Volume Title: Measuring Economic Sustainability and Progress

Volume Author/Editor: Dale W. Jorgenson, J. Steven Landefeld, and Paul Schreyer, editors

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-12133-X (cloth); 978-0-226-12133-8 (cloth); 978-0-226-12147-5 (eISBN)

Volume URL: http://www.nber.org/books/jorg12-1

Conference Date: August 6–8, 2012

Publication Date: September 2014

Chapter Title: Innovation Accounting

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Chapter URL: http://www.nber.org/chapters/c12837

Chapter pages in book: (p. 595 - 628)

# 18

# Innovation Accounting

Carol A. Corrado and Charles R. Hulten

We will be more likely to promote innovative activity if we are able to measure it more effectively and document its role in economic growth.
—US Federal Reserve chairman Ben S. Bernanke, May 2011[1]

The National Income and Product Accounts (NIPAs) are one of the most important achievements of the field of economics. They provide a time-series record of the volume of economic activity and its major components, one that is reasonably consistent over time. The NIPAs thus provide a quantitative framework for understanding the magnitude and sources of past economic growth and a framework for diagnosing current economic problems. It is hard to imagine the formulation of recent economic policy without the information contained in the national accounts.

This is precisely what policymakers had to confront during the Great Depression. Nascent GDP estimates first rose to prominence during World War II, where they played a critical role in resource planning. First published in the late 1940s, the US NIPAs have evolved to include dozens of tables that incorporate a vast quantity of data from a large number of sources.

For all this impressive effort, the national accounting system has come under criticism from a number of directions. It is essentially an account of the sources and uses of the nation's productive capacity as represented by its market activity. While such data are of great importance for addressing critical economic issues and trends, they do not address other important issues.

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For acknowledgments, sources of research support, and disclosure of the authors' material financial relationships, if any, please see http://www.nber.org/chapters/c12837.ack.

1. Quote from keynote address at an international conference on intangibles held at Georgetown University in Washington, DC., in May 2011.

For example, they omit important nonmarket activities, like those arising in the household sector of the economy, and more generally, the various activities associated with the use of time. The effect upon the environment is also an area in which the national accounts have traditionally had little to say. Finally, there is dissatisfaction with the use of gross domestic product as the summary statistic of national living standards. This concept is said to be too easily confused with economic well-being, perhaps even with happiness, which depends, among other things, on the way GDP is distributed among people and on the choices people make about nonmarket uses of time.

These issues provide the subject matter of much of this conference and proceedings. Our contribution takes a different look at the problem of GDP as a market concept. Within the general framework of the sources and uses of a nation's productive capacity as presented in the accounts, we ask whether GDP as currently measured provides a sufficient account of the forces causing GDP to grow over time. Our focus is on the processes of innovation that have both greatly affected the growth and composition of US GDP in recent decades and been a persistent long-run driver of rising living standards. Our previous work (Corrado, Hulten, and Sichel 2005, 2009; Corrado and Hulten 2010) on this topic focused mainly on how much of an economy's aggregate resources is directed to innovation.

One of the most important purposes of the national accounts is to provide a long-term historical record against which to judge trends in economic growth, and present data with which to explain these trends. Table 1.1.6 of the US national accounts, for example, indicates that real GDP in 2005 stood at \$976 billion in 1929, the first year for which GDP data are available, and that this figure rose to \$2 trillion in 1950 and then to \$13.3 trillion in 2011. These estimates imply an average annual growth rate of more than 3.2% over the 1929 to 2011 period as a whole. When viewed against the backdrop of these estimates, the 1.6 percent rate of growth since 2000 and 0.2 percent growth rate since 2007 are particularly weak. But what do we infer from this slowdown and the accompanying slowdown in productivity growth? The usual footprints of a prolonged and deep recession—or the economy's innovation processes grinding to a halt?

Accounting practice has traditionally linked inputs of capital and labor to the output of consumption, investment, net exports, and government output in the context of the circular flow of products and payments. No explicit account was taken of the innovations in technology and the organization of production that led either to a greater quantity of output from a given base of inputs or improvements in the quality of the inputs and outputs. This situation has changed dramatically with the *System of National Accounts 2008* (European Commission et al. 2009) decision to capitalize certain types of research and development expenditure in the national accounts framework. Research and development (R&D) is unquestionably an important part of the innovation process, but it is by no means the only part or even the most important part. We have found, in our previous research, that a very broad definition of innovation investment—commonly referred to as "intangibles"—has been the largest systematic driver of economic growth in business sector output over the last fifty years (Corrado and Hulten 2010), and that US businesses currently invest more in intangibles than they do in traditional fixed assets (figure 18.1). Most of these intangibles are currently omitted from both national and financial accounting practice.

This chapter describes some of the steps involved in building a more comprehensive national innovation account as a satellite to the main national accounting framework. A complete national innovation account would necessarily span intangible investments by businesses, households, and government. Our previous work has been almost entirely on the first category and the bulk of our comments here will continue to be directed at business intangible capital and its measurement. We emphasize the importance of the quality dimension of intangible investment, an issue heretofore largely absent from the intangibles literature. Our most recent work places this issue

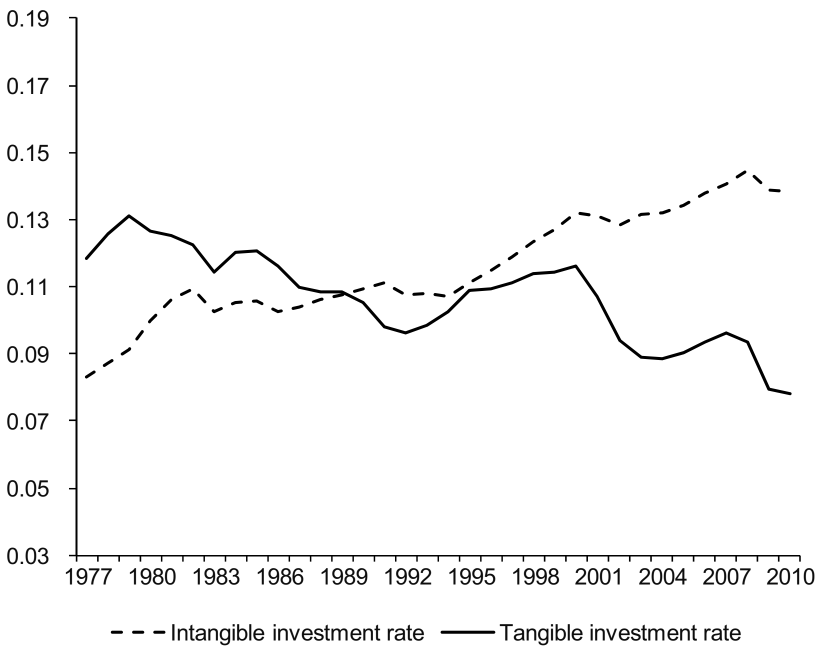


**Fig. 18.1 US business investment rates, 1977–2010**

*Source:* Update using methods originally set out in Corrado, Hulten, and Sichel (2005, 2009) modified to include the BEA's estimates of performer R&D and entertainment and artistic originals (Moylan and Robbins 2007 and Soloveichek 2010, respectively), and the revised method for estimating investment in new financial products reported in Corrado et al. (2012).

*Notes:* Ratio to business output adjusted to include new intangibles. Figures for recent years are preliminary estimates.

in the foreground of intangibles analysis (Hulten 2010a, 2010b, 2012; Corrado, Goodridge, and Haskel 2011).

## 18.1 Expanding the Existing Accounts

National income and product accounting is a familiar and well-established field of economics, as is growth accounting. Innovation accounting is not, though the SNA 2003 decision to capitalize software and artistic originals followed by, as previously mentioned, the same move for R&D in SNA 2008 are important steps in that direction. There are, of course, many innovation metrics in the innovation literature (e.g., number of patents), but they are not integrated into an internally consistent framework linked to a common performance measure. Because economic innovation is valued in large part because of its effects on income and wealth, embedding an innovation account within the larger GDP and growth accounting framework makes sense. A natural way to proceed, therefore, is to ask how the existing product, wealth, and growth accounts might be supplemented or expanded to accommodate this objective.

The growth accounting model already contains a rudimentary innovation account in the form of total factor productivity (TFP). TFP is generally associated with costless "technical change," which is one manifestation of innovation. The problem with this approach to innovation accounting is that TFP is typically measured as a residual, a fact that has earned it the name "the measure of our ignorance." Moreover, because TFP is a partial indicator of innovation outcomes, it is not a complete basis for innovation accounting itself.

The residual TFP model developed by Solow (1957) and extended by Jorgenson and Griliches (1967) is nonetheless the starting point of the analysis that follows. In the Solow-Jorgenson-Griliches model, production, $Q_t$, takes place under constant returns and Hicks's neutral productivity change, $A_t$:

$$Q_t = A_t F(K_t, L_t). \tag{1.1}$$

Under the conditions of competitive equilibrium, the value of the marginal products of labor and capital, $L_t$ and $K_t$, equal corresponding factor prices $P_t^L$ and $P_t^K$, and the GDP/GDI identity can be derived from the production function. Moreover, the growth rate of output can be decomposed into the contributions of labor and capital, weighted by their respective income shares, plus the growth rate of the Hicksian efficiency term:

$$\frac{\dot{Q}_t}{Q_t} = \left[\frac{P_t^K}{P_t^Q}\frac{K_t}{Q_t}\right]\frac{\dot{K}_t}{K_t} + \left[\frac{P_t^L}{P_t^Q}\frac{L_t}{Q_t}\right]\frac{\dot{L}_t}{L_t} + \frac{\dot{A}_t}{A_t}. \tag{1.2}$$

Expressions with overdots are rates of growth. The first two terms on the right-hand side of (1.2) are the contributions of capital and labor to the growth in output, interpreted as a movement along the production function, while the last term in the output growth occurs as a result of productivity change, interpreted as a shift in the function.

