Skills, Education, and U.S. Economic Growth: Are U.S. Workers Being Adequately Prepared for the 21st Century World of Work?

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October 9, 2015

Abstract

This paper studies trends in the demand for and supply of skills and the implications for future U.S. economic growth. We begin by noting that new technology not only increases the demand for higher order skills, it also depends on them to create and diffuse the technology. A work force that cannot play this role may limit the rate of innovation and affect the growth in living standards. Analyzing the demand for skills, we link the growth in demand for non-routine cognitive and non-cognitive skills to the rapid growth in intangible capital. When intangible capital is added to a modified version of the BLS sources-of-growth model, it is found to be the largest systematic source of growth, explaining more than a quarter of the growth of output per worker hour from 1995 to 2007. The recognition of intangibles thus accords a significantly greater role for skills and education in the process of growth than the BLS approach. We then review the evidence on trends in the supply of skills and conclude that supply of certain skills is not growing as fast as demand for those skills. This mismatch can explain some of the rise in wage inequality and has negative implications for the future of U.S. growth.

JEL codes: I2, J2, O3, O4

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I. Introduction

The growth in future living standards in the U.S. will depend to a significant degree on the continued evolution in the "knowledge" segments of the economy. These are the high valued added sectors where technical and organizational innovation generates high levels of productivity and creates new goods and markets. They are also the sectors that are the least vulnerable to global competition from low wage manufacturing economies. Technology has already transformed many sectors with innovations like e-commerce, global supply chain management, customization of manufacturing products, and GPS-based transportation management, and there is likely more to come with Big Data, the evolution of automated "workerless" factories and driverless vehicles, and developments in the areas of artificial intelligence, 3-D printing, nano-technology, and genomics. Evidence suggests that such innovations usually require a parallel transformation: the worker skill sets needed to implement and operate the new technology and business models. A work force that cannot play this role may limit the rate of innovation and affect the growth in living standards.

Recent evidence also suggests that the rate of skill formation may be slowing. As chronicled by Goldin and Katz (2008), a century ago the U.S. became a world leader in the expansion of secondary and tertiary education, a development that helped propel U.S. productivity growth for decades. However, this leadership is no longer apparent in the data, despite substantial public expenditures on formal education. Standardized student test results, like those from the recent "Nation's Report Card" (NAEP (2013), suggest that literacy and numeracy skills development of 12^{th} graders has been stagnant in recent years and that a majority of students are stuck at skill levels that are rated below proficient, with one-quarter of students below basic in reading and one-third below basic in mathematics. American students also lag those in many other countries. The 2013 Programme of International Assessment of Adult Competencies (PIAAC) found that the U.S. ranked 16^{th} of 23 countries in adult literacy, 21^{st} of 23 countries in numeracy, and 14^{th} of 23 in problem solving. American tertiary education continues to lead the world, but it has not been able to overcome the poor preparation offered by primary and secondary schools for the significant part of the population.

Moreover, these deficits are apparent to employers and new entrants to the workforce: A McKinsey study found that 30% of the graduates surveyed felt that they were *underprepared* by their college education for the "world of work"; and many employers see these new hires as poorly prepared for life on the job.

These findings are not encouraging, but whether these education deficits translate into a growth-inhibiting skills gap in the future is another matter. Formal education is one way of acquiring the skills needed for later life, and an important source for the background skills of literacy, numeracy, and problem solving. However, formal education is only part of the skill development process. Many skills, cognitive and noncognitive, are acquired outside of formal schooling, in the family and peer environments, and through training and experience. Moreover, research suggests that the cognitive and noncognitive skills developed by age three have fundamental effects on life outcomes and on the ability to learn. Schools thus have little control over a key input into their production functions, student characteristics, and the deficits revealed by test score data are not simply a reflection of weak schools (though they undoubtedly contribute to the problem). Addressing the skill needs of the future economy may be more difficult than "fixing" the K-12 school system or making college more affordable, and may require alternative strategies.

