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Measuring Capital and Technology: An Expanded Framework

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April 25, 2002

*Federal Reserve Board, University of Maryland and NBER, and Federal Reserve Board, respectively. This paper was prepared for the CRIW/NBER conference “Measuring Capital in the New Economy,” April 26-27, Washington, DC. The views expressed in this paper are those of the authors and should not be attributed to the Board of Governors of the Federal Reserve System or its staff.

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I. INTRODUCTION.

We care about technological innovation and capital formation because they are the source of rising living standards and output growth. Growth economists have undertaken the important task of measuring the relative importance of these factors in explaining the dramatic improvement in the standard of living occurring since the beginning of the Industrial Revolution. This effort has increased in recent years with the debate over the “new economy” and the question of whether labor productivity, a proxy for living standards, will continue to rise at the accelerated pace of the late 1990s. As currently measured, output per hour has risen about 1 percentage point per year faster since in the second half of the 1990s than it did during the period of lackluster growth from 1973 to 1995 (table 1).

Traditional growth-accounting analysis using published data has made important contributions to our understanding of recent developments. However, many analysts have had a vague (and perhaps stronger) sense that the traditional framework and data may not tell us all that we would like to know about the sources of economic growth. Knowledge capital has become increasingly important but does not explicitly appear in the traditional framework and data; market valuations of firms have moved far away from book values of traditional, tangible assets; and the statistical agencies have had to continuously undertake new efforts to keep their measures up to date in our rapidly evolving economy. This general sense that something may be missing from the traditional framework has appeared in many guises in different strands of the literature. Before getting to what we do in this paper, we highlight some of the different strands of analysis that have touched on these issues.

In a general sort of way, data questions have been around for a long time, much discussed in the context of the productivity slowdown of the 1970s, the “productivity paradox” of the 1980s and early 1990s, and never far from critiques of traditional sources of growth analysis. A new era of data concerns started in 1995 when Federal Reserve Chairman Greenspan observed that CPI inflation appeared to be biased upward by about 1 percentage point per year, according to the best evidence available at that time.¹ The debate that ensued led to the Boskin Commission’s 1996 report that confirmed Greenspan’s estimate and attributed about half of the bias to the failure of the CPI data to capture quality change.

Earlier in the 1990s, many observers – from Zvi Griliches to *Business Week* magazine – voiced concerns that the broader price and productivity data failed to capture the true dynamism of the economy’s services industries. Chairman Greenspan reiterated this concern in early 1997, citing the implausibility of measured negative productivity trends in some services industries in testimony on the consumer price index.² Given these concerns – and the observation that the services industries with negative productivity trends were, for the most part, the top computer-using industries (Triplett 1999) – the Brookings Institution established a workshop series in 1998 to promote research on service sector *and* technology measurement issues.

In a separate line of analysis, Robert Hall inferred from the observed values of securities, primarily the stock market, that U.S. corporations had accumulated a large quantity of intangible capital in the past decade (Hall 2000, 2001; see also McGratten and Prescott 2000). Hall’s analysis raised a central issue in the “new economy” debate: Should intangible investments in

¹ Greenspan’s estimate of the CPI bias was drawn from Lebow, Roberts, and Stockton (1994).

² Chairman Greenspan’s concerns about the measured productivity trends in services industries were first expressed in remarks to the FOMC in late 1996, based on a 1996 staff analysis (see Corrado and Slifman 1999). The BLS position concurs with this view (see the February 1999 issue of the *Monthly Labor Review*).

knowledge be treated as intermediate consumption (as now) in accounting for economic growth or should they be capitalized? Similar issues arose in the economic research that uses financial data to value firms' R&D and patent assets and to construct intangible stocks (e.g., Griliches 1981, Cockburn and Griliches 1988, B. Hall 1993) and by the literature that links organizational change and human resource development with output and productivity growth at the firm level (eg., Bartel 1992, McGuckin 1994, Lynch and Black 1995, Brynjolfsson and Yang 1999, Brynjolfsson, Hitt, and Yang 2000).

In addition, an influential line of accountancy research has studied the relationship between intangibles and corporate valuation at the firm level and advanced models and proposals for defining capital spending more broadly. This line of work – summarized in a recent book and report (Lev 2001, Blair and Wallman 2000) – views expenses for research and development (R&D) and spending on human resource development and organizational change as major forms of corporate investment. Lev argues that corporations should disclose more information about activities related to intangible investments (e.g., outlays for internal IT development, customer acquisition, and employee training) and supply more detailed information on R&D spending in their financial reports. Such information would be enormously valuable to growth and productivity analysts, particularly if complemented by broad-based survey data.

Many concerns about the existing productivity, output, and price data stem from the procedures used to construct the measures. But we have seen remarkable progress in our measurement system in recent years, and we now believe that further progress requires an advance in the theoretical infrastructure underlying the data. In particular, the current application of economic theory has left many important issues unresolved, such as those surrounding intangible inputs and output. In this paper, we attempt to take some small steps

toward a broader framework for the economic measurement of capital. We proceed along three fronts.

Section II of the paper proposes a more general theoretical framework for thinking about many (although by no means all) of the issues raised above, with special emphasis on the treatment of capital and its interaction with technological innovation. We start with the standard sources of growth (SOG) model, which is organized around the production function, following Solow (1957) and Jorgenson and Griliches (1967), and embed this model in the larger neoclassical growth framework as suggested in Hulten (1975, 1979, 1992). Capital is an intertemporal intermediate good in this expanded framework, which makes it well suited for examining two new economy issues: Should intangible investments in knowledge be treated as an intermediate input or should they be capitalized? and, How can the SOG framework be used to account for the *full* effect of technical progress on growth and welfare. We take up the latter issue first and use the expanded framework to show that conventional TFP residuals understate this full effect.

In the third section of the paper we put together some rough numbers on the extended framework *using conventional published data*. Although we have raised the issue of intangibles, we start with conventional published data to take the extended framework through its paces on a database that is widely familiar to analysts and to show how the extended framework relates to conventional SOG analysis. In particular, we calculate conventional TFP measures and our related, expanded welfare measures, where the latter account for the capital accumulation that is induced by a changes in technology.

The fourth section of the paper applies the intertemporal model to the practical issues that would be raised by including more intangible assets in the national accounts. In particular,

we pull together disparate pieces of data on investments in intangibles to gauge, in a rough way, the plausible magnitude of spending for some frequently discussed intangibles. We try to be careful to separate out those assets that are already included in the national accounts from those that are not. Also, we try to be careful, at least in principle, to distinguish those intangible assets that add to a firm's capital stock from those that dissipate too quickly to count as capital and that should therefore be counted as intermediate inputs. (For example, some advertising has a very short effective life.) Although an important goal for growth analysts is to construct capital stocks of intangibles, note that we are only going after the more modest goal of estimating *spending* on intangibles.

It is important to emphasize that we regard the results in this paper as early steps in a long process, and we recognize that we are raising many more questions and issues than we are answering. Nevertheless, there are some implications of this paper for measurement research and practice, and these are described in Section V.

II. THEORY.

A. The Production Function Approach to Growth Accounting

Contemporary growth accounting is organized around the concept of the aggregate production function. Real output is assumed to be related to a list of the inputs, with provision for changes in the productivity of the inputs. In index-number (nonparametric) versions, this last term is usually represented by a residual time-shifter of the Hicks' neutral type:

$$(1) \quad Q_t = A_t F(K_t, L_t)$$

Q_t is real output, K_t and L_t are capital and labor, and A_t is an index of the level of (costless) technology. Econometric studies of growth allow for more sophisticated parametric production

functions, but in either case, the growth in output is driven either by the growth in inputs or by technical change. The latter is represented in the standard Solow diagram by a shift in the production function (a to c in Figure 1) and the former by a movement along the function (c to b). This leads to an “explanation” of the growth in output per hour worked as a sum of two underlying forces: the propensity to save (the increase in the capital-labor ratio), and the propensity to innovate (the increase the productivity of capital and labor).

The Solow residual provides one way to sort out this dichotomy. Under constant returns to scale (CRTS) and marginal cost pricing, the production function yields

$$(2) \quad g_Q = s_K g_K + s_L g_L + g_A.$$

(the g -terms denote growth rates and the s -terms are factor shares). Each item in (2) except the last can be measured given the appropriate accounting data; the last can therefore be inferred as a residual - the famous Solow residual “measure of our ignorance.” If all assumptions are valid and the data are accurate, the residual is equal to g_A , the shift in the production function driven by costless improvements in technology and other productivity-enhancing factors. In the parametric approach of econometrics, the shares are estimated as output elasticities, and the shift is obtained from the estimated time parameters.

The data required to implement the Solow-Jorgenson-Griliches model are derived from the fundamental GDP accounting identity relates the value of output (consumption and investment) to the value of the inputs (labor and capital):

$$(3) \quad p_t Q_t = p_t^C C_t + p_t^I I_t = w_t L_t + r_t K_t .$$

This expression captures flows of money into and out of the business sector and is the economy-wide analog of a firm’s income statement. This identity is the basic empirical starting point for the sources of growth analysis in (2), but the implementation of (2) requires an estimate of

output and inputs in constant rather than current prices. This can be done by separating the consumption, investment, and labor income flows in (3) into price and quantity components using published indices; the capital income flow, however, presents a problem. Neither the price nor quantity components of $r_t K_t$ are directly observed. (In terms of quantities, the current measurement system provides a measure of I_t but not K_t .) Indirect methods must therefore be employed to isolate the quantity component of capital in order to calculate its growth rate.