In the following subsections, we will consider the modifications and additions needed to expand the basic growth accounting framework to be a more comprehensive and explicit framework for measuring innovation. This involves four general steps, some of which have already been undertaken (in part or in whole):

- introducing innovation inputs such as R&D into the underlying model
- making product quality change an explicit component of real GDP
- making quality change in the inputs of labor and capital more explicit
- making process improvements that lower unit costs and prices more explicit

We discuss each of these topics and then turn our attention to measurement.

### 18.1.1 Capitalizing Intangibles Reveals Investments in Innovation

The link between productivity, intangible investments, and innovation has roots in numerous literatures. R&D has been part of neoclassical growth accounting since the 1970s (Griliches 1973, 1979) and innovation was made explicit in endogenous growth models beginning in the 1990s (e.g., Romer 1990, Aghion and Howitt 2007).

Corrado, Hulten, and Sichel (2005, 2009) examined the question of how the amount spent on innovation in each year is represented in the current price GDP accounts. This involves two separate adjustments, one to output for the amount spent in each year and the other to factor inputs for the capitalized value of this spending. R&D tops the list of items included in this spending, but the list is in fact much longer, as emphasized in our earlier work with Sichel as well as some preceding studies (e.g., Nakamura 2001). In short, a broad concept of R&D is needed to fully represent the innovation process. Innovation involves coinvestments in marketing, worker training, and organizational development. As noted in the introduction, the items on this longer list of innovation-related expenditures have come to be called "intangible capital."

Including intangible capital in the fundamental national accounting identity involves adjustments to both GDP and gross domestic income, GDI. To keep things simple, we examine the case in which a single intangible is capitalized and added to the national accounting identity. The value of aggregate output is represented by $P_t^Q Q_t$, but now nominal-price investment in the intangible, $P_t^N N_t$, is added to the other components of final demand ($P_t^C C_t + P_t^I I_t$) to obtain GDP. On the income/input side, the gross income accruing to the stock of intangibles, $P_t^R R_t$, is treated as a component of GDI.

The expanded accounting identity now has the form:

$$(1.3) \qquad P_t^Q Q_t = P_t^C C_t + P_t^I I_t + P_t^N N_t = P_t^L L_t + P_t^K K_t + P_t^R R_t .$$

The corresponding growth accounting equation then has the form

$$(1.4)\qquad \frac{\dot{Q}_t}{Q_t} = \left[\frac{P_t^K}{P_t^Q}\frac{K_t}{Q_t}\right]\frac{\dot{K}_t}{K_t} + \left[\frac{P_t^R}{P_t^Q}\frac{R_t}{Q_t}\right]\frac{\dot{R}_t}{R_t} + \left[\frac{P_t^L}{P_t^Q}\frac{L_t}{Q_t}\right]\frac{\dot{L}_t}{L_t} + \frac{\dot{A}_t}{A_t},$$

where the output index now includes real investment in the intangible asset

$$(1.5)\qquad \frac{\dot{Q}_t}{Q_t} = \left[\frac{P_t^C}{P_t^Q}\frac{C_t}{Q_t}\right]\frac{\dot{C}_t}{C_t} + \left[\frac{P_t^I}{P_t^Q}\frac{I_t}{Q_t}\right]\frac{\dot{I}_t}{I_t} + \left[\frac{P_t^L}{P_t^Q}\frac{N_t}{Q_t}\right]\frac{\dot{N}_t}{N_t}.$$

The stock of intangible capital $R_t$ is the accumulated real intangible investment $N_t$ via the perpetual inventory model (PIM): $R_t = N_t + (1 - \delta)R_{t-1}$. The term $\delta$ is the rate of decay of appropriable revenues from the conduct of commercial knowledge production.

The accounting algebra of intangible capital is relatively straightforward. The interpretation, however, is less so.

*Enter Demand*

First, unlike tangible capital and labor, intangible capital is not a direct input to production, in the sense that an increase in R&D or marketing does not necessarily have a direct impact on the production of the goods made for sale. This raises a question about the interpretation of the share weights in equation (1.4). The literature has generally adopted the position that intangible investment affects output indirectly via the efficiency shift term, $A_t$. This is a reasonable assumption for many types of intangible capital, but not all types. Product R&D and marketing are not directed at increasing the efficiency of production but, rather, to the design and sale of goods and services. Hulten (2012) provides one solution to this problem by introducing demand-side considerations into the growth accounting framework and, following Nerlove and Arrow (1962), making the income-share weights depend, in part, on the elasticity of product demand. This solution implies that the introduction of intangibles into the accounting framework involves a basic shift in the perspective away from a pure production function foundation.

*. . . and Market Power*

Models in which innovation is explicit treat it as a source of market power, which also introduces demand-side elements to the model. Romer (1990) assumed innovators were, in effect, a separate sector of the economy (he called it the design sector) who practiced monopoly pricing. In Romer the innovator's price is given by $P = \gamma\text{MC}$, where MC is the marginal cost of producing a new good and $\gamma$ is the producer markup, a function of the good's price elasticity of demand (Romer 1990, unnumbered equations at the top of page S87). Romer goes on to formulate the intertemporal zero-profit constraint, whose solution equates the instantaneous excess of revenue over marginal production cost as just sufficient to cover the interest cost of the innovation investment (equations 6 and 6', page S87).

In a two-sector neoclassical growth model where the two sectors are a production sector and an R&D sector, Romer's solution for producers' markups can be shown to be a transformation of the factor share of intangible capital (Corrado, Goodridge, and Haskel 2011, 12). Let this ratio be denoted as $s^R$, which is $P^R R / P^Q Q$ from above, time subscripts ignored. When intangible investment is equated to Romer's "innovation investment" and variable production costs $C$ are equated with marginal costs,[2] Corrado, Goodridge, and Haskel (2011) showed that the Romer producer markup equals $1/(1 - s^R)$; that is, that it must be sufficient to generate revenue that covers the "interest cost" of innovation.

The existence of market power in the innovation sector stems from a host of underlying business dynamics that are suppressed for the sake of simplicity in an aggregate model. Commercial knowledge is modeled as nonrival and appropriable in these models—but in reality new products and processes constantly come and go, each with a finite period of appropriability. Commercial knowledge may be thus represented as a single asset being produced and "sold" at a monopoly price in all periods in these models, but the underlying dynamics involve overlays of case after case of Romer's intertemporal zero-profit solution.[3]

Romer notes that the design sector can of course be in-house, consistent with the fact that most business intangibles are produced and used within the confines of a firm and therefore do not generate an externally observable price and quantity. This is not a problem for theory, which can appeal to shadow prices in the place of market-determined prices, but it poses serious problems for the measurement of these intangibles. Measurement is discussed in a separate section below.

### 18.1.2 Real Output Includes Quality Change

GDP is a measure of the volume of output flowing through markets, valued at current market prices. This is a source of strength as well as a source of weakness. It is a strength because market flows are observable by the statistician and market valuations are an arm's-length indicator of the value

2. Variable production costs exclude the costs of R&D labs.

3. One implication of this solution is that value of own-produced intangibles in a given industry at a given point in time includes an innovator markup, $\mu_{i,t} \geq 1$, that may be modeled as a multiple of the competitive factor costs of the inputs used up in the innovation process. Variants of such a formulation entered BEA's R&D satellite account (Moylan and Robbins 2007), the calculations in Hulten and Hao (2008), and Corrado, Goodridge, and Haskel's (2011) suggested method for calculating R&D price deflators. Like $s^R$, in the Corrado, Goodridge, and Haskel (2011, unnumbered equation, p. 18) model, the parameter $\mu$ is related to the price elasticity of demand, and ignoring time and industry subscripts, the producer markup $\gamma$ then becomes $1/(1 - \mu s^R)$.

of the transaction to both seller and buyer. GDP growth also has important implications for employment and personal incomes. On the other hand, aggregate GDP does not address the question of how the gains from innovation are shared in the population, nor does it address nonmarket activity.

The greatest potential weakness from the standpoint of innovation accounting is that it may not capture the full benefits of new or greatly improved products. The point was forcefully made by William Nordhaus (1997, 5–55) when he argued in his paper on the history of lighting that "official price and output data may miss the most important revolutions in history," because they miss the really large ("tectonic") advances in technology.[4] The importance of quality change and the potential for measurement bias are underscored by Bils and Klenow (2001), who use Engel curve analysis to estimate the rate of quality upgrading in a cross-section sample of sixty-six consumer durables over the years 1980 to 1996. They found that quality growth in their sample occurred at an average annual rate of about 3.7 percent, and concluded that BLS price estimates "did not fully net out the impact of quality upgrading" (p. 1029), missing some 60 percent of the quality effect.[5]

Quality change can occur both through upgrading of existing products and through technological breakthroughs that result in new goods, and both offer the possibility of measurement bias. This bias tends to lead to an overstatement of the growth in prices and a corresponding understatement in the growth in real output, measured in units of effectiveness rather than transaction units (e.g., a personal computer measured in units of computing power versus the physical computer sold). When an adjustment for quality is made, an increase in the effectiveness of a good is measured in terms of the equivalent quantity of the older vintage of the good needed achieve the same result. In other words, "better" is treated as "more."

