It is hardly news that we are in the midst of rapid economic change. The advances in information and communication technology (ICT), in the life and other sciences, and their profusion of innovative products, from the newest electronic devices to the latest drugs and treatments, are ample evidence. Equally pervasive are new business models in services (big box retail, online banking, on-demand media) and the explosion in social networking and new business practices ushered in by the Internet (telework, virtual meetings, job boards). Given the magnitude of the changes brought on by these innovations, it is useful to step back and ask: What does economic analysis have to say about the sources and mechanisms of these shifts and revolutions, and what economic metrics are available to measure their overall size and impact?

The received theory of economic growth is the natural candidate for this job. It came of age in the 1950s and 1960s with the neoclassical models and emergence of aggregate growth accounting. The latter has become the workhorse of empirical macroeconomic growth analysis and the basis for official productivity statistics put out by the Bureau of Labor Statistics (BLS) since 1983. A technological revolution appears, in this framework, as an increase in the fruits of innovation, as measured by the shift in an aggregate production function (termed multifactor productivity or MFP), and possibly as an increase in the aggregate saving rate, as reflected in an increased rate of capital formation. MFP is an exogenous phenomenon in the growth accounting framework, and the subsequent development of endogenous and “Schumpeterian” models of economic growth have attempted to endogenize this variable (see Charles R. Hulten 2009b for a review).

The common feature of the received theory is a reliance on the production function as the organizing framework of the analysis. But companies are moving away from the making of things in the United States and focusing increasingly on services or product development, design, and marketing. Theories of growth based on standard inputs and even the endogenous growth approaches based on the production of ideas by scientists and engineers thereby become less compelling as frameworks for analyzing productivity and economic change.

A new strand of the empirical growth literature has emerged over the last decade, aimed at addressing this problem by updating the way that business activity is depicted in macroeconomic data and analysis. It builds on diverse literatures, including the microeconomic work on R&D and ICT that established linkages between these investments, their co-investments, and increases in productivity at the firm level; the related literature that established similar linkages for workplace practices; and the business literature that documents actual innovation processes (for references to microproductivity studies, see Carol A. Corrado, Hulten, and Daniel Sichel 2005, 2009, hereafter CHS; for innovation process examples see Corrado 2009).

The main features of the new approach are (i) that a company’s expenditures on product design, marketing and customer support, and human capital and organizational development are essential inputs to innovation along with spending on R&D, broadly defined, and (ii) that these innovation-related expenditures (collectively termed “intangibles”) are investments that are produced within the business sector and need to be included in GDP as business investment.
The stock of scientific R&D appeared in the production function literature very early on, but only as an input. This approach focused on the consequences of privately performed R&D for the production of output, but not on R&D as a final output of the economic system (that is, as an investment that adds to GDP). Moreover, innovation encompasses but is more than the advances in science and engineering captured in US R&D data. New ideas, whether the result of perspiration or spontaneous inspiration, are only the starting point for successful innovation. They define the possibilities but not the outcome, and history is littered with products and companies that failed the test of commercialization. Innovation involves linking products to unmet customer needs and preferences, and the simple truth is that most new products do not sell themselves without effort. Any attempt to measure innovation needs to acknowledge these facts, and this involves a broader view of the process than is offered by simply putting the stock of R&D or ICT equipment into a production function.

The following pages of this paper review some of the key ideas about intangibles in the existing literature and present new sources-of-growth estimates for the US nonfarm business sector. The latter significantly expand the time horizon of our previous study with Sichel (by almost 30 years). The extended time perspective shows that the recent technological revolution, in its various manifestations, is associated with a dramatic shift in the composition of investment spending and in the factors driving the growth of output per worker hour. This is the main result of this paper.

I. Intangibles: Scope, Characteristics, and Measurement

Expenditures for R&D, product design, marketing, and organizational development are treated as current costs and thus excluded from measured output under conventional financial accounting practice, as well as in the National Income and Product Accounts (although R&D investment is scheduled to be included in GDP in 2013). Perhaps the first question that needs to be answered is: “Why should expenditures on these intangibles be reclassified and treated as capital?” The answer given in CHS is that saving occurs when resources are used to provide for future rather than current consumption, and, from the producers’ standpoint, investment is the commitment of current resources to gain future profits. Business fixed investment satisfies these criteria, but so does much spending on intangibles. A look at the biotechnology sector shows that R&D projects can take more than a decade to produce revenue and then require large co-investments in marketing. Other product development cycles may be shorter and involve little or no science but are clearly aimed at future production and profit rather than at current production and profit. The same can be said of investments in brand equity and organizational capability.