The basic two-step procedure used to solve this problem was developed by Jorgenson and Griliches (1967). The estimate of I_t from the left-hand side of (3) can be used to impute a capital stock using the perpetual inventory model:

$$(4) \quad K_{t+1} = I_t + (1-\delta)K_t.$$

Investment in each year is added to the preceding year's stock, which is adjusted for retirement and in-use loss of productivity (we assume a constant rate of deterioration/depreciation for simplicity of exposition). An estimate of the initial stock of capital, K_0 , serves as the starting point for the perpetual inventory method. This procedure must be implemented for every category of investment good included as part of the aggregate of I_t . Note that this procedure has the feature that whatever is included in I will be included in K .

Aggregate capital income $r_t K_t$ must then be allocated to each type of capital good when more than one type exists. Following Jorgenson and Griliches, this is accomplished using the Hall-Jorgenson user cost for capital good j :

$$(5) \quad r_{jt} = (i_t + \delta_j) p_{jt}^I - \Delta p_{jt}^I,$$

where i_t is the overall nominal rate of return to capital. Given a user cost for the j^{th} type of capital and the corresponding stock, a separate $r_{jt} K_{jt}$ can be computed for each type of stock and

the result used to calculate a share-weight for use in constructing a capital aggregate and the Solow residual. Such a procedure, however, will not separately identify the influences of capacity, markup, and scale effects, and these factors may become embedded within the estimated return to capital.

Despite the power of this approach, the theory behind it is not helpful in addressing the problem of which input and output should be included in the analysis, because the production function (1) only asserts that there is a stable relation between output and inputs. Indeed, the production function is a structural equation embedded in a larger model, and by itself offers no explanation of the evolution of labor, capital, and technical innovation. These variables are treated as exogenous, without any rule for determining how the variables ought to be defined or which belong in the analysis. Thus, this framework fails to provide guidance on a host of questions about the “boundaries” of economic variables: Should output be measured gross or net of depreciation? What “razor” should be used for determining which inputs are intermediate and which should be capitalized? How should intangible inputs and outputs be treated? Should capital-embodied technical change be ignored or explicitly included?

We will approach these boundary problems by embedding the production function in a larger framework in which the variables of interest are endogenized. There are a number of options in this regard: the Solow-Swan and Cass-Koopmans neoclassical growth models endogenize capital formation, and the Lucas-Romer endogenous growth models endogenize technology and capital (see also Barro and Sala-i-Martin 1995). In an empirical context, Rymes (1971) and Hulten (1975,1979) examined some of the implications of the endogeneity of capital for growth accounting using the conventional accounting model (2), and Mankiw, Romer, and Weil suggest an alternative model based on the Solow-Swan model. In the following section of

this paper, we continue this line of analysis but apply it to the problem of model specification and the appropriate measurement of capital and technology variables.

B. Fisherian Optimal Growth

Contemporary optimal growth theory embeds the production function in a larger model in which an intertemporal utility function $U(C_1, \dots, C_T)$ is maximized subject to the constraints of technology, capital accumulation, and initial resources. Since we are ultimately interested in the model's implications for accounting practice, we explore a variant in which prices are assumed to be proportional to marginal utilities. This permits us to restate the intertemporal welfare problem as one of maximizing the present value of consumption,

$$(6) \quad W_{0,T} = \sum_{t=0}^T \frac{p_t^C C_t}{(1+i)^{t+1}},$$

subject to the production function $C_t + I_t = A_t F(K_t, L_t)$, the initial and terminal stocks of capital K_0 and K_T , and the accumulation condition $K_{t+1} = I_t + (1-\delta)K_t$.³ In equation 6, the initial and terminal stocks of capital are set to zero, p_t^C is the consumption price, and i is the (assumed constant) nominal rate of discount. The economic problem is to determine the optimal division of current output between consumption and investment at each point in time. The resulting optimal consumption path $\{\hat{C}_t\}$ maximizes wealth, $W_{0,T}$.

Capital appears as an explicit variable in the constraints in this formulation. However, it largely disappears when these constraints are expressed in equivalent form as

³Of course, in a measurement world with chain weighting, real output does not equal the simple sum of C and I if the relative prices of consumption and investment are changing. However, to keep the exposition simple, we will assume that there is a single output that can be used either for consumption or investment. We will relax this assumption in our empirical work.

$$(7) \quad \Phi(\{C_1, \dots, C_T\}; \{L_1, \dots, L_T\}; \{A_1, \dots, A_T\}; K_0, K_T) = 0 .$$

This is the intertemporal production possibility frontier, indicating all combinations of the consumption vector $\{C_1, \dots, C_T\}$ that are possible given the vector of labor input, costless technology levels, and the initial and terminal stocks of capital. Setting the initial and terminal stocks of capital to zero eliminates the explicit presence of capital (and simplifies the exposition of the intertemporal optimization problem).

The intuition behind this formulation is shown in Figure 2 for the case of two time periods. The feasibility constraint Φ is represented by the curve AB, and the intertemporal utility function $U(C_1, \dots, C_T)$ by the curves UU and U'U'. The optimal consumption plan is represented by the point a, and this point defines the maximal wealth of the economy WW. The optimal point is an explicit function of labor input and level of technology in each period. Capital is implicit in the optimal solution, because $A-C_1$ units of consumption are foregone in period 1 and the resources freed-up by this abstinence are used to make capital goods, which are then used up in production in period 2. Capital is in effect an intermediate intertemporal good .

The relative roles of capital formation and technical change can be explored using the following thought experiment: What would have been the outcome had technology not increased from A_1 to A_2 , with labor held constant? The production possibility frontier in the case of zero technical change is shown as the curve AB', and the optimal solution as b. The effect of capital formation on the optimal consumption plan (in the absence of technical change) is represented by the notional jump from A to b, and the effect of technical change (including the effect of the induced capital accumulation) as the jump from b to a. The latter is the "wealth effect" of technical change much discussed in recent years, but note that it arises only from unexpected increases in the level of technology. Expected increases in technology are

already embedded in the long-run consumption plan of the optimizer (that is, C_1 is invariant to expected technical change).

Under certain circumstances, the optimal trajectory implied by the maximization of the (6) subject to (7) converges to a balanced growth path (Cass (1965) and Koopmans (1965)). For optimal consumption paths that do not necessarily lie on a balanced path, the results of Weitzman (1976) are useful in augmenting the basic Fisherian accounting framework implied by (6) and (7). We turn to this issue in the following section.

III. NET AND GROSS OUTPUT, WELFARE AND GROWTH

A. Net and Gross Output: Theory

In his seminal contribution, Solow (1957) defined output as net of depreciation, and calculated his TFP residual accordingly. This approach was also taken by Denison, but Jorgenson and Griliches (1967) advocated the use of gross output. Advocates of the net output argue that the net concept provides a better indicator of the welfare gains from economic growth than does the gross output concept, because gross output can be increased by using up capital and natural resources. Advocates of gross output point to the fact that factories and businesses do not produce units of output net of depreciation, and if the objective is to measure the growth in productive efficiency, gross output is the right concept.

The intertemporal framework developed in the preceding section makes a useful contribution in resolving this debate. Weitzman (1976) shows that the optimal solution to the intertemporal optimization problem implies an “annual” measure of the increase in consumer welfare: $p_t^C \hat{C}_t + p_t^K \Delta \hat{K}_t$, where the “hats” imply optimal solutions to the problem (6) and (7).

This term – consumption plus the net change in capital – is really nothing more than the Hicksian definition of income: the maximum amount of output that could be consumed each year without reducing the original amount of capital (or “sustainable” consumption). It is also the definition of Haig-Simons income: consumption plus change in net worth. A little algebra also reveals that it is equivalent to gross product, as defined in (3), less economic depreciation (Hulten 1992). Thus, the usual measures of income and net product fall out of the intertemporal optimization problem and are indicators of the annual increase in consumer welfare.

These results may seem to encourage the view that NDP should be used instead of GDP in computing TFP-like residuals. However, this is not the case. The improvement in welfare made possible by technical change is a matter of the “A” terms in the welfare constraint shown in equation 7. The TFP residual computed using real gross output is the right measure of each “A,” not the net-output TFP residual. What, then, is the right way to link welfare to productivity? We will see in the following section that the correct welfare concept is a linear function of the gross-output TFP residual.

B. The Dynamic-Welfare Residual

Equation 6 expressed the increase in wealth (welfare) from period 0 to period T as:

$$(8) \quad W_{0,T} = \sum_{t=0}^T \frac{p_t^C C_t}{(1+i)^{t+1}} + \frac{p_T^K}{(1+i)^{T+1}} K_T - p_0^K K_0$$

$$= \sum_{t=0}^T \frac{w_t^L L_t}{(1+i)^{t+1}},$$

where p_t^C and p_t^K are the prices of consumption and capital goods, respectively, and w_t^L is the wage rate of labor. The first equality in equation 8 is, in effect, the intertemporal budget constraint of the economy, the analogue of the static constraint (3). The second equality shows that the accumulation of wealth can be expressed as the discounted sum of wage payments.