The translation of "better" product into "more" can be incorporated into the growth accounting framework in the following way. Following Hulten (2010a, 2010b), let output in effectiveness units be denoted by $Q_t^e$ and the

4. The issues involved with output quality adjustment can be illustrated by the following example. There are two countries, A and B, each with two workers who can produce one unit of output each (widgets). Labor productivity in both countries is thus equal to one. Country A then deploys one worker that is employed in research aimed at increasing productivity while the other worker remains in production and now produces three widgets. Labor productivity rises to 1.5. Country B does almost the same thing, but its researcher is employed in improving the quality of widgets so that one new widget is the equivalent of three old ones. If country B's new widgets are not adjusted for quality, then the measure of labor productivity will appear to have fallen to 0.5. On the other hand, if a quality adjustment is made, labor productivity in B is the same as in country A. Failure to make a quality correction thus leads to a biased comparison of growth in the two countries.

5. On the other hand, Greenlees and McClelland (2011) use a hedonic characteristics approach and find that, in the case of packaged food, BLS likely has *underestimated* price change. The complexity of the quality measurement issue is discussed in greater detail in appendix B of this chapter.

corresponding transaction-based quantity by $Q_t$. The corresponding prices are $P_t^e$ and $P_t$. Because the total amount spent on acquiring the good $V_t$ is invariant to the units of measurement, we have:

$$(1.6) \qquad V_t = P_t Q_t = P_t^e Q_t^e \text{ , and } Q_t^e = V_t / P_t^e.$$

In the hedonic model, $Q_t^e$ is viewed as a bundle of characteristics (faster processor, more memory, etc.), and an increase in $Q_t^e$ is seen as an increase in one or more of the characteristics. The overall amount of the increase is determined by computing the hedonic price of each characteristic using regression techniques and using the results to determine the implied $Q_t^e$. This procedure makes $Q_t^e$ depend on customers' valuation of the innovation.

The implication for growth accounting is that the growth in output in effectiveness units—that is, inclusive of product innovation—has two components: a pure production quantity component and a quality component based on prices,

$$(1.7) \qquad \frac{\dot{Q}_t^e}{Q_t^e} = \frac{\dot{Q}_t}{Q_t} + \left[\frac{\dot{P}_t}{P_t} - \frac{\dot{P}_t^e}{P_t^e}\right].$$

There is a reasonable argument for both concepts of output as the appropriate variable for the production function (1.1). This argument disappears in favor of $Q_t^e$ when product-oriented R&D is made an explicit input in the production function as per the discussion of investments in innovation in the previous section (after all, why would funds for this purpose be expended?).

The TFP residual then becomes

$$(1.8) \qquad \frac{\dot{A}_t^e}{A_t^e} = \frac{\dot{A}_t}{A_t} + \left[\frac{\dot{P}_t}{P_t} - \frac{\dot{P}_t^e}{P_t^e}\right]$$

The algebra of product quality may be straightforward, but like the issues that arise when analyzing intangibles as investments in innovation, the conceptual framework requires a shift from a purely supply-side view of growth accounting to one in which output is both produced and sold, and involves elements from the demand side.

### 18.1.3 Other Elements in the TFP Residual

Product-oriented innovation is reflected in the price terms of the quality-corrected real GDP identity, equation (1.7), and in TFP, equation (1.8). It is there that the profusion of new or improved products arising from the IT revolution is reflected. However, the IT revolution has also had major impacts on process innovation. Advances in computing and software and Internet engagement are widely acknowledged as sources of ongoing productivity-enhancing business process improvements (e.g., from moving B2B transactions to the Internet, to adopting whole new systems for supply-chain and inventory management). These impacts operate through two different channels involving the $\dot{A}_t / A_t$ term in equation (1.8). This term is a function of the amount of process-oriented intangible capital, and increases as the stock increases. This is the direct efficiency effect of intangibles. There is also an indirect effect associated with spillovers from the original innovator to other users. This is the lower cost (sometimes no cost) externality effect, akin to the manna from heaven formulation of the original Solow residual. There is also a component of the efficiency term that arises from autonomous "tinkering" and learning effects. These effects serve to increase output per unit input and lower unit costs.

The reallocation of resources between efficient and inefficient firms is also a source of aggregate efficiency gain in the $A_t$ parameter. Empirical research has shown that this is an important effect (Foster, Haltiwanger, and Krizan 2001), particularly when the reallocation is due to young, rapidly growing innovators displacing incumbent firms. Reallocation also has an important international dimension, and innovators in the United States and Europe outsource the production segment of the international value chain to foreign countries. A complete account of innovation would thus involve both a domestic industry and firm level of detail, as well as a global dimension.

### 18.1.4 Real Inputs and Quality Change

The preceding formulation implicitly implies that quality change affects final goods and services (i.e., output). An adjustment to this model is needed when quality change occurs in investment goods because capital is also an input to the production process.

*Quality Change and Capital Goods*

The capital services term that appears as an input into the production function must be adjusted for the quality change embodied in the successive vintages of investment that comprise its underlying net stocks. Solow's 1960 model of capital-embodied technical change is one way to proceed. In this model, investment goods are measured in both effectiveness and transaction units that are linked by an efficiency index: $H_t = \Phi_t I_t$. As with the consumption goods model, the efficiency index is equal to the price ratio $P_t^I/P_t^H$. The capital stock in any year is built up using a perpetual inventory equation for both the efficiency and transaction unit denominated stocks.

Hulten (1992) shows that the resulting efficiency stock (Solow's "jelly" stock $J_t$) is proportional to the transaction-based stock, $K_t$, implying that $J_t = \Psi_t K_t$. The proportionality factor, $\Psi_t$, is the weighted sum of the past efficiency indexes, $\Phi_t$, and the corresponding capital-embodied growth accounts can therefore be expressed as a quality-modified version of equation (1.2):

$$(1.9)\quad \frac{\dot{Q}_t}{Q_t} = \left[\frac{P_t^K K_t}{P_t^Q Q_t}\right]\frac{\dot{K}_t}{K_t} + \left[\frac{P_t^L L_t}{P_t^Q Q_t}\right]\frac{\dot{L}_t}{L_t} + \frac{\dot{A}_t}{A_t} + \left\langle \left[\frac{P_t^K K_t}{P_t^Q Q_t}\right]\frac{\dot{\Psi}_t}{\Psi_t} - \left[\frac{P_t^I I_t}{P_t^Q Q_t}\right]\frac{\dot{\Phi}_t}{\Phi_t}\right\rangle.$$

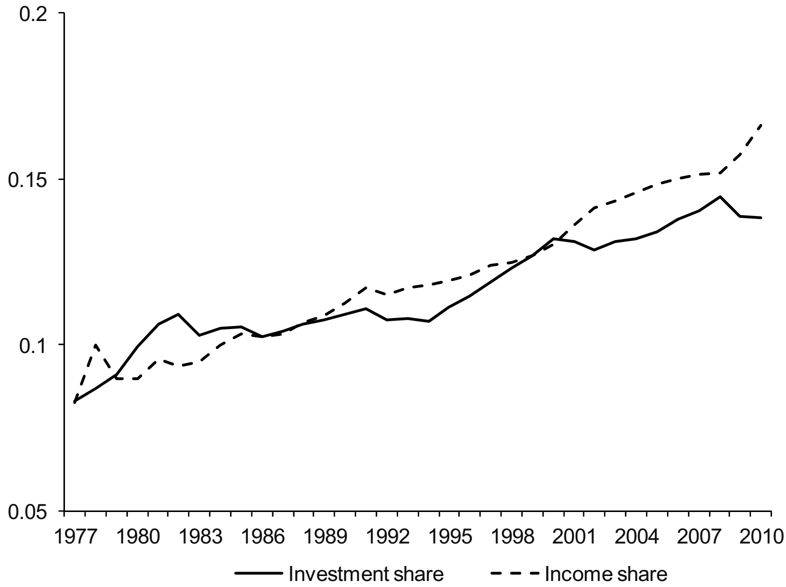


**Fig. 18.2 Intangible investment and capital income**
*Note:* Ratio to business output adjusted to include new intangibles.

As before, the correction for quality change involves additional terms in the growth account. From a practical standpoint, the efficiency terms can be estimated using a hedonic price model and the corresponding price equations are: $\Phi_t = P_t^I/P_t^H$ and $\Psi_t = P_t^K/P_t^J$. (Note that for simplicity's sake, we show $Q$, not $Q^e$ in this equation.)

If improvements in efficiency proceed at a constant rate along the optimal consumption path of a Golden Rule steady state, capital income and investment shares are equal. The terms in (1.9) that correct for quality change cancel out in this special case, including the terms in intangible capital, not shown in (1.9), but which parallel those for tangible capital. The shares for intangible capital are shown in figure 18.2, which illustrates that while these shares run close to one another, the term generally is a source of change.