Recognizing the dynamic nature of skill development is also important. When skills gaps occur, skill and education premia can be expected to change in response to market conditions. The skill accumulation process is complex and lengthy, with many stages shielded from market incentives, so skill supply responds slowly and imperfectly as demand changes. There is a "time-to-build" problem in skill formation that can lead both to long lags in the response of supply to an increase in demand, as well as to "boom-and-bust" cycles and periods of excess supply.[2] Moreover, there are only weak, largely non-market, mechanisms that cause school curricula to respond to changes in skill demand. It is therefore no surprise that the U.S. can experience long periods in which wage premia for certain skills grow dramatically, as documented in the work of Goldin and Katz (2008), while at the same time some commentators point to the emergence of "skill gaps."

[2] Cobweb cycles in the market for engineers are well-documented, as for example, by Freeman (1976)

The Kuznets Curve is a second, more subtle and uncertain, form of the skills dynamic. Kuznets (1955) advanced the hypothesis that benefits of technological revolutions tend to accrue narrowly to those best positioned to take advantage of the new opportunities, with the result that income inequality increases. As the new technology matures, the benefits become spread more widely as the premia created by the first-mover advantage are reduced or eliminated as the learning takes place and younger workers have an incentive to acquire the necessary skills. Greenwood (1997) applies this hypothesis to the information revolution and the associated education premium. This line of analysis is particularly important because sustaining economic growth is not the only skill-related concern. There is also the widely-discussed labor-market polarization dynamic. Some of that problem may be due to the prolonged slump in the job market following the Great Recession, but the education premium and the shift in the demand for skills predate the Great Recession. Reversing this polarization while sustaining innovation is one of the major challenges facing the work place of the 21st century.

Much has been written recently summarizing various aspects of the skills and education literature (Hanushek and Woessmann (2008), Goldin and Katz (2010), Acemoglu and Autor (2011,2012), Levy and Murnane (2013), Autor(2014), Hanushek (2015)). One of the main goals of this paper is to link this literature to the aggregate growth framework provided by the BLS empirical sources-of-growth model, in order to assess the relative importance of skill development and education compared to other factors explaining economic growth. The BLS accords only a small (and diminishing) role to "quality" improvement in the composition of the labor force, which includes education as one of the main components. This seems implausible in an era dominated by the information revolution, and we discuss various reasons why the sources-of-growth assessment may understate the true importance.

Our main contribution is to link the growth in demand for non-routine cognitive and non-cognitive skills to the rapid growth in intangible capital. Labor skills are tied to the capital and technology with which they operate, and the shift within firms away from production activities (and tangible capital) to non-production activities (and intangible capital) generates a parallel shift in the demand for the higher-order professional skills of the managers, scientists,

engineers, and marketers needed to work with an organization's knowledge-based intangible capital. Another key point is that investment in intangibles like R&D endogenizes technical change by making it the result of systematic investments. Thus, not only does the new information technology increase the demand for higher order skills, it also depends on them to create and diffuse the technology.

Section II of the paper studies the role of education and skills in a growth accounting framework. When intangible capital is added to a modified version of the BLS sources-of-growth model (following Corrado, Hulten, and Sichel (2009)), it is found to be the largest systematic source of growth, explaining more than a quarter of the growth of output per worker hour from 1995 to 2007. Much of this contribution was enabled by the growth in work-force education and skill. Indeed, it is hard to imagine the information revolution and its associated capital occurring with the education levels prevailing in the 1950s, when less than 10% of the population had college degrees, and a majority did not have even a high school degree.

We then turn to the supply side of the education-skill market in Section III. We start with the increase in educational attainment in the U.S. over the last half-century and the rapid rise in spending on education. This is followed by a look at some of the problems with the education system: stagnant test scores, a significant fraction of K-12 students scoring below proficient levels in reading and math, rising college tuitions and student debt burdens, and problems with college graduation rates. We then turn to the average college wage premium, which has grown to be substantial. The key issue, here, is the finding that, in recent years, the marginal returns to education may be much lower, and that the college wage premium does not exist for many graduates.