To go to the next step, Hulten (1992) totally differentiated equation 8 to yield an expression parallel to the Solow residual that allocates the change in wealth to its sources. For the period from period 0 to period T, this exercise yields the residual $\Omega_{0,T}$, defined as:

$$(9) \quad \Omega_{0,T} = \mathcal{E}_W - \sum_{t=0}^T \omega_{L,t} \mathcal{E}_L$$

$$= \sum_{t=0}^T \omega_{C,t} \mathcal{E}_{C,t} + \omega_{K,T} \mathcal{E}_{K,T} - \omega_{K,0} \mathcal{E}_{K,0} - \sum_{t=0}^T \omega_{L,t} \mathcal{E}_{L,t}$$

where the $g_{J,t}$ refers to the growth rate of variable J in period t and $\omega_{J,t}$ refers to the appropriate weight on variable J (consumption, capital, and labor input) in period t. The $\omega_{J,t}$'s are defined as:

$$(10) \quad \omega_{C,t} = \frac{p_t^C C_t}{(W_{0,T})(1+i_s)^t}$$

$$\omega_{K,T} = \frac{p_T^K K_T}{(W_{0,T})(1+i_s)^T}$$

$$\omega_{K,0} = \frac{p_0^K K_0}{W_{0,T}}$$

$$\omega_{L,t} = \frac{w_t^L L_t}{(W_{0,T})(1+i_s)^t}.$$

The decompositions in equation 9 represent the intertemporal sources of welfare equation. Equation 9 shows the $\Omega_{0,t}$ residual can be expressed as the growth rate of wealth less an appropriately weighted average of capital and labor inputs. This form is analogous to the conventional SOG decomposition in which TFP can be expressed as output growth less the appropriately weighted growth rates of inputs. The second equality in equation 9 expands the elements of the term for the growth rate of wealth.⁴ The important conceptual difference

⁴There is a difference in the timing convention used in this decomposition relative to the conventional SOG analysis. The conventional decomposition of output growth provides year-by-year figures that often are averaged together across years to gauge average contributions of different sources of growth over time. In contrast, the $\Omega_{0,T}$ residual does not provide year-by-year figures, but rather provides a single breakdown for the full period from period 0 to

between the $\Omega_{0,T}$ residual and the Solow TFP residual g_A lies in the interpretation: the Solow TFP residual measures the shift in the production function due to costless improvements in productive efficiency (figure 1), while the $\Omega_{0,T}$ residual measures the resulting shift in the intertemporal consumption possibility frontier (figure 2). The $\Omega_{0,T}$ residual is thus a measure of the improvement in economic welfare over the time interval from period 0 to period T arising from the annual shifts in technology, g_A . For this reason, we will use the term “dynamic welfare residual,” or DWR, when referring to $\Omega_{0,T}$.

This intuitive linkage is verified in Hulten (1979 and 1992), where it is shown that DWR can be expressed as the weighted sum of the conventional TFP residuals:

$$(11) \quad \Omega_{0,T} = \sum_{t=0}^T \omega_t^Q g_{At} .$$

where ω_t is:

$$(12) \quad \omega_t^Q = \frac{P_t^Q Q_t / (1+i_s)^t}{W_{0,T}}$$

Equation (12) indicates that the weight, ω_t^Q , equals the ratio of current-dollar gross output in period t discounted back to the base period and the denominator is the total amount of wealth accumulated over the period as given by equation 8. Equation (11) shows that the conventional TFP residual and the DWR are complements, not substitutes.

It is no accident that the weights in equation (12) sum to an amount greater than one. This reflects the intermediate good nature of capital, which allows us to appropriate the Domar weighting scheme developed to aggregate Solow TFP residuals across industries (Hulten

period T.

(1978)). In the interindustry case, the Domar weights are the ratio of nominal gross output in an industry to the sum of nominal final demand across industries (GDP). These weights sum to an amount greater than one to reflect the leverage that productivity change at the industry has on aggregate output, because of the induced expansion in intermediate inputs. In the case of the DWR, the weights sum to more than one to reflect the effect that productivity change has on total consumption, because of the induced expansion in capital as an intertemporal intermediate input.

This point can be elaborated in terms of NDP, which we have seen is equal to Haigs-Simons-Hicks-Weitzman income: $p_t^C \hat{C}_t + p_t^K \Delta \hat{K}_t$. Note that the intertemporal budget constraint (8) can be re-expressed as the equality of the discounted present value of $p_t^C \hat{C}_t + p_t^K \Delta \hat{K}_t$ on the one hand, and the present value of labor income on the other.

DWR can be shown to be equal to the share-weighted average of the NDP-based residuals, where the weights are analogous to equation 12, but are based on NDP and sum to one. The individual NDP-based residuals are therefore not to be interpreted as the correct welfare-based measure of productivity. However, it is true that if the NDP residuals are constant over time, they are equal to DWR.

Some further linkages between DWR and other growth-related measures are worth noting. We noted in section II above that the optimal consumption path may converge to a balanced-growth path under certain conditions. One condition is that productivity grow at a constant Harrodian rate, g_H . The Harrodian rate is defined as the shift in the production function (1) measured with respect to a constant capital-output ratio (along the line a to b in

figure 1), whereas the Hicksian rate, which underlies the Solow residual, is measured along a constant capital-labor ratio (along the line \underline{a} to \underline{c} in figure 1).

Thus, the Harrod rate, g_H , which includes induced capital accumulation, is equal to the Hicksian-Solow-Residual rate, g_A , divided by labor's share of income, as in $g_H = g_A / s_L$. With a little algebra (see Hulten (1992)), it can be shown that the DWR equals the constant Harrodian rate on a balanced-growth path. The reason that the contribution of TFP growth is “blown up” in steady state is that TFP growth induces capital accumulation and, ultimately, the pace of capital accumulation in steady state depends on TFP growth.⁵ Thus, on a balanced-growth path in steady state, DWR also equals the long-run contribution of TFP to output growth.

These linkages between DWR, the Harrodian rate of technical change, and the steady-state contribution of TFP to output growth in a simple one-sector model provide some comfort that the DWR is simply a generalization of a familiar concept and not some exotic way of looking at growth accounting. Moreover, the link between DWR and Harrodian technical change provides an interesting interpretation of Harrodian technical change. Namely, Harrodian technical change is more than just the shift in the production function along a constant capital-output ratio; under certain conditions it is a valid measure of the increase in consumer welfare made possible by the shift.

C. Net and Gross Output: Empirical Analysis

In this section, we put some rough numbers on DWR and other TFP-type residuals using *conventional published data*. These numbers will help to make the concept of DWR concrete

⁵ These steady-state relationships are more complicated in a multi-sector model. For example, see Oliner and Sichel (2002).

and to cement ideas about how DWR relates to other TFP-type residuals. This illustration is most effective using a database that is widely familiar to analysts.

Table 2a shows numbers for the key concepts. Before discussing DWR, it is useful to review results for conventional residuals based on gross and net output. The first column shows the conventional TFP numbers based on real GDP in the nonfarm business sector (less housing) for selected periods. (Note that the gross output TFP numbers for the nonfarm business sector in table 2a differ from those in table 1 only because of differences in the time periods shown.) Between 1950 and 1973 – the so-called golden era of productivity growth – TFP rose an average of about 1.7 percent per year (line 1). Following the productivity slowdown in 1973, TFP growth from 1973 to 1995 dropped back to just 0.4 percent per year. Then, from 1995-2000, TFP growth picked up to about 1.2 percent per year, a substantial improvement over its lackluster pace during the prior twenty-some years.

This pattern of TFP – and particularly its role in the productivity resurgence of the late 1990s – has received much attention from economists.⁶ As discussed above, these conventional TFP numbers provide useful information about shifts in the production constraint. However, other measures also provide important insights into the nature of economic activity.

We show the residuals based on net domestic product in the nonfarm business sector in column 2 because they have received attention in the past.⁷ Interestingly, the “net” TFP figures remarkably similar to those based on gross output. Thus, even if one were to disregard the arguments laid out above and use residuals based on *net* domestic product as an indicator of

⁶For example, see Oliner and Sichel (2000), Oliner and Sichel (2002), Jorgenson and Stiroh (2000), Jorgenson, Ho, and Stiroh (2002), and Gordon (2002).

⁷BEA publishes real net domestic product for the nonfarm business sector less housing back to only 1987. For growth rates from 1987 and back, we used the growth rate in real net domestic product for the total economy.

welfare, the numbers in table 2a suggest that the story delivered by the NDP (TFP^{net}) residuals would be essentially the same as that by the GDP residuals (TFP^{gross}).

Column 3 of table 2a shows average annual growth rates of DWR (Ω); these residuals rose nearly 2.5 percent per year from 1950 to 1973, but then slowed dramatically in the period from 1973 to 2000 to a pace of just about 0.8 percent. Although the period from 1995-2000 is too short to obtain sensible estimates of DWR, a comparison of lines 2 and 3 indicate that growth rates $\Omega_{0,T}$ and wealth are noticeably higher when the period extends to 2000 than when it ends in 1995.⁸ More generally, note that the growth rate of DWR is larger than growth rates of the conventional residuals shown in columns 1 and 2. This occurs because DWR takes account of the capital accumulation induced by technical change, whereas the conventional residuals only capture the proximate sources of growth and do not take account of capital accumulation induced by technical change.

