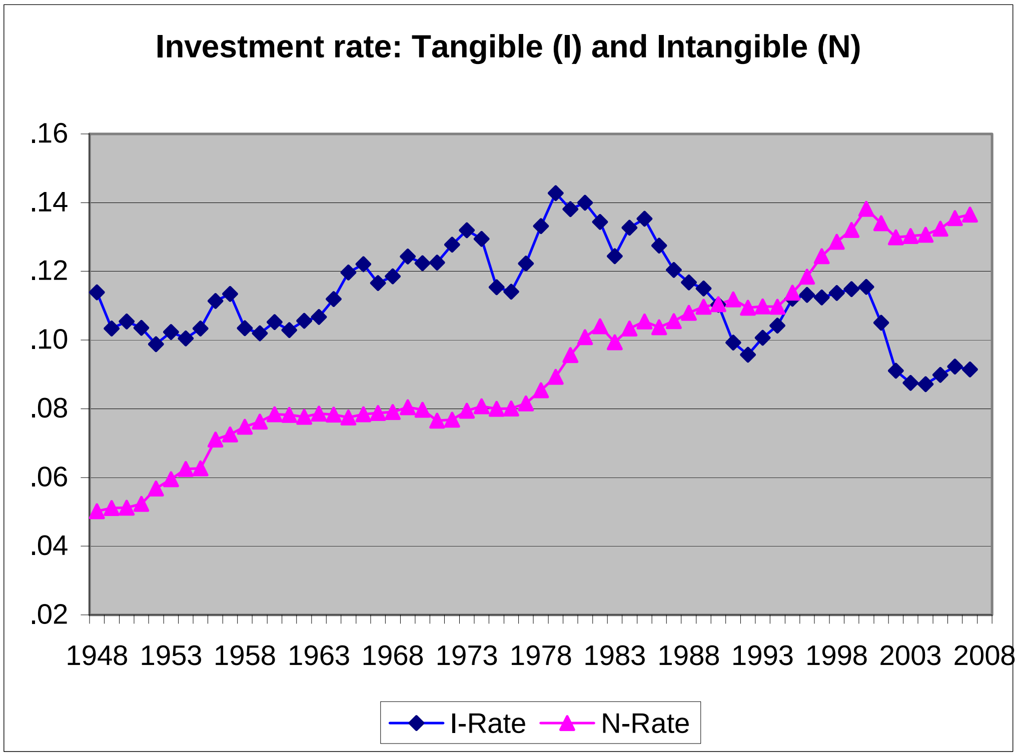

Source. Data issued by the Bureau of Labor Statistics, indexed to 1948=1.0.