There is a body of econometric evidence, reviewed in CHS, which shows a positive correlation between various types of intangible capital and firm market value. Capitalizing intangibles is also helpful in explaining the so-called market-to-value puzzles noted by Baruch Lev (2001) and others. The puzzle arises because the market price of corporate equities consistently exceeds the book value of the shares reported on company financial statements. Hulten and Janet X. Hao (2008) find that the book value of equity explained only 31 percent of the market capitalization of a sample of 617 companies drawn from the COMPUSTAT database for the year 2006; when estimates of the capitalized cost of the stock of intangibles were added to the balance sheets of these companies, the fraction of the market capitalization explained by the augmented measure of book equity rose to 75 percent.

One of the first steps in developing a measurement framework for intangibles is a classification system. Lev (2001) offers one system based on the structural characteristics of the intangibles themselves: innovation-related, human resource, and organizational. The business models of several leading technology companies are shown to be anchored in these categories. Other researchers have developed strategies for measuring the value of the implicit net income stream associated with intangible assets. But neither approach yields the kind of comprehensive measure needed for national accounting or sources-of-growth analysis.

This consideration has led to the development of estimates of business investment in intangibles based on their cost of production. The approach was first taken by the OECD...
in 1998 (see www.oecd.org) and Leonard Nakamura (2001) and then by CHS (2005). The approach has the virtue of using the same cost-based accounting that is used for tangible assets, where arbitrage is assumed to bring the cost of acquiring the marginal asset into equality with the discounted present value of future income. CHS (2005) offered a broad scheme for categorizing business intangible investment (computerized information, innovative property, and economic competencies) and listed specific assets for inclusion in each category.

CHS (2009) took additional steps and estimated corresponding capital stocks by translating the investments to real terms and accumulating them using the perpetual inventory method. A depreciation rate is needed to implement the perpetual inventory method, and an output-based price index is needed to deflate intangible investment. The concept of depreciation applicable to privately owned, knowledge-based assets is the rate of decay of appropriable revenues. For further discussion, see Ariel Pakes and Mark Schankerman (1984).

II. Trends in Intangible Investment

We update our previous estimates for the US nonfarm business sector to 2007 and carry them backward in time to 1948. These estimates imply a total investment in intangibles of $1.6 trillion in 2007, or 11.3 percent of GDP and they are $1.3 trillion above the Bureau of Economic Analysis (BEA) estimates because two important intangible assets (software and mineral exploration) are already capitalized in the US national accounts. When time-series of these investments are accumulated into the corresponding capital stocks, the result is an additional $4.1 trillion in wealth beyond the conventional US fixed asset measures for 2007.

Table 1 shows the average rate of investment in tangible and intangible capital for the three subperiods between 1948 and 2007 (the three periods shown in the table correspond to the high-growth period after World War II, the productivity slowdown from 1973 to the mid-1990s, and the resumption of growth thereafter). This table highlights the shifts in the composition of business investment that have occurred.

When viewed from the perspective of total tangible capital formation (line 1), the rate of business investment appears about flat. A closer look at its composition, however, reveals a shift toward ICT equipment (line 1a), an important correlate of intangible asset creation (Erik Brynjolfsson, Loren M. Hitt, and Shinkyu Yang 2002). An even bigger change in perspective occurs when the picture is enlarged to include the investment in intangible assets (line 2). The average rate of investment in intangible capital formation more than doubles over the three sub-periods shown in Table 1 and when considered with ICT equipment, the dramatic increase in these rates implies that very strong compositional effects within business investment have been at work during the past 60 years. Although less dramatic because shorter time periods are used, similar results have been obtained for other countries (Bart van Ark et al. 2009).

The last two lines of Table 1 show the compositional shift in tangible and intangible capital inputs associated with the investment flows. The compositional shift is less evident here because capital input shifts more slowly than the investment flows and the average rate of depreciation is much higher for intangibles (21.5 percent) than for tangibles (5.3 percent). Nevertheless, the main story of business capital formation in the postwar period is a story about the growth of intangible capital. For further compositional detail, see the paper’s supplementary tables and figures in the online Appendix (available at http://www.aeaweb.org/articles.php?doi=10.1257/aer.100.2.99).