Column 4 of the table shows our estimate of Harrod TFP, which is defined as conventional TFP based on gross output (column 1) divided by the average income share of labor over the period shown. What is striking about these numbers is how similar they are to the growth rates of DWR in column 3. For example, Harrod TFP increased at an average annual rate of about 2.4 percent from 1950-1973, just about the same rate of rise as DWR over that period. Similarly, during 1973-2000, the Harrod TFP rose about 0.8 percent per year, the same rate as the dynamic residual. More generally, the analysis here highlights the degree to

⁸Figures are not reported for short periods because, conceptually, these calculations pertain to forward-looking behavior where agents are thinking about long-term wealth (welfare) maximization; very short horizons are not really consistent with this long-term perspective. Also, calculations over short periods of time tended to be unstable in the sense that extending the time horizon by one year often changed the numerical results considerably.

which conventional TFP based on gross output, DWR, and Harrod TFP are complements that illuminate different aspects of growth and welfare.

The numbers in table 2b highlight another way in which conventional TFP and DWR provide information about different economic concepts. This table shows the fraction of real GDP growth in the nonfarm business sector explained by the conventional TFP residual and the fraction of increases in wealth explained by DWR. This key pieces of this relationship for conventional TFP are shown in the first three columns of the table. The first column repeats the numbers from table 2a for $TFP_{t1,t2}^{gross}$, the second column shows the growth rate of real output in the nonfarm business sector less housing, and the third column displays the fraction of output growth explained by TFP (the ratio of column 1 to column 2). As shown in column 3, TFP explained more than 40 percent of output growth from 1950-73. This share dropped back sharply after 1973, but recovered somewhat after 1995. Despite the recovery, from 1995-2000, TFP growth accounted for only about 26 percent of output growth over this period, a smaller fraction than during the period from 1950-1973.⁹

Columns 4 to 6 show a parallel set of calculations for DWR. Column 4 repeats the numbers for DWR from table 2a, column 5 shows the average annual increment to wealth (as defined in equation 8), expressed as a growth rate. Column 6 displays the fraction of wealth gains explained by the DWR; that is, the ratio of column 4 to column 5. From 1950-73, DWR accounted for more than 60 percent of the robust gains in wealth; that is, technical change accounted for 60 percent of the increase in wealth 1950-73. In contrast, from 1973-2000 (line

⁹The smaller share of output growth explained by TFP growth in the 1995-2000 period relative to the 1950-1973 period reflects the substantial pickup in capital deepening that also occurred during 1995-2000.

2), the rate of increase in wealth fell back somewhat, but the fraction of that wealth gain explained by technical change dropped substantially to just 24 percent.

A comparison of columns 3 and 6 yield an interesting observation. Namely, the fraction of gains in wealth explained by DWR (column 6) are larger than the fraction of output growth explained by TFP in the conventional analysis (column 3). This occurs because the extended framework allows for the full effects of changes in TFP over time; that is, increases in TFP induce future capital investment. The conventional SOG framework does not take account of the effect of that induced capital formation on output growth, while the extended framework does account for the effect of that induced capital formation on future wealth gains. Put another way, column 3 summarizes the role of conventional of TFP on output growth, while column 6 shows how this output growth contributes to welfare after taking account of induced capital accumulation in subsequent periods.¹⁰

IV. THE SCALE OF BUSINESS INVESTMENT

Although the precise determinants of the pickup in U.S. productivity in the late 1990s shown in tables 1 and 2a remain a subject of debate, most observers ascribe an important role to one or more of these factors: the enhancement of business performance made possible by computers and related technology, the increased availability of new products and new production processes, and improvements in “firm dynamics” made possible by new workplace practices. However, a significant chunk of the spending related to these activities is for intangibles and is

¹⁰Column 6 could also be interpreted as showing the steady-state contribution of TFP growth to output growth in a simple one-sector model.

not accounted for in the standard SOG analysis. In this section, we begin to confront the boundary issues related to intangibles by applying the framework discussed in Section II.

A. Implications of the Intertemporal Framework for Measurement.

The model and framework presented in section II has several important implications for current measurement practices. First, Figure 2 makes clear that any use of resources that reduces current consumption in order to increase it in the future (for example, the movement along AB from the point A on the horizontal axis to the optimal point \underline{a}) qualifies as an investment. Thus, if resources are devoted to R&D to generate innovations that increase future consumption, an investment has occurred. (The same is true of students' deferral of entry into the labor force in order to pursue a higher education.)

Put differently, Figure 2 argues for symmetric treatment of all *types* of capital. As a result, there is no theoretical basis for treating investments in knowledge and human capital any differently than investments in plant and equipment in national economic accounting systems. One way to treat all capital symmetrically would be to add knowledge and human capital to the "I" in "C+I+G." An alternative approach, indeed, the full logic of the section II, argues for treating capital as an intertemporal intermediate input. The appropriate accounts are then intertemporal and based on a functional form for (1) that links labor input and technology directly to the attainable consumption path; intertemporal accounts drop capital (except for noting the initial and terminal period values).

Real world accounting systems are not intertemporal, however, and pursuing the full logic of Figure 2 does not imply dropping conventional procedures. Real world systems need to include investment because they report data according to the GDP identity (3) and, implicitly, a

recursive scheme for capital that is based on a fixed “length” for the accounting period. The periodicity is the choice of the accountant.

An aspect of the specific choice of a length for the accounting period, usually one year, bears mention. Although it is an arbitrary figure, the choice of a length for the accounting period determines what is a “fixed” asset and what is an intermediate input (or consumption): If a system of accounts selects a daily periodicity, inventories of pencils and paper are fixed capital; if the accounting period is five years, much high-tech equipment and software are intermediate inputs; and if the period is 100 years, almost all equipment purchases would need to be expressed as intermediates. The intertemporal model thus implies that the *scale* of business fixed investment and GDP is somewhat arbitrary, whereas the underlying economic welfare, measured by (8), is invariant to the choice of the accounting period.

Note that because what becomes fixed investment is arbitrary, what becomes inventory investment is also arbitrary in this model. Any input that is not used for current consumption and is intended to increase future consumption is “capital” in the sense of section II, even if it is not classified as fixed capital. Such an input would simply be an inventory carried over for future use. Indeed, in the framework of Section II, all capital is an inventory of intermediate goods.

To summarize, the intertemporal framework presented in section II suggests that business expenditures designed to raise productivity or increase the range of production possibilities in the future is investment, while those that are inputs to production processes and used up within the accounting period are intermediate consumption. Moreover, from a national accounts perspective, the framework offers a clear guideline for the categorization of many types of business expenditures as either fixed investment or intermediate inputs: Is the

replacement cycle of the input less than/greater than the accounting period selected? And, the framework reminds us that, when changes in produced intermediates can be identified and valued, they must be included in inventory investment and the corresponding asset recorded on the national balance sheet.

B. Basic Types of Investment and Capital

Following Lev (2001), we interpret and use the terms “knowledge capital,” “intangibles,” and “intellectual property” interchangeably, and note, as he has, the tendency of economists to use knowledge capital, while intangibles is used in the accounting literature and intellectual capital and/or intellectual property in the management and legal literature. Moreover, economists have tended to view *human capital* as a significant component of knowledge capital. The scope of knowledge capital is thus quite broad; the problems of classification and measurement vary from type to type; and the size of the bias resulting from the exclusion of each type must be considered separately.

Human capital, whether produced *by the household sector* (through their deferral of entry into the labor market) or *by the education sector* (through spending on formal education) is not treated as an asset on the national balance sheet. Measuring the output of the educational sector and the impact of household sector investments in human capital poses an immense challenge. Many important aspects of that challenge have been addressed in an impressive body of work by Dale Jorgenson, Barbara Fraumeni, and others (Jorgenson and Fraumeni 1989a, 1989b, 1992; Eisner 1989; Ironmonger 1996, 1997; Landefeld and Howell 1997; and Jorgenson, Ho, and Stiroh 2002), however. A major result is that the household account expanded to include their human capital investment is *very* large: The available estimates run from 40 to 300 percent of the existing GDP (Fraumeni 2000).

At this point, we turn to non-human *knowledge capital produced by the private business sector*, and we will not explore human capital in the household sector further. How large might such spending be? Some observers have suggested that official GDP and business investment measures are vastly understated because they are limited to capturing spending for tangible, physical assets, rather than expenditures for legally recognized intangible assets, such as patents and copyrights. Nakamura (2001) places the undervaluation of business investment in the late 1990s in the neighborhood of \$1 trillion annually, roughly 10 percent of the existing GDP. Brynjolfsson and Yang (1999) argue that, for each dollar spent on computer and computer-related hardware, nine more are spent on related intangibles, implying that at least \$750 billion, or more than 8 percent of existing GDP, is being missed by business spending on IT-related intangibles.¹¹

These figures suggest that a move to the accounting logic of the intertemporal model, which suggests that business intangibles (and human capital) should be recognized in national accounting systems (or satellite accounts), could result in a significant changes in measures of economic activity. The remainder of this section presents our best attempts to put some numbers on intangibles spending by the business sector.