*The Composition of Labor Input*

The single labor term in the production function (1.1), $L_t$, assumes that labor is a homogenous input. If there are $N$ categories of workers, this single variable must be replaced with the hours worked in each of the $j$ different categories $H_{j,t}$. In this case, the production function is assumed to have the form

$$Q_t = A_t F(L(H_{1,t}, \ldots, H_{N,t}), K_t), \tag{1.10}$$

where $L(H_{1,t}, \ldots, H_{N,t})$ is an index of the different types of labor. If each type is paid the value of its marginal product, the growth rate of the labor index is equal to the growth rate of the hours worked by each type of labor, weighted by its share in the total wage bill:

$$\frac{\dot{L}_t}{L_t} = \sum_{j=1}^{N} \frac{w_{j,t} H_{j,t}}{\sum_j w_{j,t} H_{j,t}} \frac{\dot{H}_{j,t}}{H_{j,t}}. \tag{1.11}$$

Following Jorgenson and Griliches (1967), the left-hand side of this equation can be decomposed into two components, one representing total hours worked by all types of worker, $H_t = \sum_j H_{j,t}$, and another the share-weighted change in the relative composition of hours worked:

$$\frac{\dot{L}_t}{L_t} = \frac{\dot{H}_t}{H_t} + \sum_{j=1}^{N} \left[ \frac{w_{j,t}\ H_{j,t}}{\sum_j w_{j,t}\ H_{j,t}} \right] \left[ \frac{\dot{H}_{j,t}}{H_{j,t}} - \frac{\dot{H}_t}{H_t} \right]. \tag{1.12}$$

The first term on the right-hand side represents the change in labor input due to increases in total hours worked, while the second term measures the increase in effective labor input as the composition of total hours worked shifts to higher productivity (wage) categories. For this reason, the composition term is sometimes called labor "quality." The Jorgenson-Griliches labor decomposition (1.12) can thus be inserted into the growth accounting equation (1.4) to yield yet another "effectiveness" correction.

The labor composition adjustment does not involve innovation per se. In practical applications of the model, workers are often disaggregated along education and occupation dimensions. And an important finding in the literature is that increases in educational attainment have been a significant contributor to the growth in output per worker in the United States, especially in the last three decades. Thus, while not innovation per se, the labor composition term is generally regarded as the *direct* channel through which the impact of human capital accumulation on economic growth occurs.

As may be seen in the accompanying chart (figure 18.3), when the growth in US labor input is broken down into just three skill-based categories, the contribution of high-skilled labor dominates the picture of the past fifteen years. The contribution of skilled workers and managers to economic growth via the accumulation of intangible capital *within* firms (and thereby owned and exercised *by* firms) is over and above the direct influence of private returns to such workers in the labor composition, or labor "quality," term, plotted in figure 18.3.

## 18.2. Implementation and Measurement

The theoretical problems of establishing an innovation account even in the limited sense of this chapter present many difficulties, but the issues of implementation present equally great, or perhaps even greater, difficulties. A


**Fig. 18.3 Labor services contributions by skill type, 1996–2009**

*Source:* Author's elaboration of data from the World Input-Output Database, available at www.wiod.org.

major problem arises from the fact that much innovation occurs within the confines of the firm and the processes giving rise to the innovation are hard to observe. Indeed, firms usually have a strong interest in preventing them from being observed in order to protect intellectual property. In some cases, these processes may be imperfectly seen or understood by the managers of the firm (the financial crisis and the role of new financial instruments). In this section, we also examine the implications for innovation accounting of some of the measurement issues that arise in these areas.

### 18.2.1 Extending the Asset Boundary

When questioned about the relevance of the existing asset boundary for intangibles in national accounts more than six years ago, US BEA director Steve Landefeld answered, "No one disagrees with [the capitalization of intangibles such as R&D] conceptually. The problem is in the empirical measurement."[6] Since then researchers and practitioners at national statisti-

6. Reported on page 66 of "Unmasking the Economy," *Business Week* (February 13, 2006, pp. 62–70), by Michael Mandel.

cal offices and international organizations have done much to remedy "the problem in empirical measurement."[7]

The discussion and equation (1.3) above suggests that to estimate intangible capital and analyze its role in economic growth as per equations (1.4) and (1.5), we need:

- a list of intangible assets to be measured
- magnitudes for the nominal investment flows $P_t^N N_t$ for each asset type
- a means to separate these flows into price $P_t^N$ and quantity $N_t$ components
- service lives of each asset to enable the compilation of net stocks $R_t$
- a means to estimate $P_t^R$

We briefly review the state of measurement in these areas. Many more details and discussion are found in Corrado et al. (2012, 2013).

*Asset Types Anchor the Framework*

In broad terms, as of a March 2012 OECD (Organisation for Economic Co-operation and Development) expert meeting on the measurement of intangibles, the list of intangible asset types proposed by Corrado, Hulten, and Sichel (2005) remained the main framework for measurement (table 18.1). By contrast, methods used to estimate the nominal investment flows and develop an understanding of the underlying innovation processes represented by intangible assets are evolving and advancing. A major reason for the forward progress on measurement is intense interest by The Conference Board, the European Commission, and the OECD (among others) to better understand the macroeconomic impact and underlying nature of the innovation investments needed for knowledge-based economies to continue to grow and compete effectively in current global markets.

We will not discuss the asset categories in table 18.1 here in detail, except to note that assets fall into three broad categories: computerized information, innovative property, and economic competencies, and that these categories are populated with nine asset types (the rationale for each subcategory is discussed in detail in Corrado, Hulten, and Sichel 2005, 2009). The list is surprisingly similar to that in the IRS guide for reporting the value of financial assets following a corporate merger or acquisition, though the two frameworks were developed independently.[8] It is notable that both embrace

7. This section draws liberally from an elaboration and "harmonization" of what was learned from work under two projects funded by the European Commission (COINVEST and INNODRIVE, which concluded late 2010/early 2011, respectively) and the ongoing work on intangibles at The Conference Board. See Corrado et al. (2012) at http://www.intan-invest.net/ for further details.

8. The US tax code specifies twelve intangible assets to be valued and listed as financial assets following a merger or acquisitions, including the value of the business information base, the workforce in place, know-how (listed along with patents and designs), and customer and supplier bases. (See US IRS *Publication 535*, *Business Expenses*, 2–31).

**Table 18.1** **Knowledge-based capital of the firm (a.k.a. intangibles) by asset type**

| Asset type | Included in national accounts? |
|---|---|
| *Computerized information* | |
| 1. Software | Yes |
| 2. Databases | ?[a] |
| *Innovative property* | |
| 3. Mineral exploration | Yes |
| 4. R&D (scientific) | Satellite for some[b] |
| 5. Entertainment and artistic originals | EU-yes, US-no[c] |
| 6. New product/systems in financial services | No |
| 7. Design and other new product/systems | No |
| *Economic competencies* | |
| 8. Brand equity | |
| a. Advertising | No |
| b. Marketing and market research | No |
| 9. Firm-specific resources | |
| a. Employer-provided training | No |
| b. Organizational structure | No |

*Source:* Corrado et al. (2012, 13).

[a]SNA 1993 recommended capitalizing computerized databases. The position of most national statistical offices is that databases are captured in current software estimates.

[b]R&D satellite accounts are available, or under preparation, in many countries. Results for Finland, the Netherlands, United Kingdom, and the United States are publicly available.

[c]The US BEA plans to include entertainment and artistic originals and R&D as investment in headline GDP in a revision in 2013.

modern business realities and value assets whose ownership is not typically protected by legal covenants.

### *Alternative Approaches to Estimating Nominal Investment Flows*

There are at least two basic models for how to proceed to estimate nominal intangible investment flows for each of the asset types in table 18.1, which are data from deep within firms. The first is to use a survey instrument, such as the R&D surveys that are run in most industrialized countries. Businesses are accustomed to this survey, and its long and successful history suggests that a survey approach to measuring innovation costs for business functions that are separate, identifiable departments within a company is a reasonable way to go. Note also that these surveys distinguish between own company costs and purchased R&D services, as well as license payments to and from other companies.

The second approach is to follow the "software" model; that is, use data on purchases from a regular industry survey (combined with information on exports and imports) and estimate production on own-account using information on employment and wages in relevant occupations. Both approaches thus boil down to the same idea, namely, that one needs to obtain measures for *both* in-house and purchased components of intangible investment. A general expression for estimating nominal intangible investment flows was set out in Corrado et al. (2012) and Corrado and Hao (2013). Further details are shown in an appendix.

A number of other developments in the measurement of investment flows are also noteworthy. First is the pioneering work on Japan (Fukao et al. 2009) that disaggregated intangible investment according to manufacturing and nonmanufacturing. Since then the Japanese (Miyagawa and Hisa 2013) and researchers in Australia (Barnes 2010), and the United Kingdom (Dal Borgo et al. 2011) have experimented with industry-level estimates of intangibles, as such disaggregation can be important for policy analysis. Box 18.1 highlights some of the hurdles that need to be crossed to develop accurate data on intangibles by industry for the United States.

Second is the emerging survey work on investment in intangible assets in the United Kingdom (Awano et al. 2010). The UK survey goes beyond R&D and asks companies for information on own-account expenses and purchases of intangibles for five major categories of intangibles (software, R&D, new product development expenses not reported as R&D, information on investments in worker training, and likewise for organizational development). The approach relies on firms being able to report spending in certain categories that lasts more than one year and contrasts with the approach in innovation surveys (the "community innovation surveys" popular in Europe and elsewhere) that require firms to know what innovation is, which in turn requires defining innovation and assuming firms interpret the questions and instructions in a consistent manner.