Section IV brings the supply and demand sides together in an effort to get at the question of this paper: the skills needed for the future work force. We start with an in-depth look at the skill base of the U.S. as portrayed in the OECD's 2013 Survey of Adult Skills, which shows that the proverbial glass is at best only half full. The U.S. does have a substantial body of skilled workers in its "inventory", but generally lags the OECD average. The performance on this survey by the younger age cohorts, the college educated, and those in high-skill

occupations is of particular concern for staffing the needs of the knowledge economy and its capital. Other evidence points to a deficit in soft skills, singled out in employer surveys as an area of concern. We also consider, at the end of this section, the question of whether a skill problem actually exists in light of what appears to be a growing excess supply of college students and a leveling-off of the demand for their services.

Section V takes up the problem of wage inequality. It looks at the issue of the labor market polarization, and at the wage premium that has helped create a class of educated workers and entrepreneurs whose incomes have diverged from those with less education or skills. It also addresses the question of access to the education and skills so necessary for success, and the socio-economic variables known to be an important determinant of access. Students from a lower SES background have been shown to have a lower graduation rate than higher SES students even though they have the same SAT scores. These issues are discussed in this section, along with possible remediation strategies. A final section sums up.

II. Education, Skills, and Economic Growth

Growth accounting

The Solow-Jorgenson-Griliches sources-of-growth model has become the standard framework for assessing the relative importance of the various factors driving aggregate economic growth. The model identifies three general sources: the growth of aggregate capital, aggregate labor, and the growth in the productivity with which they are used. These are linked to aggregate output via a neoclassical production function:

$$Y_t = F(K_t, L_t, t) \ .$$

The time trend t in the function allows for productivity growth, and is associated with a shift in the function (usually identified as "technical change"). The Solow residual is derived from this function under the assumptions that the function exhibits constant returns to scale, factors are paid the value of their marginal product, and the shift in technology has the Hicksian multiplicative form: $Y_t = A_t F(K_t, L_t)$. Under these conditions, the sources of growth equation has the form

$$\dot{y}^{*} = s_K \dot{k}^{*} + s_L \dot{\ell}^{*} + \dot{a}^{*} .$$

(Dots over variables indicate rates of growth and time subscripts are dropped for clarity, although all variables are understood to have a time dimension unless otherwise indicated.) All the elements of this equation can be measured using data on prices and quantities except the last term on the right-hand side, which is measured as a residual (total factor productivity). Under the restrictions on the production function, the income shares s_K and s_L are equivalent to output elasticities.

There is no specific provision for the contributions of education or skills in the basic formulation. This issue was addressed in the seminal contribution of Jorgenson and Griliches (1967), who proposed a version of the production function that allowed for different types of labor, differentiated by worker characteristics like education, which have different wage rates and marginal products. The production function becomes $Y = A\, F(K, L(H_1, \ldots, H_N))$, where the H's are the hours worked at each of the N cohorts within a dimension, total hours are $H = \Sigma_i H_i$, and $L(\bullet)$ is a function that aggregate the N cohorts into an index of total labor input. The growth rate of L is the share-weighted contribution of each cohort's hours to the total hours, where the s_{Hi} are each cohort's share of total *labor* income:

$$\dot{\ell}^{*} = \dot{h}^{*} + \sum_{i=1}^{N} s_{Hi} (\dot{h}_i^{*} - \dot{h}^{*}) = \dot{h}^{*} + q_{LC} .$$

The growth rate of labor input is thus the sum of the growth rate of total unweighted hours plus the labor composition effect, q_{LC}. The associated growth equation is then

$$\dot{y}^{*} = s_K \dot{k}_t^{*} + s_L \dot{h}^{*} + + s_L q_{LC} + \dot{a}^{*} .$$

The variable q_{LC} records the effect on output of a shift in worker hours among groups with different marginal products/wages, and is positive when the composition of the labor force

shifts toward higher productivity groups. In practice, multiple worker characteristics are included in the index (Jorgenson and Fraumeni (1989,1992)).[3]