C. The Accounting Period of Capital: An Examination of Current Practice.

The 1993 System of National Accounts (SNA) acknowledges that the period of accounting is a choice of national accountants, but advises them to choose a period of at least one year so that

¹¹ In 1999, however, BEA substantially broadened its core business investment measure by adding computer software, a major type of intangible asset. Thus, some business intangibles *are* represented in the U.S. national accounts, contrary to what some commentators suggest. BEA estimates that business spending on software was more than \$160 billion annually in the late 1990s, a noticeable amount, but not large enough to satisfy these and other critics of the current NIPA measures.

seasonal effects are avoided. Longer periods “may not adequately portray changes in the economy ... [while] ... periods that are too short have the disadvantage that statistical data are influenced by incidental factors.”

With regard to the U.S. NIPAs, different sectors apply different accounting periods for capital, and there is no single recent statement that represents the choices in the system.¹² For business and government, according to a more than 25-year-old study, equipment is defined as durable goods having an average service life of more than one year; for households, equipment (consumer durables) is defined as durable goods having an average service life at least three years (Young and Musgrave 1976). In practice, the available source data introduces additional twists in BEA practices: For example, the Census of Governments uses five years as a cut off to determine whether a purchase is equipment. But, for the business sector, where the flows are built using data *by asset type* according to the commodity-flow method (see Grimm, Moulton, and Wasshausen 2002), the NIPAs currently do not recognize any assets having a service life of less than three years.

If the NIPAs maintain current practice and essentially define fixed assets as inputs with a useful service life of at least three years, the recognition of intangibles, many of which are inherently elusive and not long-lasting – such as certain types of advertising – could have a relatively small effect on measured business fixed investment. On the other hand, if the accounting period selected for the NIPAs *is* really just one year, and if the BEA were to recognize business intangibles, many types of business expenditures may need to be counted as fixed assets, and measured business fixed investment could be scaled upward by a noticeable amount.

¹² The information in this paragraph was obtained in conversation with Brent Moulton, Associate Director for National Accounts, Bureau of Economic Analysis.

D. Identifying and Measuring Spending on Business Intangibles.

The literature on intangible capital approaches the problem of classification from different starting points (eg. Lev 2001, OECD Secretariat 1998). Despite the different starting points, however, the attempts generate similar classifications and similar lists of items that represent private business spending on intangibles.

Table 3 summarizes the items that have been most commonly cited and groups them into three broad categories, similar to groupings used by Lev and others (eg., Khan 2001). The grouping suggests that the knowledge capital of a firm consists of the following components: computerized information, technology and innovative property, and economic competencies. The table also indicates whether the current NIPAs or the 1993 Systems of National Accounts (SNA) categorizes each type of spending as intermediate consumption or fixed investment and provides brief comments on the availability of data for each item. Finally, table 3 presents an estimated size range for each broad group; in some instances, these are based on highly preliminary and/or rudimentary estimates for the individual items shown.

Computerized information. This component reflects knowledge embedded in computer programs, and we estimate that investment in this category of knowledge capital ranged from \$145 billion to \$165 billion annually in the late 1990s.

When computer software was recognized in the NIPAs in 1999, not only were purchases of prepackaged and custom software newly counted as investment, the estimated costs of software created by firms for their own use also were included. The own-account estimates were developed from detailed occupational data on employment and wages in private industry, in conjunction with an estimate (50 percent) of the average time spent by individuals in the relevant occupations on “software development” (Parker and Grimm 1999). This method of

estimating investment, though imprecise, is consistent with the framework of Figure 2: Some uses of time (development) are investment, others uses (maintenance and routine repair) are consumption.

The upper end of the range for spending in this category reflects the NIPA computer software estimates for 1998 to 2000 (which averaged about \$160 billion) plus a small figure (less than \$2 billion) for computerized databases, an item not capitalized in the NIPAs.¹³ The lower end of the range reflects the subtraction of the value of systems software currently included in the NIPA figures (about \$15 billion). Even though the intertemporal framework does not address the boundary *between* tangible and intangible investments, the lower bound accommodates a position held by some that the software that controls the basic function of the computer (systems software) should be classified as a tangible investment (e.g., Clement, et. al, 1998, Vosselman 1998).¹⁴

The bounds in the table also reflect the preliminary nature of the current NIPA estimates for computer software. Although BEA made innovative use of the limited data and research available when the estimates were introduced in 1999, the BEA's commodity-flow method requires a current benchmark Input-Output (I-O) table to reliably estimate GDP components from source data on industry production and trade. Moreover, a great deal more statistical

¹³ Much of the production of computerized databases probably is done by firms for their own use. Thus, some, if not all, of computerized database production may already be included in NIPA own-account computer software, and, as a result, a separate own-account estimate for computerized database is not included.

The figure cited in the text, less than \$2 billion, reflects the 1998-2000 average annual revenue of the new NAICS industry, database and directory publishers (excluding advertising sales, contract printing, and other) as reported in the 2000 *Services Annual Survey* (SAS), issued by the Census Bureau.

¹⁴ Indeed, the software that is bundled with the sale of a computer is already included in figures on computer purchases.

The figure cited in the text reflects the 1998-2000 average annual revenue for the system software sub-category of the NAICS industry, software publishing, as reported in the 2000 SAS. Only a very small deduction was made for the software bundled with equipment sales, consistent with the assumptions built into the current NIPA estimates.

information on computer software is now available, and the current NIPA estimates will be substantially refined and updated for the 2003 benchmark revision.¹⁵

BEA's experience with the capitalization of computer software illustrates several of the challenges intangible capital poses for national accountants. First, when production is carried out by firms for their own use and must be estimated, information on *employee uses of time* is required – here, software maintenance/repair versus software development. A paucity of this type of information, both *at a point in time* and *over time*, is not limited to employees that create and develop computer software. Second, conceptual problems frequently arise when own-account production is estimated; here, because software is a tool in research and development, there is a conceptual overlap between the figures for own-account software and the available data on R&D expenditures.¹⁶ Third, the dynamism of industries producing and investing in intangible capital may pose difficulties when standard estimating methodologies are applied to basic survey data and I-O information that are out-of-date and/or incomplete.

Technology and innovative property. This is the “R&D” component of business knowledge capital. It reflects the scientific knowledge embedded in patents, licenses, and general know-how (not patented) *and* the innovative and artistic content in commercial copyrights, licenses, and designs. Thus, both scientific and nonscientific types of product development costs comprise business expenditures on “R&D.”

¹⁵ For purchased software, the refinements include the inclusion of improved estimates of the software bundled with other equipment and more accurate data on exports and imports; for own-account software, improved employment and wage data will be used to estimate production. These changes are expected to reduce business spending on software (see Moylan 2001).

Beginning in 2003 the Census Bureau hopes to have developed a new quarterly indicator survey covering the output of the software industry (pre-packaged and custom); the availability of this new, more comprehensive data will substantially enhance the accuracy of the quarterly NIPA measures.

¹⁶ This point is emphasized in the OECD work on intangibles (e.g., Vosselman 1998, Khan 2001).

The BEA makes an adjustment to exclude software R&D from own-account software. Currently, the adjustment is largely judgmental, but it will be refined with the introduction of the 1997 benchmark I-O table in the 2003 benchmark NIPA revision. (Conversation with Carol Moylan.)

According to most economic models and several decades of economic research conducted by Zvi Griliches, Edwin Mansfield, and many others, R&D is unequivocally a business investment.¹⁷ The R&D data that have been the subject of most of the research in the United States, and the data that have been collected since the early 1950s for the National Science Foundation, are “science and engineering” R&D. These data are defined to include expenditures ... “on the design and development of new products and processes, and the enhancement of existing products and processes,” but to *only* cover activities carried on by persons trained, either formally or by experience, in the physical sciences, the biological sciences, and engineering and computer science. As a result, measured private R&D is conducted mainly by manufacturers and software publishers, and it was relatively high at about \$185 billion annually in the late 1990s.¹⁸ Adding in an estimate of mining R&D (about \$15 billion),¹⁹ yields the lower bound shown in the table for the size of this broad category; that is, about \$200 billion annually in 1998-2000.

¹⁷ In contrast, as indicated in the table, the SNA recommends treating R&D expenditures as intermediate consumption rather than a fixed asset. Even though the aim of most R&D is new patents, new inventions, and new processes, the SNA explicitly states that research and development expenditures “do not lead to the acquisition of assets that can be easily identified, quantified and valued for balance sheet purposes,” and that because it is difficult to meet these requirements, “the outputs produced by research and development ... are treated as consumption even though some of them may bring future benefits.”

¹⁸ The NSF data also reveal the industrial composition of R&D. Most R&D is conducted in manufacturing and, within manufacturing, mainly by makers of pharmaceuticals, computers, semiconductors, and communications equipment. Nonetheless, the nonmanufacturing segment of total R&D has been growing rapidly in recent years, and some have interpreted this development as suggesting that a broad trend toward R&D in services industries is under way. The finding, however, reflects the growth of R&D in one nonmanufacturing industry, software publishing, as well as the growth in biomedical labs and “science parks” serving manufacturers. In short, the industrial composition of R&D reflects its definition.