Third is the research that has used detailed information of occupations and/or microdata to study the link between intangibles and performance at the firm or industry level. This research has yielded insights on the value of the parameters that appear in equation (A1.1) of the appendix and it has identified new or improved sources for indicators used for components. For example, an improved own-cost indicator for investments in new financial products was developed, first, in the COINVEST project funded by the European Commission, and then by Corrado and Hao (forthcoming) using a grouping of occupational codes identified for the analysis of financial innovation; for further details and comparative results using this new indicator for twenty-seven European countries plus Norway and the United States, see Corrado et al. (2012, 2013). The move notably lowered estimates of investment in new financial products but did not otherwise change the comparative analysis of saving and economic growth with intangibles in these countries.

Another line of work uses linked employee-employer microdata, including data on firm performance; such data sets have been used to study human capital formation and its link to market performance in the United States as, for example, in Abowd et al. (2005). The INNODRIVE project funded

**Box 18.1**
**Industry analysis of intangibles a tough haul for the United States**

Analysis of innovative activity with establishment-based industry data presents certain difficulties in the United States. With the implementation of the NAICS (North American Industry Classification System) nearly fifteen years ago in the United States, some of the country's most innovative firms (Apple, Cisco, Nvidia, and other so-called factoryless makers, including certain pharmaceutical companies) were regarded as resellers of imported goods (imagine!) and placed in the wholesale trade sector.* The headquarter operations of many companies (which may include marketing and IT departments) were placed in a separate sector (Management of Companies), and company-owned but separately located R&D labs were lumped with independent producers of R&D services in the R&S services industry. Because the BLS did not necessarily implement NAICS in the same way as did the census, industry-level productivity analysis, particularly for IT industries, has been hampered by the switch to NAICS (National Research Council 2006).

The difficulty that arises in the analysis of intangibles is that the fruits of innovative activities (profits) cannot be easily linked to the costs of innovation in industry data with head offices and R&D labs sometimes (but not always) split off. This complicates what is already a difficult problem, which is the usual disconnect between company and establishment-based industry data systems. In the United States, the Statistics of Income provide data on advertising by industry, but this is on a company basis.

The BEA worked to surmount the R&D lab location issue in developing its R&D satellite account, and the periodic Economic Census began to collect information on industries served for the Management of Companies sector in 2007 (such data were unavailable since 1997), suggesting fewer such hurdles going forward. We also speculate that industry-level estimation of intangibles is less challenging in countries where IT and pharmaceutical production outsourcing has been less abrupt and/or prevalent and classification systems did not split head offices and R&D labs from operations until very recently.

*Obviously we do not have direct knowledge of how the census classifies any given firm, but they confirm that factoryless producers are placed in wholesale trade. For the R&D survey, which is conducted by the Census Bureau for the National Science Foundation (NSF), the NSF instructs the census to classify firms by the primary line of sales for the company as a whole (i.e., on a global basis). In BLS surveys, firms more or less self-classify.

by the European Commission built linked data sets for six European countries, and one of its first findings shed light on the relative value of the intermediate and capital costs of own-account organizational capital production (Görzig, Piekkola, and Riley 2010); that is, the $P_j^M M_j$ and $P_j^K K_j$ of equation (A1.1) of Appendix A. Their findings suggest these costs are consequentially different from zero, the implicit assumption in the Corrado-Hulten-Sichel (CHS) framework.

Piekkola (2012) then pointed out that, when allowing for imperfect competition and markups, such data sets can be used to estimate both the marginal product *and* output elasticity of an asset type. He used the Finnish data set in an exercise that, among other purposes, evaluated the 20 percent assumption embedded in the CHS estimates of own-account organizational capital.[9] On balance, Piekkola found that 21 percent of the wage costs of those doing managing, marketing, and administrative work with a tertiary education can be considered as investment in organizational capital. Organizational capital is the largest component of the CHS broad category, economic competencies, and it is rather remarkable (and we do not say this lightly) that a rigorous study confirms the basic approach of CHS to estimation.

*Updated Estimates of Nominal Intangible Investment Flows*

The composition of US intangibles for the major categories of table 18.1 are shown in figure 18.4, which is a disaggregation of the intangible investment trend shown in figure 18.1. These estimates reflect many of the advances noted above, to the extent possible. Several points are noteworthy. First, R&D is a rather small fraction of the total intangible investment rate. The recent move by the BEA to capitalize R&D is a major step in the direction of a national innovation account, but it is a first step. The most important subcategory in terms of size is economic competencies. It is also responsible for much of the growth in the total rate.

*Net Stocks of Intangible Capital and the Perpetual Inventory Method*

The estimates shown in figure 18.4 are annual rates of investment. The corresponding annual investment flows determine the size and growth rate of the stocks of each type of intangible asset, in conjunction with the rate of depreciation of the existing stocks. The conventional perpetual inventory method used to estimate the stocks of tangible assets is the logical starting point for the estimation of intangible capital stocks from these annual investment series (recall, here, the discussion of equation [1.5]) However, technical and data issues confront this approach. At the conceptual level, use of the perpetual inventory method (PIM) presumes that the contributions of dif-

9. This refers to the assumption that managers devote roughly 20 percent of their time to strategic functions, and therefore that 20 percent of managerial compensation can be used as an estimate of organizational capital investments on own-account.

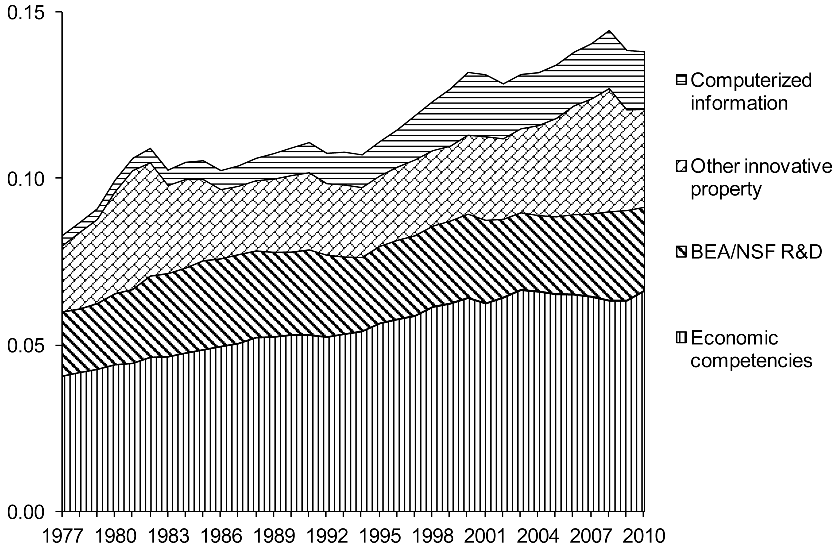


**Fig. 18.4 Intangible investment by broad type, 1977–2010**
*Source:* See source note to figure 18.1.
*Note:* Ratio to business output adjusted to include new intangibles.

ferent vintages of investment are separable, which is a strong assumption to impose on investment in knowledge capital (Hulten 2012).[10]

The most empirically important problem is perhaps the recognition that a model of economic depreciation reflects two distinct processes, discards and economic decay (a topic discussed extensively in Corrado et al. 2012). A design might exhibit no "economic decay" (i.e., it will never "wear out" in a quantity sense) but might be "discarded" as, for example, fashions change. The geometric depreciation rate $\delta$ in the PIM must capture the net effect of both these terms.[11] Similarly, worker training may earn long-lasting returns

10. It is not unreasonable to measure the stock of, say, vehicles, at any point in time as the sum of past purchases, adjusted for retirements and wear and tear. This is the conventional PIM approach. It is quite a different matter to assume that annual R&D expenditures by a research laboratory are highly independent, or "strongly separable" in the terminology of aggregation theory.

Moreover, the unexpected nature of returns to certain investments in intangibles and the nonrival nature of knowledge capital challenges the plausibility of the PIM when applied to intangibles. Patent protection and business secrecy give the innovator a degree of protection from the nonrivalness problem, but the value of the investment to the innovator is limited to the returns on the investment that can be captured, which in turn provides the basis for calculating net stocks. See, for example, Pakes and Schankerman (1984).

11. The geometric depreciation rate is given by $\delta = d/\overline{T}$, where $\overline{T}$ is an estimate of the service life of an asset and, intuitively, $d$ is a parameter that reflects the degree of convexity (or curvature) of the age-price profile. Higher values of $d$ are associated with higher discards/lower survival rates.

**Table 18.2** **Depreciation rates for intangible assets**

| Asset type | Depreciation rate |
|---|---|
| *Computerized information* | |
| 1. Software | .315 |
| 2. Databases | .315 |
| *Innovative property* | |
| 3. Mineral exploration | .075 |
| 4. R&D (scientific) | .150 |
| 5. Entertainment and artistic originals | .200 |
| 6. New product/systems in financial services | .200 |
| 7. Design and other new product/systems | .200 |
| *Economic competencies* | |
| 8. Brand equity | |
| a. Advertising | .550 |
| b. Market research | .550 |
| 9. Firm-specific resources | |
| a. Employer-provided training | .400 |
| b. Organizational structure | .400 |

*Source:* Corrado et al. (2012, 25).

to the firm making the investment, conditional of course on the probability that the worker stays with the firm (the "survival" factor again). The Bureau of Labor Statistics (BLS) reports that the average tenure of employees in the United States is between four and five years, and this forms the basis for setting a "service life" for employer-provided training.