III. The Sources of Growth Model with Intangible Capital

In the CHS model, the conventional Solow-Jorgenson-Griliches sources-of-growth framework is expanded to include intangible investments in output and the corresponding stocks in capital input. In implementing the model, a term used by the BLS to account for the shift in the composition of total hours worked to workers with higher wage rates (usually interpreted as a shift to more highly educated workers) is included, and capital is estimated in sufficient detail to capture corresponding shifts in the composition of total capital input to assets with higher rental prices. The results for the period from 1948 to 2007 (including subperiods) are shown in Table 2.

A look at Table 2 shows that the growth rate of output per hour is virtually the same in the
By itself, this appears to be a reprise of Robert Solow’s famous quip that “you see the computer age everywhere except in the productivity data.” But one does see the computer age in the compositional shift toward contributions of ICT equipment (line 2a) and every type of intangible capital deepening (see detail under line 3). When combined, these sources contributed less than one-half percentage point to the growth rate of output per hour in the first subperiod, but this rose to more than two percentage points in the last. The shift came at the expense of MFP and non-ICT capital growth, which went from contributing about 2 1/2 to 1 1/2 percentage points to top-line growth in the two sub periods. By the end, intangibles had overtaken tangibles to become the largest systematic (that is, non-MFP) source of growth.

The dramatic changes seen in Table 2 provide support for the idea that innovation-related intangible inputs are an increasingly important...
driver of US economic growth. Moreover, the omission of these inputs gives a biased picture of the sources of growth. A parallel set of estimates without intangibles would overstate the contribution of MFP to growth since 1995, from the 43 percent of Table 2 (column 4) to 62 percent absent all intangibles (supplementary Table A2.2, see online Appendix). The results of Table 2 may thus suggest an answer to the question “How do you measure a technological revolution?”: you must include a broad range of intangible investments in the analysis, as both inputs and outputs, because they are an essential part of the innovation process and they loom increasingly large in accounting for economic growth.

While intangibles provide an answer to the question posed in this paper, they are only a partial answer. Innovations in product quality are an important aspect of economic (technological or other) change, providing both better consumer and better capital goods (and, indeed, better intangibles). Whether the price indexes that determine real output and capital inputs and affect the MFP estimates in Table 2 actually reflect the actual improvements in product quality and design is an open question, however (William D. Nordhaus 1997).

The magnitude of the product quality problem is illustrated by two recent studies. In a study of the Microsoft Corporation’s sources of growth by Hulten (2009a), MFP is growth measured as per our Table 2 and shown to be composed of two components: a product quality effect that accounts for 77 percent of the measured MFP residual, and pure factor productivity accounting for the rest. Absent the quality adjustment, the growth of Microsoft’s output and MFP would be significantly understated. David M. Byrne and Corrado (2009) looked at whether recent advances in communications technology (wireless, voiceover IP, etc.) are being fully captured in prices for the equipment and systems that power modern communications networks and concluded existing measures for 1995 to 2007 understate these advances in the neighborhood of 7½ percentage points per year.

Getting a better grip on the quality change aspect of innovation is a priority for improving both the output and the capital input side of the sources-of-growth analysis. As with the identification, classification, and price-deflation of intangibles, difficult measurement problems must be overcome, but these problems are not insurmountable, and progress in these areas is essential for a more accurate analysis of the factors shaping modern economic growth. Advances will undoubtedly require measurement systems that look deeply into the operations of the companies where much of the innovation originates (Corrado and Julia Lane 2009).

IV. Conclusion

A major shift in the composition of investment and capital formation toward intangibles has occurred over the last 60 years. We have argued that this shift is of critical importance for the analysis of growth over this period, and, in particular, for understanding how the recent wave of innovation has shaped the US economy. The message is clear: the innovation that has shaped recent economic growth is not an autonomous event that falls like manna from heaven. Nor is it a result of R&D and ICT investments alone. Instead, a surge of new ideas (technological or otherwise) is linked to output growth through a complex process of investments in technological expertise, product design, market development, and organizational capability. This process affects all sources of growth to one extent or another but is most clearly detected in the growing contribution of intangible capital.

REFERENCES