¹⁹ Note that, in contrast to R&D expenditures, the SNA states, “whether successful or not, [mineral exploration is] ... needed to acquire new reserves and ... [the costs] ... are, therefore, all classified as gross fixed capital formation.”

The figure cited in the text is the NIPA figure for mining exploration plus an estimate of the output of the industry, geophysical surveying and mapping services, for which quinquennial data are available from the Census of Mineral Industries.

The upper bound of the technology and innovative property category reflects the addition of a rudimentary estimate (\$100 billion) of business resources devoted to technology and innovation in other industries; see Nakamura 2001 for a discussion of the derivation of this estimate. Information sector industries (book publishers, motion picture producers, and broadcasters) and financial services industries routinely research, develop and introduce new products, but we have no data on the resources they devote to these activities, that is, we know very little about their R&D. Moreover, our knowledge of the production processes and new product introduction patterns in these and other services industries is very limited.

With regard to nonscientific R&D, therefore, much needs to be learned. We need broader industry coverage of the spending devoted to innovative activity. We also need to know more about the development and process lags for each industry's new products and the productive lifetime of the innovative property created by the spending. For instance, is the average *economic* lifetime of an original sound recording greater or less than three (or even 1) years.²⁰ Richard Caves (2000) points out that much of the spending on new products in the entertainment industry pays off very quickly, while other costs are "paid for" by advertising and still others (such as the cost of developing a new television series and a new copyright film) are investments that generate, on average, long-lasting revenue streams.

Economic competencies. This component of knowledge capital represents the value of brand names and other firm-specific human and structural resources; sometimes the latter two components are called "organizational" capital (Lev 2001), and sometimes the first is designated as a separate component, "marketing." Table 3 groups them together as business

²⁰ Note that the SNA advises to treat these costs as investment, presumably because the spending leads to an "identifiable" asset, such as a copyright or a broadcasting right, that can be recorded on a balance sheet. In the SNA, the produced fixed asset is called an "artistic or entertainment original."

expenditures designed to raise productivity and profits, other than the software and R&D expenses classified elsewhere.

Even though the line of causality from a specific workplace practice, to organizational change, to profitability in the marketplace is not entirely clear, most observers suggest that investments in economic competency can be approximated by business spending for employee training programs, organizational innovation and change (management time and management consultant fees), market and consumer research, and advertising. As shown on the table, a raw tally of estimates for these items suggests that spending on this component could have been very large in the late 1990s, nearly \$700 billion annually, or, considerably smaller but still large at \$200 billion per year. The wide range reflects data quality issues and classification questions.

According to our framework and the results of research that has studied employer-provided worker training at the firm-level (eg., see Black and Lynch 2000, Bassi, Harrison, Ludwig, and McMurrer 2001), expenditures on workforce training and development, the first item listed under this broad category, are an investment. We estimate that private businesses spent between \$15 and \$65 billion on workforce training the late 1990s, a not large, but still noticeable item.²¹ By contrast, we estimate that spending on organizational development and change was a relatively large sum, maybe \$300 billion (see below), and that outlays for brand equity maintenance and development (represented by purchases of advertising services and the

²¹ (Authors note: This estimate is subject to refinement.) This estimate was derived using the information from a special employer survey conducted by the BLS in 1994 and from similar surveys conducted since 1996 by a private research firm (cite). <more detail to come>

revenues of the industry, market and consumer research services), about \$240 billion annually from 1998 to 2000, did not all represent fixed investment.²²

Investments in organizational change and development have both own-account and purchased components, but not all outlays and resources devoted to managing and running an organization are investment. Management consulting services revenues rose from \$38.5 billion in 1994, to more than \$80 billion annually during 1998-2000. Because marketed purchases do not include an own-account component and because a trend toward outsourcing may have occurred, these figures understate the *level* of resources devoted to organizational development and change but likely overstate its *rate of growth*. The own-account portion, executive time spent in support of investment decisions, is viewed as proportional to the cost and number of persons employed in executive occupations. In short, executive time is viewed as a proxy for organizational change and development, as argued by Nakamura, Lev, and others.

The share of employment in executive occupations in total employment was less than 9 percent from 1950 to 1970, but it rose to more than 13 percent of total employment in 1994 and to more than 15 percent by 2000, implying relatively rapid rates of change in the 1990s (Nakamura 2001). And, given that executive median pay exceeds the median pay for other employees, the fraction of total private payroll spent on executives and managers is (conservatively) estimated to have been substantially larger, almost 22 percent in 2000 (Nakamura 2001).

²² The advertising data are from Bob Coen's *Insider's Report*, issued by Universal McCann at <http://www.mccann.com/insight/bobcoen.html>. The data for the revenues market and consumer research industry are from the 2000 SAS. Advertising expenditures were \$215 billion per year from 1998 to 2000, and the market research industry revenues were nearly \$15 billion per year for the same period. The total cited in the text, \$240 billion, ignores expenses on own-account.

Applying the executive and manager payroll share to total private business sector compensation, managerial and executive costs were nearly \$1 trillion per year in the late 1990s (1998 to 2000). If just one-fourth of management time is spent on organizational innovation, then, businesses devoted another \$250 billion per year to improve the effectiveness of their organizations during this period.²³ This figure is extraordinarily sensitive, of course, to the admitted arbitrary choice of one-fourth as the fraction of time managers spend on investing in organizational development and change; as a result, the lower bound on the table incorporates a one-tenth fraction (\$100 billion) and the upper more than one-third (\$340 billion). Adding in the annual expense for management consulting, our estimate thus centers on \$300 billion per year, with the lower bound at \$180 billion and the upper at \$420 billion.²⁴

As indicated above, the marketing subcomponent is represented by purchases of advertising services and the revenues of the industry, market and consumer research services. The marketing literature has addressed the measurement of brand equity and the role of advertising in creating brand equity at the firm level; it has also evaluated the effectiveness (lifetime) of ad campaigns in specific media using statistical techniques and customer surveys. This body of work needs to be rigorously evaluated for its economic measurement implications, and more refined data and information may still be needed to determine the fraction of advertising outlays and market research services that represents new information and brand-building (investment), rather than maintenance expenditures (intermediate consumption).

²³ Consulting expenses and the estimated value of executive time conceptually overlap by a small amount (the value of executive time in the management consulting industry). Whatever that amount may be, however, it is dwarfed by the use of an arbitrary fraction for the amount of executive time devoted to organizational change and development.

In addition, some portion of management time arguably overlaps with nonscientific R&D (“organizational R&D”), so that, for some industries, the line between industry-specific process innovation and organizational change more generally may not be drawn easily

²⁴ (Authors note: This estimate is preliminary in that company formation expenses have not been included.)

Lacking this evaluation and such data, the range on table 3 incorporates an arbitrary lower bound (\$25 billion) for the advertising and market research that accompanies *new* product introductions and an equally arbitrary upper bound (\$215) that assumes that not *all* advertising can constitute fixed investment.

D. Summing up the Measures on Business Spending on Intangibles

Business spending on intangibles *may have exceeded* \$1 trillion annually in the late 1990s (the sum of the upper bounds on the estimates in table 3). Moreover, we estimate that the full recognition of business intangibles in the NIPAs would imply *at least* \$420 billion in additional business fixed investment spending during that period (the sum of the lower bounds on the R&D and economic competencies components). Because remarkably little is known about innovative activity outside of the industries that employ scientists and engineers and because quantifying the precise investments that enable businesses to acquire increases in economic competency is difficult, the tentative nature of the estimates presented in table 3 cannot be underscored too emphatically. Nonetheless, one cannot escape the conclusion that spending on unrecognized business intangibles was a substantial fraction of the existing GDP in the late 1990s.

We cannot readily assess the impact of our estimate of business spending on intangibles on business sector net worth without improved information on the replacement cycle/service lives of intangible assets. Thus, it is somewhat difficult to compare the implications of our estimates for valuing the capital stock including intangibles to Bob Hall's (2000) estimate that the additional *q*-adjusted market value of intangibles amounted to about \$4 trillion in the late 1990s. Of course, there is a rate of depreciation for knowledge capital that could reconcile our upper- or lower-bound estimates with Hall's, but sufficiently little is known about depreciation

rates for us to be very definitive at this point. But, bear with us: for example, if the stock of knowledge depreciated at a rate of 18 percent per year, then *very* roughly speaking it would take additional fixed investment spending of more than \$700 billion annually to add \$4 trillion to business net worth in a simple steady state. This amount of spending is consistent with the midpoint of the ranges of the R&D and economic competencies categories shown in table 3. Even though this simple calculation is of interest, we do not have the information needed to fully analyze how the productivity and welfare measures shown in tables 1 and 2a would change if the boundaries of our current economic measures were expanded.

V. CONCLUSION

The remarkable performance of the U.S. economy in the second half of the 1990s has refocused attention on identifying the underlying sources of economic growth. In the introduction of this paper, we discussed some of the different strands of literature that have, in different ways, started to stir the pot of growth and productivity analysis and measurement.