Direct estimates of life lengths from surveys are a relatively new source of evidence. Surveys conducted by the Israeli Statistical Bureau (Peleg 2008a, 2008b) and by Awano et al. (2010) with the UK Office of National Statistics ask about the "life length" of investments in R&D (by detailed industry in Israel) and intangible assets (R&D plus five other asset types in the United Kingdom). The bottom line is that the Israeli survey supports lengthening the service life for R&D (as does a good bit of the R&D literature), while the UK survey confirms that the very fast depreciation rates CHS assumed for economic competencies are about right. As a result, in terms of depreciation rates, the main change that has thus far been made to the original CHS rates is to use a depreciation rate of .15 for R&D (see table 18.2), which is the central estimate of the depreciation rate for R&D adopted by BEA in its satellite account (Moylan and Robbins 2007).[12]

12. One complication here is that technical knowledge and design investments are not only "inputs" to the production of goods and services, they are also inputs to the production of further intangible capital. One implication is that some knowledge investments may have a longer useful life.

*Prices for Intangible Investments and Assets*

Intangible investment in real terms—obtaining each $N_j$—is a particular challenge because units of knowledge cannot be readily defined. Although price deflators for certain intangibles (software, mineral exploration) are found in national accounts, generally speaking, output price measures for intangibles have escaped price collectors' statistical net.

An exception is the emerging work on price measures for R&D. The US BEA (Bureau of Economic Analysis) offered an R&D-specific output price in its preliminary R&D satellite account (Moylan and Robbins 2007; Copeland, Medeiros, and Robbins 2007; and Copeland and Fixler 2009). A contrasting approach is in the recent paper by Corrado, Goodridge, and Haskel (2011), which casts the calculation of a price deflator for R&D in terms of estimating its contribution to productivity. The solution hinges importantly on the decomposition of productivity change, which depends on parameters such as the producer and innovator markups discussed in section 18.1.1, the degree to which quality change is captured in existing GDP (section 18.1.2), and the extent to which the current growth path deviates from the "maximal" consumption path (illustrated in figure 18.2).

Applying their method to the United Kingdom yielded a price deflator for R&D that *fell* at an average rate of 7.5 percent per year from 1995 to 2005, and thus implied that real UK R&D *rose* 12 percent annually over the same period. This stands in sharp contrast to both the science policy practice of using the GDP deflator to calculate real R&D (the UK GDP deflator *rises* 3.75 percent per year in the comparable period) and the results of applying the BEA method to the UK data (the UK BEA-style deflator rises 2.1 percent on the same basis).

The link between the price of an investment good in any year, in this case our $P_t^N$, to the price of its corresponding capital services (user cost), in this case our $P_t^R$, is a forward-looking discounted expected value:

$$P_t^N = \sum_{\tau=1}^{\infty} \frac{(1-\delta)^{\tau} E(P_{t+\tau}^R)}{(1+r)^{\tau}}, \tag{2.1}$$

which brings to light several valuation issues relevant to intangible assets. One is that expectations are not so easily reduced to an annual intertemporal valuation (and revaluation) of an asset's marginal product; in reality, the evaluation/revaluation often takes place within a strategic planning cycle. And in some circumstances, investments are made without specific expectations of a given use.

Intangible investments as firm-strategic investments suggests that they derive value from the options they may open or create (or do not rule out) down the road. It is therefore unsurprising that a literature and practice of "real" options and risk-adjusted R&D project evaluation has emerged. This literature, associated with Lenos Trigeorgis, among others (e.g., Trigeorgis 1996), will not be reviewed or evaluated here in detail, except to say that in the practice of capital budgeting by firms, only special circumstances give rise to the situation in which the value of R&D is equal to conventionally calculated net present value (NPV) based on expected cash flows.

NPV as conventionally calculated ignores the strategic value (i.e., the option values) of the flexibility of R&D assets to respond to changes in the marketplace or technology outlook—and this implies that returns to ordinary capital cannot be compared with returns to R&D unless the option values of R&D are factored in.[13] We cannot be sure of the size of the unobserved option values, of course, but it is not uncommon in case studies of "medium" risk projects for real asset values to *double* after taking account of option values (Boer 2002). These findings and line of work are an important topic for future work on intangible investment prices for and thinking about the $\delta$ in equation (2.1) and the PIM.

The managerial flexibility offered by intangible capital also implies that current market developments are unlikely to impact the present value calculation of all vintages equally. In vintage capital models (e.g., Hall's 1968 analysis of quality change in pickup trucks) this possibility and the identification problem it presents that, in turn, prevents complete analysis is acknowledged. Not only must the same (and then some) be said of intangible capital, but also the possibility that the same shocks may not affect capital and wealth equally. The latter depends on the degree of financial intermediation, the transparency of the intermediation process, and agents' perceptions of firm balance sheets. The valuation of wealth, $W_t$, and of capital, $P_t^I K_t + P_t^N R_t$, occurs in different sectors with different agents, and a disconnect can arise when such valuations diverge (and/or when measurements diverge from reality). When this happens, we have

$$P_t^I K_t + P_t^N R_t = q_t W_t, \tag{2.2}$$

where $q_t$ is Tobin's average $q$ ratio. This possibility (and the underlying reasons for it, measurement or reality) is important for the study of innovation and its impact because the rush of new products and processes in the financial sector has been implicated in the recent financial crisis, and the $q$ ratio did indeed fluctuate (Corrado and Hulten, forthcoming).

### 18.2.2 Implications of Intangible Capital for Growth Accounting

Table 18.1 showed that current national accounting systems in the United States and European Union capitalize just some of the knowledge-based assets of firms. A more complete list is needed to represent how modern

13. A common approach that integrates real options and NPV for project evaluation was quantified by Trigeorgis as: NPV of real asset investment = NPV of estimated cash flows + Option Values.

business allocates revenue between current expenditures and investments in future capacity. Given the very substantial effort needed to extend the national accounts to include the more complete list of intangible assets, it is reasonable to ask what is gained from the effort. Clearly the level of GDP increases, as does the overall rate of investment, but what of the growth rate of real GDP, the basis for improvements in living standards? The following two tables address this question.

Table 18.3 shows results of capitalizing the investments listed in table 18.1 on the sources of growth in output per hour in US private industries. It is the empirical counterpart of the growth equation (1.4). The results were generated using estimates of intangible investment from the BEA (R&D and entertainment and artistic originals) and our own prior work (Corrado, Hulten, and Sichel 2005, 2009; Corrado and Hulten 2010) as revised and updated for INTAN-Invest (2012) (Corrado et al. 2013).

Table 18.4 shows comparably calculated results using the existing asset

**Table 18.3** **Sources of growth in US private industry output per hour, including intangibles, 1980–2011**

| | 1980–2011 (1) | 1980–1990 (2) | 1990–2001 (3) | 2001–2007 (4) | 2007–2011 (5) |
|---|---|---|---|---|---|
| 1. Output per hour | 2.25 | 2.20 | 2.58 | 2.24 | 1.44 |
| | *Contribution of:* | | | | |
| 2. Capital deepening | 1.18 | .96 | 1.38 | 1.13 | 1.27 |
| 3. Tangible[a] | .53 | .40 | .70 | .45 | .49 |
| 4. Intangible | .66 | .56 | .69 | .68 | .77 |
| a. Computerized information | .17 | .12 | .23 | .15 | .16 |
| b. Innovative property | .25 | .26 | .19 | .25 | .42 |
| c. Economic competencies | .23 | .18 | .26 | .27 | .19 |
| 5. Labor composition | .29 | .31 | .32 | .19 | .34 |
| 6. TFP | .77 | .94 | .88 | .92 | –.16 |
| | *Memos—Percent of line 1 explained by:* | | | | |
| 7. Intangible capital deepening | 27.0[b] | 25.5 | 26.6 | 30.3 | — |
| 8. Total capital deepening | 49.5[b] | 43.6 | 53.6 | 50.7 | — |
| 9. TFP | 38.5[b] | 42.5 | 34.1 | 41.0 | — |
| 10. Total capital deepening *without* new intangibles[c] | 36.7[b] | 30.8 | 41.8 | 35.1 | — |
| 11. TFP *without* new intangibles | 49.8[b] | 53.3 | 44.6 | 55.3 | — |

*Sources:* Elaboration of output, hours, and fixed asset data from the BEA; labor composition index is from the BLS. Estimates of intangibles not capitalized in the US national accounts as of May 2013 are based on data from the BEA (R&D and entertainment and artistic originals) and INTAN-Invest (2012).

*Notes:* Private industry excludes education, health, and real estate. Figures are annualized percent change calculated from natural log differences. Contributions are in percentage points and independently rounded. Column (2), (3), and (4) periods are between years with business cycle peaks as defined by the NBER.

[a]Excludes land (but includes inventories).

[b]Calculated from 1980 to 2007.

[c]Based on results shown in table 18.4.