Chart 2

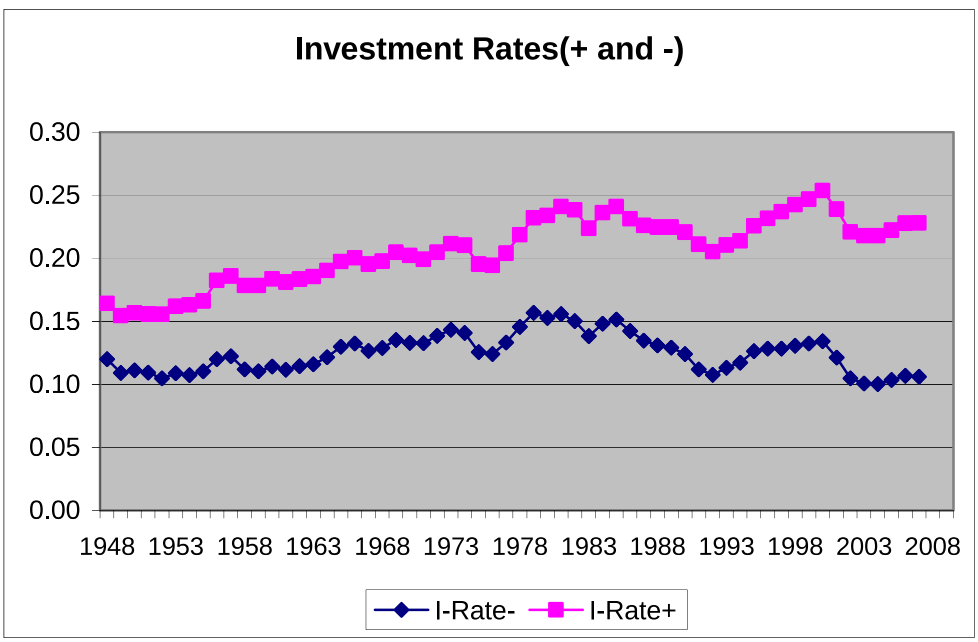



Source. Data from Bureau of Economic Analysis R&D Satellite Account, indexed to 1959=1.0. Last point plotted is 2004.

Chart 3

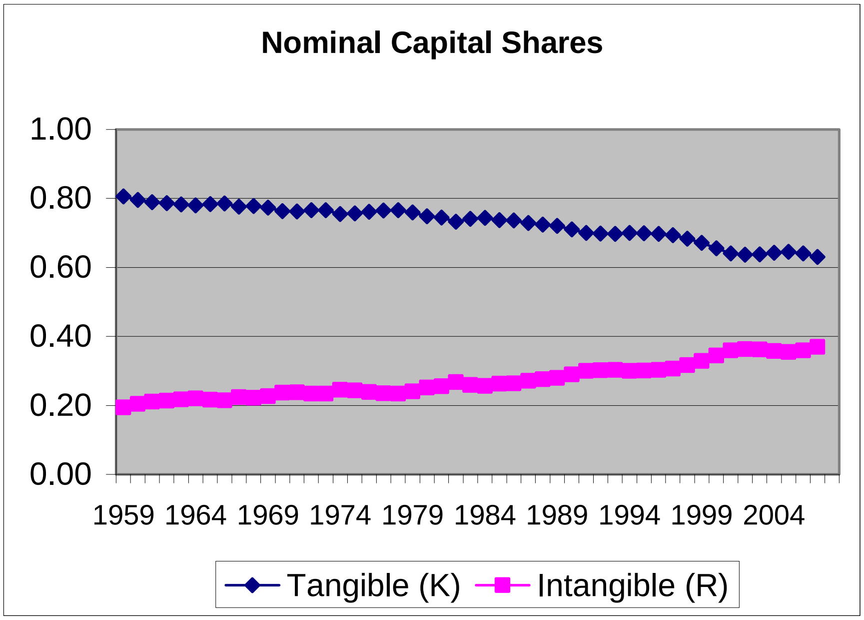



I-Rate is the tangible investment rate, and N-Rate in the intangible investment rate in a system of data in which intangibles are capitalized.




I-Rate+ is the total investment rate including intangibles (the sum of I-Rate and N-rate from above). I-Rate- is the total investment rate from a system of data in which intangibles are not capitalized.

Chart 4


Nominal Capital Shares
1.00
0.80
0.60
0.40
0.20
0.00
1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Tangible (K)
Intangible (R)