We too share the general sense that the conventional modeling framework and currently available data are not telling us all that we need to know to understand economic growth. This paper has attempted to take some first steps toward a broader framework for the economic measurement of capital. This is a very difficult task, and we regard this paper as an effort put some issues on the table for further thought rather than as a set of answers to some extremely difficult questions.

On the theory side, described a growth framework that adds an explicitly intertemporal dimension to the standard Solow growth-accounting framework. One important way in which the extended framework is useful is by providing guidance on the “boundary” question of what

should be included as investment and therefore what measure of capital should be entered into the production function. The conventional framework provides no guidance on this point, while the extended framework yields the razor necessary to define investment: In particular, any use of resources that reduces current consumption in order to increase consumption in the future qualifies as an investment. Thus, a host of intangible investments – including R&D, copyrights, computerized databases, development of improved organizational structures, brand equity, etc. – should, in principle, be counted as investment. We also work through other implications of this extended framework for measuring growth, technology, and welfare.

To show the power of this framework and how it relates to conventional growth analysis, we presented estimates for key concepts of the extended framework – including a dynamic welfare residual (DWR) – along with conventional gross output and net output TFP residuals. These estimates are based on *conventional published data* in order to highlight the linkages to earlier work using a traditional SOG approach. We argued that DWR is the appropriate measure for gauging the contribution of technical change to the growth in wealth (welfare). And, we show that growth rates of DWR are quite different from those of TFP residuals based on net domestic product, a measure that some analysts have suggested – incorrectly in our view – is the most appropriate for relating technical change to welfare. DWR also grows more rapidly than conventional TFP (based on either gross or net product) because, in the intertemporal framework, DWR accounts for the capital accumulation that is induced by technical change. Finally, we demonstrated that DWR is closely related to measures of technical change from the conventional framework. Thus, argued that DWR is not a new, exotic way to think about growth, but rather a measure that complements the traditional SOG framework.

As we indicated, this empirical implementation of the extended intertemporal framework does not go beyond conventional measures. To do so requires confronting a host of practical issues given severe data limitations. To take a small step in terms of practice, we have pulled together data on investment in intangibles (using the types of definitions that national income accountants might use) to provide a rough gauge of their possible magnitude. Our range of estimates suggest that investment in intangibles – outside of human capital accumulated in the household sector – could be nearly \$1 trillion of business fixed investment in recent years and perhaps even more. Given that overall business fixed investment in 2001 was a bit over \$1.2 trillion, such a magnitude of intangible investment would be very big deal indeed. Including this intangible investment would significantly boost the investment share of GDP and output per hour. It is not clear, however, that including these intangibles would boost the growth rate of real GDP or of labor productivity.

We regard our numbers on intangible spending and investment as illustrative, not definitive, and we recognize that they are not ready for the prime time of the national income and product accounts. Nonetheless, we believe that research efforts (both inside the statistical agencies and in the broader research community) should be undertaken to construct satellite accounts for as many of the categories as possible of intangible investment. Satellite accounts would shine the light of day on these numbers, providing a focal point for researchers to suggest improved techniques and data sources. At the same time, the use of satellite accounts would insulate the headline national income and product accounts from the spotty data that invariably would be used for many of these satellite accounts. One noteworthy effort in the development

of satellite accounts is the work of Fraumeni and Okubo (2002), who take a first look at GDP including scientific R&D.²⁵

As indicated, we regard this paper as a small step in a long process. In addition to issues touched on in this paper, many other capital-measurement issues also will require further research. For example, the standard sources of growth framework is only beginning to take account of cyclical factors and adjustment costs (Kiley (2001) and Basu, Fernald, and Shapiro (2001)), and thus is only beginning to address one of the central issues that confront policymakers in filtering the incoming measurements on productivity. Also, the profession's empirical research on capital depreciation remains startlingly scant, while the relatively abundant research on hedonic techniques still leaves many questions unanswered about "best practices" for measuring quality-adjusted price indexes for investment, as well as consumption, by statistical agencies.²⁶

Despite the challenges ahead, we believe that useful progress is being made and that substantial further progress is both possible and necessary.

²⁵Interestingly, the SNA indicates that R&D should *not* be included in business investment because it does not create an "identifiable" asset that can be quantified and valued for "balance-sheet purposes." Although the SNA has many useful insights to offer on measuring and accounting for intangibles, we disagree with their recommendation for R&D.

²⁶A recent Brookings Workshop, "Hedonic Price Indexes: Too Fast, Too Slow, or Just Right?" addressed this issue. (The papers are available at: <http://www.brookings.edu/es/research/projects/productivity/workshops/20020201.htm>.)

Table 1**Growth of Labor Productivity, Nonfarm Business Sector**

	1948 - 1973	1973 - 1990	1990 - 1995	1995 - 2000
Labor productivity ¹	2.9	1.4	1.6	2.6
<i>contribution of:</i> ²				
Capital deepening	.8	.8	.5	1.1
IT equipment and software	.1	.4	.4	.9
Other equipment and structures	.7	.3	.1	.2
Labor composition	.2	.2	.4	.3
Multifactor productivity	1.9	.4	.6	1.2
<i>contribution of:</i>				
R&D	.2	.2	.2	.2

Source: Bureau of Labor Statistics, *Multifactor Productivity Trends, 2000* (2002).

1. Output per hour of all persons; percent per year.

2. Percentage points per year; contributions may not add to total due to rounding.

Table 2a
Alternative Measures of TFP-type Residuals, Nonfarm Business less Housing
(average annual growth over periods shown, percent)

	(1)	(2)	(3)	(4)
	$TFP_{t1,t2}^{gross}$	$TFP_{t1,t2}^{net}$	$\Omega_{t1,t2}$	$Harrod\ TFP_{t1,t2}$
1. 1950 - 1973	1.72	1.87	2.45	2.43
2. 1973 - 2000	.53	.63	.78	.78
3. 1973 - 1995	.38	.44	.60	.57
4. 1995 - 2000	1.20	1.44	...	1.76
5. 1950 - 2000	1.08	1.19	1.41	1.58

Notes:

- (1) $TFP_{t1,t2}^{gross}$ TFP based on real GDP in the nonfarm business sector.
- (2) $TFP_{t1,t2}^{net}$ TFP based on real NDP in the nonfarm business sector.*
- (3) $\Omega_{t1,t2}$ DWR. The dynamic-welfare residual calculated as described in the text.
- (4) $Harrod\ TFP$ Harroddian TFP. Calculated as column (1) divided by the average income share of labor over the period shown.

*Currently starts in 1952. Will fix to extend back to 1950. Also, uses nfb figures for growth rate back to 1988 and total economy for earlier years.

Table 2b
Conventional TFP and Dynamic-Welfare Residuals, Nonfarm Business less Housing
(average annual growth over periods shown, percent)

	(1)	(2)	(3)	(4)	(5)	(6)
	$TFP_{t1,t2}^{gross}$	$Y_{t1,t2}$	$TFP_{t1,t2}^{gross} / Y_{t1,t2}$	$\Omega_{t1,t2}$	$\overline{WN}_{t1,t2}$	$\Omega_{t1,t2} / \overline{WN}_{t1,t2}$
1. 1950 - 1973	1.72	4.04	42.5	2.45	4.06	60.5
2. 1973 - 2000	.53	3.27	16.3	.78	3.31	23.7
3. 1973 - 1995	.38	2.95	12.9	.60	3.01	19.9
4. 1995 - 2000	1.20	4.65	25.8
5. 1950 - 2000	1.08	3.62	29.8	1.41	3.59	39.3

Notes:

- (1) $TFP_{t1,t2}$ Conventional TFP based on real GDP in the nonfarm business sector.
- (2) $Y_{t1,t2}$ Real GDP in the nonfarm business less housing sector.
- (3) $TFP_{t1,t2} / Y_{t1,t2}$ The fraction of the increase in output explained by increases in TFP from year t1 to year t2, in percent.
- (4) $\Omega_{t1,t2}$ DWR. Dynamic-welfare residual.
- (5) $\overline{WN}_{t1,t2}$ The average annual growth in wealth from year t1 to year t2, expressed as percent per year.
- (6) $\Omega_{t1,t2} / \overline{WN}_{t1,t2}$ The fraction of the increase in wealth explained by increases in TFP from year t1 to year t2, in percent.