**Table 18.4** **Sources of growth in US private industry output per hour, existing asset boundary, 1980–2011**

| | 1980–2011 (1) | 1980–1990 (2) | 1990–2001 (3) | 2001–2007 (4) | 2007–2011 (5) |
|---|---|---|---|---|---|
| 1. Output per hour | 2.22 | 2.13 | 2.60 | 2.20 | 1.45 |
| | | *Contribution of:* | | | |
| 2. Capital deepening | .88 | .66 | 1.09 | .77 | 1.01 |
| 2a. ICT | .55 | .46 | .76 | .44 | .37 |
| 2b. Non-ICT[a] | .33 | .20 | .33 | .33 | .64 |
| 3. Labor composition | .33 | .34 | .35 | .21 | .39 |
| 4. TFP | 1.02 | 1.14 | 1.16 | 1.22 | .06 |
| | | *Memos:* | | | |
| 5. Output | 2.92 | 3.53 | 3.82 | 2.56 | –.51 |
| 6. Hours | .70 | 1.40 | 1.22 | .36 | –1.96 |

*Sources:* See sources for table 18.3.

*Notes:* See notes for table 18.3, except only intangibles in the current asset boundary, computer software and mineral exploration, are included.

boundary, and is the empirical counterpart of the growth equation (1.2). Periods shown correspond to periods between business cycle peaks, except the last, which extends from the most recent peak to the most recent full year of data (2011).

As in our prior work, one of the main results of extending the asset boundary to include investments in innovation is that capital deepening becomes the dominant factor explaining the growth of labor productivity (line 8 compared with line 10 of table 18.3). Moreover, intangible capital deepening has been the dominant component of total capital deepening for the last forty-plus years. Intangibles *alone* explain about one-fourth of the growth in output per hour between 1980 and 2007—nearly one-third from 2001 to 2007 (line 7 of table 18.3).

Total factor productivity growth averaged more than .9 percent per year from 2001 to 2007 but has contracted, on balance, since then (table 18.3). Using the existing asset boundary (table 18.4), total factor productivity shows roughly the same declining pattern after 2007 as the corresponding estimates of table 18.3, which includes all intangibles. The decline in TFP starts from a higher rate in table 18.4, however (1.22 percent over the period 2001–2007, compared to 0.96 in table 18.3). The recent productivity results do not, of course, signal a new underlying trend due to the incomplete nature of the economic recovery, although the poor results to date have been interpreted with much pessimism (e.g., Gordon 2012).

Absent from Gordon's discussion, of course, are the trends shown in figure 18.1 (intangible investment did not slow as sharply as did tangible investment in recent years) and figure 18.3 (spending on industrial R&D remained relatively strong)—both reasons for a certain degree of optimism about prospects for US productivity in the medium term. On the other hand, the trend in output per hour declines even when intangibles are included in the analysis.

However, before too much is made of this finding, the Nordhaus point about the inability of conventional statistics to capture the effects of "tectonic" innovations should be revisited. The IT revolution surely qualifies as tectonic, with major structural changes affecting businesses, consumers, and markets (e-commerce is just one example, "workerless" factories and driverless autos are others). The tectonic revolutions of the past were subject to a downward bias in estimated real GDP, according to Nordhaus, but given the intangible nature of information and knowledge and the difficulty in even defining the units in which they are measured, the tectonic bias associated with the IT revolution may be larger. Sorting this out is a priority for future research and for the development of an innovation account. Some further thoughts on this subject are offered in appendix B of this chapter.

## 18.3 Conclusion

Innovation accounting requires recognizing that innovation is not costless, that innovation is a source of market power, and that innovation accounting requires a shift in thinking from the pure production model to one that factors in elements of demand. Building on previous work, we have described a national innovation account that incorporates a broad range of intangible assets (based on the Corrado-Hulten-Sichel framework) and that separately identifies the quality component in price change, and thereby the direct contribution of product innovation to economic growth. A corresponding decomposition of conventional TFP follows (based on Hulten 2010a, 2010b), one in which the same component is used to decompose productivity into product and process innovation.

The innovation accounting discussed here focuses mainly on business activity. But it emphasized the importance of thinking about how innovation improves welfare through increasing consumer surplus on the one hand, and growing income faster than price change on the other—issues related to the theme of this conference.

The analysis and material developed in this chapter have two natural extensions. The first is an extension of the accounting model to include the effects of globalization. This is not a simple matter of considering an open economy in the usual way. Indeed, the simple abstraction that all firms operate globally would be an important first step to developing an understanding of the relatively higher rate of private investment in intangible assets by the United States compared with other advanced countries (van Ark et al. 2009) and changes in incomes and costs in the US economy in recent decades.

Second, a complete set of national accounts that include explicit time use, household, and human capital components could be further expanded using elements introduced in this chapter. Linkages between the activities of business, including the benefits that flow to consumers from innovation (including lower costs of production abroad) and the benefits that flow to business from education, seem essential ingredients to forming strategies that promote economic growth and competitiveness of advanced economies. Although these components exist in part or in whole (Christian 2009, Bridgeman et al. 2012), building this larger system is a complicated endeavor beyond the scope of this chapter.

## Appendix A

The Corrado et. al. (2012) model is based on the following equation, shown below as in Corrado and Hao (2013):

$$\text{(A1.1)} \quad P^N N_t = \sum_{j=1}^{J} \mu_j (P^L L_{j,t} + P^K K_{j,t} + P^M M_{j,t})$$
$$= \sum_{j=1}^{J} \mu_j^{shadow} (P^L L_{j,t} + P^K K_{j,t} + P^M M_{j,t})^{own-account} + P_j^N N_{j,t}^{purchased}$$
$$\cong \sum_{j=1}^{J} \sum_{s=1}^{S} (\mu_{s,j}^{shadow} (P^L L_{s,j,t} + P^K K_{s,j,t} + P^M M_{s,j,t})^{own-account}$$
$$+ P_j^N N_{s,j,t}^{purchased})$$
$$= \sum_{j=1}^{J} \sum_{s=1}^{S} (\mu_{s,j}^{shadow} \gamma_{s,j}^{own-account} \lambda_{s,j}^{own-account} OwnCost_{s,j,t}^{Indicator}$$
$$+ \gamma_{s,j}^{purchased} \lambda_{s,j}^{purchased} Purchased_{s,j,t}^{indicator}).$$

In this equation, $P^N N$ is first expressed as an aggregate of $J$ assets using terms set out for the model of section 18.1.1 above (but here we of course include the intermediate inputs used in the production of the intangible). A closed economy is assumed.

The parameter $\mu \geq 1$ is a measure of the degree of market power, the "innovator" markup over competitive factor costs of inputs used up in the innovation process. This parameter varies of course across industries as it depends on customers' price elasticity of demand for an industry's products.

The first line of equation (A1.1) holds whether an economy's intangibles are self-produced or marketed purchases. What changes when investment moves from the former to the latter is the origin of the innovator markup, namely, whether it is an imputed "shadow" value or a factor embedded in transactions data (i.e., embedded in $P^N$). To underscore this equivalence, the second line of equation (A1.1) expresses intangible investment in terms of both sources of supply. The superscript "own-account" denotes intangibles produced and consumed *within the same firm*.

The third line is a more general expression where aggregation now is over a subset of private domestic sectors ($S$). This line is conceptually equivalent to the first two lines in the absence of public investments and international trade in intangibles and underscores that, to date, most work on measuring intangibles has concentrated on private, not public, investments.[14] As to the internationalization of intangibles, very little is known, with the exception of R&D. As a practical matter, *net* international trade in R&D remains relatively small for the United States but is consequential for other countries, such as Finland. In general, trade in services, especially business and professional services, is expanding rapidly (e.g., Jensen 2011), and the internationalization of intangibles is an important topic for future work. Here we simply note that, in reality, when intangibles are capitalized, the adjustments to production and gross domestic capital formation need not be identical as implied by the discussion in section 18.1.1.

The variables $OwnCost_{s,j,t}^{Indicator}$ and $Purchased_{s,j,t}^{Indicator}$ in the fourth line are time-series indicators of the actual in-house intangible production or purchased intangible assets in each sector. The parameters $\lambda_{s,j}$ and $\gamma_{s,j}$ are sector- and asset-specific capitalization factors that adjust the indicators to benchmarks for each asset and sector. The first factor adjusts the indicator to business spending (in the case of using compensation as an own-cost indicator, the factor used transforms it to gross output); the second adjusts spending to a measure of investment if, say, an indicator were a mix of short- and long-lived expenditures. As previously mentioned, sector cost indicators could be derived from employment surveys (or firm-level microdata as in Piekkola et al. 2011), and sector purchased indicators could be obtained from input-output relationships, from which historical time series can be derived.

# Appendix B

## *Measuring Quality Change and Accounting for Business Dynamics*

Each term in (1.8) helps frame dimensions along which businesses innovate and compete, and thus subsumes many phenomena addressed in the industrial economics, consumer demand, and microproductivity literatures. In what follows we make a modest attempt to link innovation accounting via equation (1.8) to some of these phenomena, and to do this we need to shift our focus to the industry level and discuss the creation of consumer welfare and introduce certain aspects of price measurement.

### Product Innovation at the Industry Level

The output of each industry or sector in the economy is modeled as consisting of two groups of products in a given period. The first group

14. An example of an exception is the van Ark and Jaeger (2010) study of public intangibles in the Netherlands.

consists of the same products the industry or sector produced in the previous period, and the second group consists of products that are new to the market. The latter encompasses a wide range of innovations of course, from the introduction of simple new varieties, to substantially new designs, to "truly new" goods. Such distinctions will be consequential to our analysis in a moment, but for now we assume the new-to-the-market grouping of products is homogeneous at the industry or sector level. We also assume no exiting products.