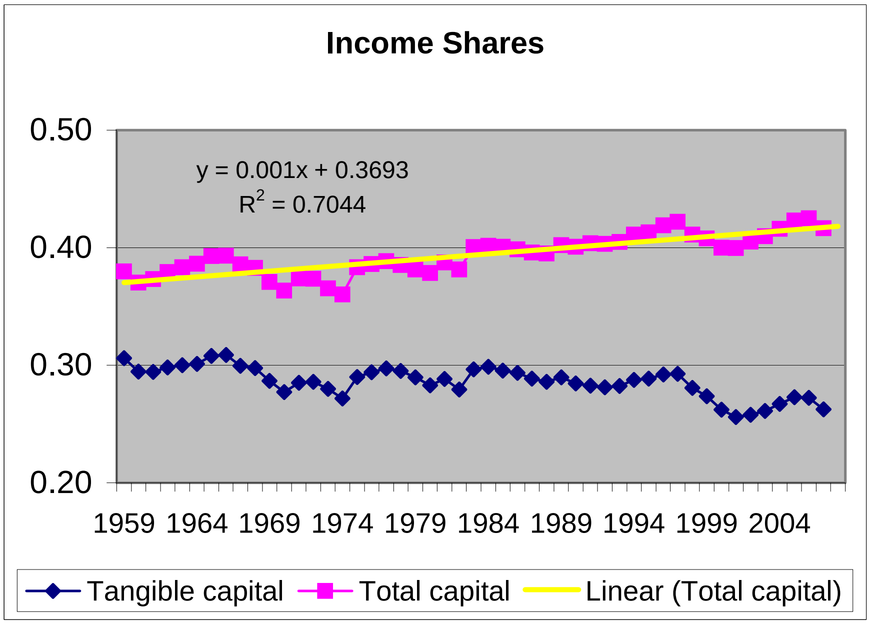
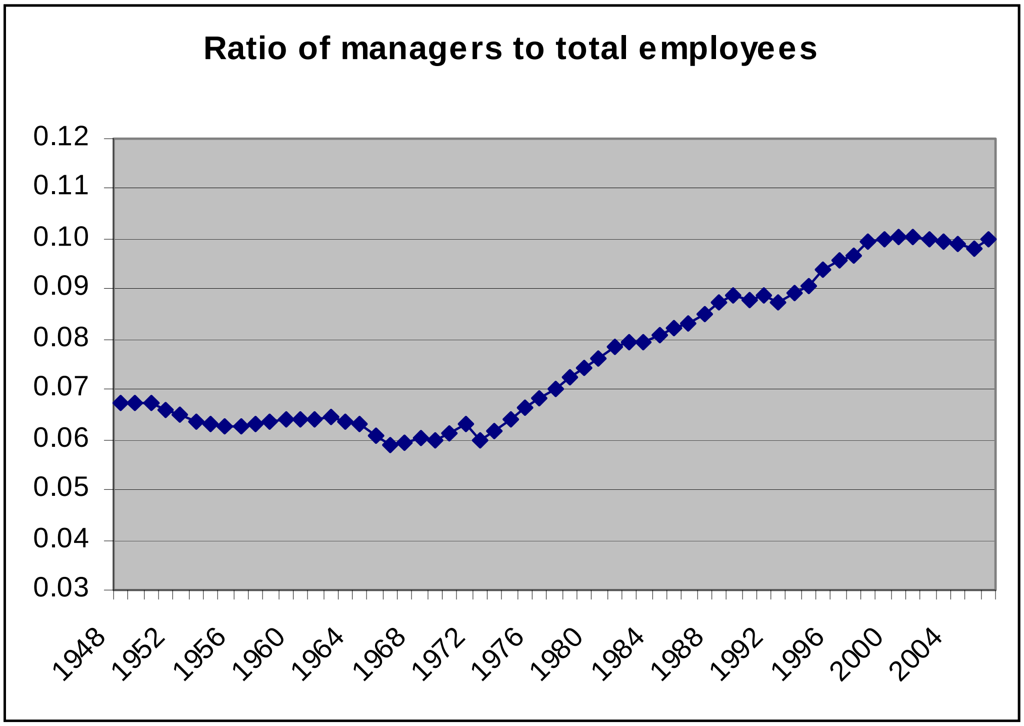

Income Shares
0.50
0.40
0.30
0.20
y = 0.001x + 0.3693
R2 = 0.7044
1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Tangible capital
Total capital
Linear (Total capital)

Chart 5




Source: Estimates based on data from the Current Population Survey and Decennial Census. Excludes farm managers.