Table 3
Business Spending on Intangibles

TYPE OF ASSET OR SPENDING	CATEGORY ¹		ESTIMATED SIZE (1998-2000 AVE.) AND COMMENTS
	NIPA	SNA	
Computerized information:			\$ 140-165 billion
1. Computer software (including expenses of software developed for a firm's own use)	I	I	BEA is further developing two of its three software components for the 2003 revision. Census proposes to develop new survey measures of software spending.
2. Computerized databases	C	I	Some portion of the development costs are likely captured in the NIPA computer software measures.
Technology and innovative property:			\$ 200-300 billion
3. Science and engineering research and development ("R&D") (costs of new products and new production processes, usually leading to a <i>patent</i> or <i>license</i>)	C	C	NSF data are available from the early 1950s and cover work done in the physical sciences, the biological sciences, and engineering and computer science. ² (Mainly R&D in manufacturing and software publishing industries; about \$185 annually in 1998-2000)
4. Mineral exploration (spending for the acquisition of new <i>reserves</i>)	I	I	NIPA data do not include geological or geophysical research. (Mainly R&D in mining industries)
5. Copyright and license costs (spending for the development of entertainment and artistic originals, usually leading to a <i>copyright</i> or <i>license</i>)	C	I	No broad statistical information. The film industry capitalizes movie-making expenses in financial reports. (Mainly R&D in information industries, except software publishers)
6. Other product development and research expenses (not necessarily leading to a patent or copyright)	C	C	No broad statistical information. (Mainly R&D in finance and other services industries).
Economic competencies:			\$ 220-700 billion
7. Firm-specific human capital (costs of developing workforce skills, i.e., on-the-job training and tuition payments for job-related education)	C	C	A broad survey of employers was conducted by BLS in 1994. Similar surveys for since 1996 were conducted by a private research firm.
8. Organizational structure (costs of organizational change and development; company formation expenses)	C	C	No broad statistical information, except employment and wages by detailed occupational group. Value of executive time can be estimated using these data. Management consulting services.
9. Brand equity (advertising expenditures and market research for the development of <i>brands</i> and <i>trademarks</i>)	C	C	Some, if not all, expenditures on advertising and market research represent intermediate consumption. Data by type of advertiser from 1935 on are available from Universal McCann (\$215 billion ave., 1998-2000)

¹ C = Intermediate consumption; I = Investment; NIPA = U.S. National Income and Product Accounts; SNA = 1993 System of National Accounts.

² But excluding geophysical, geological, artificial intelligence, and expert systems research.

Figure 1

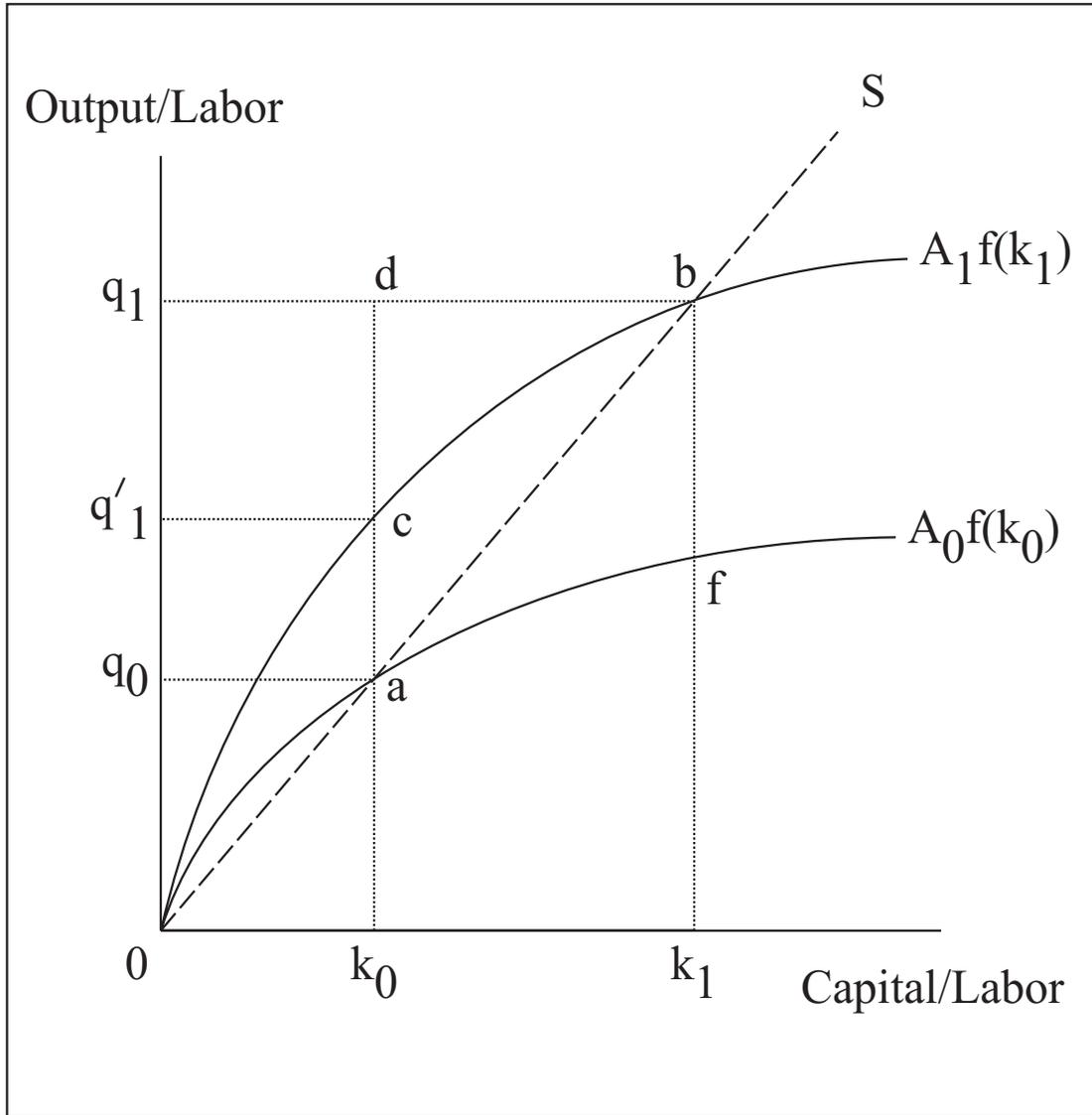
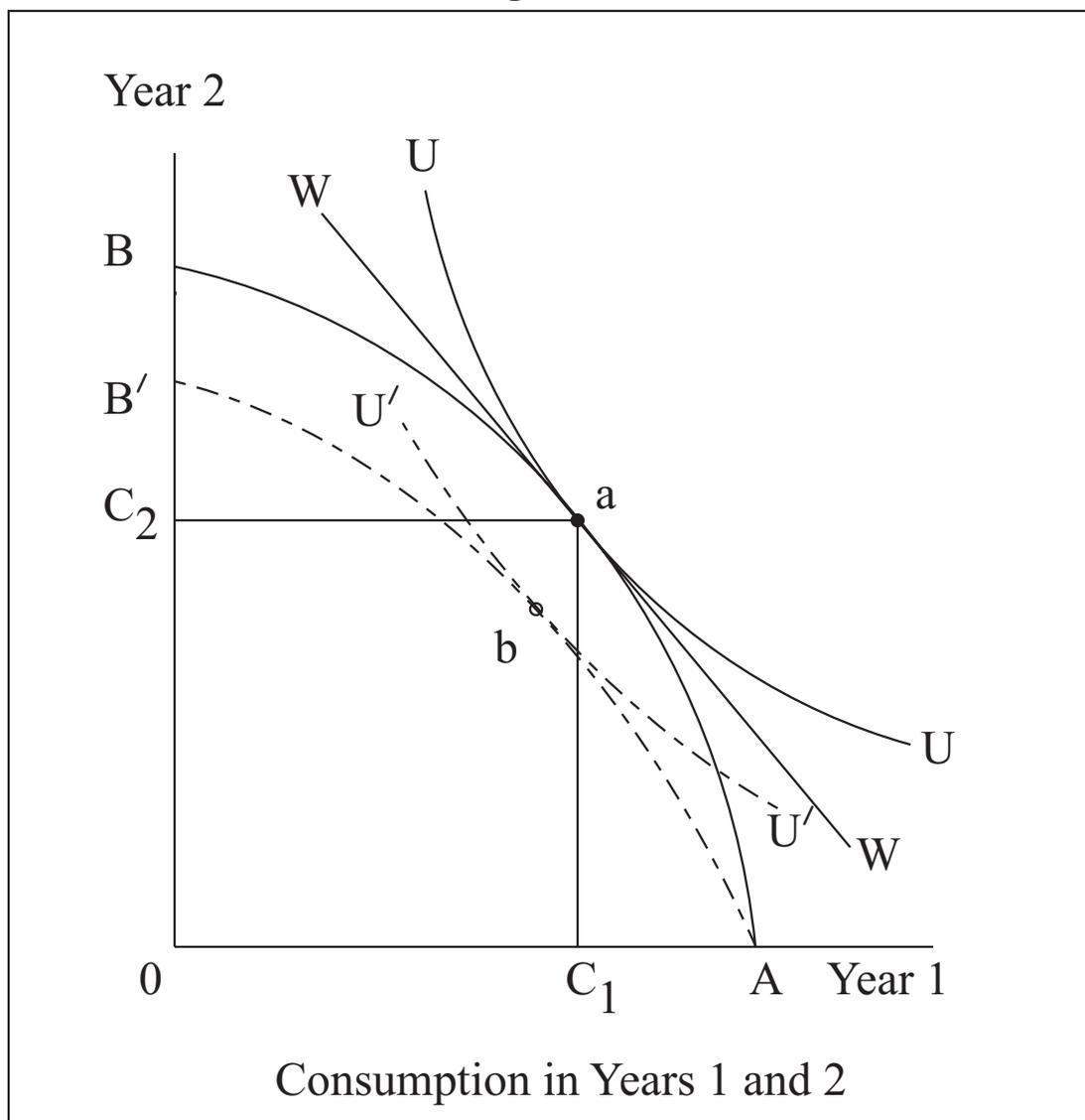


Figure 2



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