Let $\upsilon_i$ be the $i$-th industry's share of total revenue ($V_i$) originating from new-to-the-market products in a period (time subscripts are ignored). Then effective price change for an industry over the period can be expressed as a weighted average of price change for its new products ($\dot{P}_i^{new}/P_i^{new}$) and price change for its continuing products, which is the simple change in unit value or transactions price ($\dot{P}_i/P_i$):

(A2.1) $$\frac{\dot{P}_i^e}{P_i^e} = (s_i^{new})\frac{\dot{P}_i^{new}}{P_i^{new}} + (1 - s_i^{new})\frac{\dot{P}_i}{P_i},$$

where the variable $s_i^{new}$ is the Divisia weight for new-to-the-market product price change, which equals $.5 * \upsilon_i$ from the above. This equation yields an operational expression for the quality component term on the right-hand side of equation (1.8) of the previous section, namely,

(A2.2) $$\frac{\dot{P}_i}{P_i} - \frac{\dot{P}_i^e}{P_i^e} = s_i^{new}\left(\frac{\dot{P}_i}{P_i} - \frac{\dot{P}_i^{new}}{P_i^{new}}\right).$$

This equation states that the quality component term for an industry is differential price change between continuing and new products, weighted by half the revenue share of new products.

The term ($\dot{P}_i^{new}/P_i^{new}$) is not in the static choice set of the standard neoclassical growth accounting model, but the microtheoretic underpinnings of ($\dot{P}_i^{new}/P_i^{new}$) were set out by Hicks in 1941 and can be used as a starting point. Because prices of new products in a previous period are by definition nonexistent, an estimate of the "virtual" price—the price that sets demand to zero in the previous period—must be used in the calculation of ($\dot{P}_i^{new}/P_i^{new}$) at $t = 1$, the period of introduction of the new product or service.

Various methods are available to generate such estimates. Without going into details and therefore generally speaking, different approaches may be used depending on just where the new product or service is along a "newness" continuum. After all, product differentiation is as much about the introduction of new varieties, product replacement cycles, and the like as it is about the introduction of truly new goods and services. And although both ends of the "newness" continuum generate gains in consumer welfare as per equation (A2.2), it is sensible to make some distinctions because the different ends are captured in statistics in different ways.

Consider first the "routine" model turnover/new variety phenomenon that affects many types of goods and services. Statistical agencies have established generally accepted methods for dealing with this; for a review, see Greenlees and McClelland (2008). High rates of item replacement and flat price profiles for items priced are little-appreciated facts of life for price collectors in dynamic economies. Noncomparability (the inability to form $(\dot{P}_i/P_i)$ from one month to the next) is in fact a pervasive issue even for technologically stable goods such as packaged food (Greenlees and McClelland 2011). In some sense this is the flip side (or dual) of a large body of work that has used census microdata to study business entry and exit, productivity, and worker dynamics (e.g., Dunne, Roberts, and Samuelson 1988; Davis, Haltiwanger, and Schuh 1996; and Foster, Haltiwanger, and Krizan 2001).

Much quality change (the "garden variety" change) is therefore deeply embedded in our price statistics. Greenlees and McClelland (2011) use the characteristics data collected along with Consumer Price Index (CPI) price quotes since the start of the twenty-first century to analyze and evaluate how well BLS has fared in its monthly linking of items that cannot be matched from one period to the next. For the class of goods they studied (packaged food), they found that BLS likely has *underestimated* price change. Needless to say, this line of research is exceedingly important for improving the accuracy of our price statistics. But it also shows that BLS has the wherewithal to decompose its monthly chained consumer price index according to equation (A2.1) for feeding into the operational expression (A2.2) for the quality component term in the "new" real GDP identity.

Innovation accounting even without the precise identification of "garden variety" quality change can still proceed, however. Consider now the time period of analysis. We have been implicitly assuming equations (A2.1) and (A2.2) refer to *monthly* price change, and $s_i^{new}$ for many new-to-the-market products and services will in all likelihood be quite small. For example, Apple's iPhone was an immense success as a product innovation (it accounted for nearly 60 percent of the company's revenue in 2012) but in the quarter of introduction (2007:Q3), it accounted for just 2.5 percent of its total sales. Because industries that routinely innovate through introducing new products will have higher fractions of total revenue originating from new products over longer periods of time, a business cycle, five years, or even a decade, would appear to be a more informative period for innovation accounting.

In fact, BEA's Moulton and Wasshausen (2006) have done just that. Using data on PC prices from 2000 to 2005 and assuming $s_i^{new} = 1$, they estimated the computer industry's ongoing quality component term using a procedure equivalent to equation (A2.2). Their result (11.5 percent per year) was not the full drop in quality-adjusted PC prices (16.4 percent) because unit prices for PCs were found to have fallen nearly 5 percent per year. And because computer final sales are but 0.8 percent of GDP in the United States, the contribution of quality change for computers was calculated to be less than 0.1 percentage point of average annual real GDP growth during the period they studied.

Although Moulton and Wasshausen's result is small in the aggregate (more on why this is the case in a moment), their decomposition adds a small piece to the puzzle of why income and employment generated by computer production grew so much less than the quality-adjusted real value added by the industry. Quality-adjusted price change *is* an indicator of consumer welfare, but with product innovation (and in the case of PCs, falling unit prices also) the welfare increase is not necessarily tied to an increase in the real personal disposable income of workers in the industry or locality in which production takes place. Decomposing the extent to which process innovation has allowed incomes (costs) to grow faster than unit price change would be a helpful addition to the productivity and welfare analysis toolkit.

**Price Change at the "Truly New" End of the Continuum**

Consider now the opposite end of the continuum from which we started. Price change for new products is equal to the change in welfare due to the introduction of the new products (with, of course, a reversal of sign). Equivalently, as shown by Hausman (1981), the welfare gain is the change in expenditure that holds utility constant with the introduction of the new product, otherwise known as the compensating variation (CV), or consumer surplus.

As an operational matter, Hausman (1999) also provided an approximation to the $(\dot{P}_i^{new}/P_i^{new})$ term requiring the unobserved Hicksian "virtual" price in the period prior to introduction. The CV can be used to capture price change from this point to the period when the market share of the new good has stabilized, that is, a period like the five years for innovation accounting studied by Moulton and Wasshausen. Hausman showed that the CV from new goods can be approximated, in our notation, as

$$CV \approx (.5 * \upsilon_i * V_i)/\alpha_i, \tag{A2.3}$$

where $\alpha_i$ is the own-price elasticity of demand for the *i*-th industry's products. The equation is a lower-bound linear approximation to the actual demand curve. Using it only requires an estimate of the price elasticity of demand (PED) along with data on revenue of new products for each industry (i.e., it does not require estimation of the demand curve).

Equation (A2.3) is useful for innovation accounting because it illustrates how new products that gain significant demand ($V_i$) can lead to large measured gains in productivity—and just how large depends on the own-price elasticity of demand ($\alpha_i$). New goods that are very similar to existing ones (i.e., new varieties) will have high own-PEDs, and thus their contribution to welfare change will be considerably smaller than the contribution of products that have relatively low PEDs and experience high demand.[15] The former category may include a new model year car, whereas the latter category might include a new statin drug, such as Lipitor, which was introduced in 1997 and by 2003 became the best-selling pharmaceutical in history.[16]

The analysis of equation (A2.3) also suggests that firms will exercise market power when PEDS are low and demand is high, especially when the situation was created by a firm's own customer savvy, mastery of technology, and marketing. Nor should we be surprised to see that firms that innovate on the variety margin must also compete on the cost margin; high PEDs (and the availability of substitutes) are frequent in these situations, and the demand for new "brands" often must be stimulated by lowering costs or by advertising. This underscores that innovation accounting needs to acknowledge the presence of imperfect competition (as per section 18.1.1)—and also that estimates of intangible investment at the industry level are needed (as per box 18.1 in section 18.2.1) so that the dynamics of costs, prices, and intangible spending can be analyzed more fully.

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15. To fix this idea, assume innovation accounting is performed for a five-year period for an industry whose change in unit costs is zero and whose product line completely turns over. In other words, after five years, products being produced and sold are not the same as those at the end of the previous five years, which implies $\upsilon_i = 1$. Now assume $V_i = 10$, $V = 1{,}000$, and $\alpha_i = 2.5$, where the latter is a relatively high value for the price elasticity of demand (hereafter, PED). A table of estimates for selected products is available at http://en.wikipedia.org/wiki/Price_elasticity_of_demand. Equation (A2.3) then states, after taking into account the relative size of the example industry, that product innovation in the industry contributes 0.2 percentage points per year to aggregate productivity change (recall we assumed the change in unit costs to be zero). But if the PED was a much larger value, say 4, the contribution of product innovation in this industry would be much smaller, less than 0.1 percentage point on an annual basis (more or less equivalent to the Moulton and Wasshausen analysis).

16. Again, to be concrete, if the gain in demand were the same magnitude as the example in the previous footnote and the PED was, say .5, the contribution of the innovation would be estimated at 1 percentage point per year, which is very large indeed.

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