This growth accounting framework has become an official statistical program at the BLS official program. The left-hand panel of Figure 1a shows a variant of the BLS results for the U.S. nonfarm business sector over the period 1995 to 2007 (the last year before the Great Recession).[4] Over three-fifths of the 2.6% increase in output per hour was driven by total factor productivity, that is, by improvements in the efficiency of production processes as well as by other unmeasured variables. Capital per hour is divided into information technology (ITC) and other components. The labor-composition effect, which includes the contribution of educational attainment and other characteristics to the increase in output per hour, only contributed 9% to this increase. This relatively small contribution of worker knowledge-related characteristics seems inconsistent with the growth of the knowledge economy occurring over the period 1995 to 2007. This finding calls for a closer look at the labor composition term.

The sources of labor quality change

Quality change in the sources-of-growth model is a theoretical formulation based on the hours worked in each category and the associated marginal product, without specifying the mechanisms through which change occurs. One immediate observation is that labor quality is not, itself, a product available for purchase in the desired quantity in a market. It is mostly embodied in people and acquired by hiring workers directly or indirectly through purchased services.[5] An increase in high-order cognitive skills, for example, generally involves acquiring

[3] It is important to recognize, here, that labor quality as a stand-alone variable whose components can be studied separately from the structure of production must assume that the hours variables, H_i, are separable via $L(\bullet)$ from the rest of the function. This is a very strong assumption when there are multiple capital goods, because separability requires that the marginal rate of substitution between types of labor be independent of the quantity and composition of capital (Hulten (1973)). This is a particularly problematic assumption to apply to the knowledge revolution with its increased emphasis on knowledge-based intangible capital. This issue will be revisited in a subsequent section, but it is important to emphasize here that without the separability assumption, there is no guarantee that a labor-quality index based on $(H_1, \ldots, H_N)$ is unique.

[4] Figure 1a actually shows the sources of growth of output per hour, rather than output alone. The constant-returns production function in this variant is $Y_t/L_t = A_t F(K_t/L_t)$.

[5] "The best way to send information is to wrap it up in a person", J. Robert Oppenheimer quoted in Stephan (2007).

the services of workers who possess skill-related characteristics like education, experience, and, most likely, personal traits like reliability, creativity, and perseverance. When the demand for skills shifts, as documented for non-routine cognitive skills by the research of Autor, Levy, and Murnane (2003), the supply-side response must come in those worker characteristics associated with those shifts. This has led to a focus on higher education.

The influential book by Goldin and Katz (2008) documents the rise of a wage premium for higher education, and explains the rise as an imbalance between the supply of graduates and a more rapidly growing demand for their services. The combination of the growing premium and the rising level of educational attainment has led to a major shift in the income shares of workers with higher education degrees, from around 20% in 1950 to almost 60% in 2005. This is shown in Figure 2, where the sharp decline in the shares on workers with less than a high school degree is also shown. An increase in the wage share of the college educated, combined with a corresponding increase in quantity from 5% to around 30% should lead to a significant increase in the education component of the labor quality term in Figure 1a. But despite this increase, the overall labor-quality effect in Figure 1a is small. It was larger for the post-WWII period as a whole, 16%, but this result still does not suggest a role for education commensurate with the perceived contribution of the post-war education boom to economic growth. It is, however, consistent with the Goldin and Katz estimate that human capital growth contributed about 14% of GDP growth between 1915 and 2005.

Skill-biased technical change and the TFP residual

The structure of production also figures in Acemoglu and Autor (2012), who argue in their review of Goldin and Katz's book that the standard labor-quality decomposition surely underestimates the contribution of human capital to growth, because it makes additional contributions to the creation and adoption of frontier technologies. Acemoglu and Autor present a generalized task-based factor-augmentation model that builds on Autor, Levy, and Murnane (2003), Acemoglu and Autor (2010), and others, which allows for both *LQ* and *TFP* effects. In this scenario, part of human capital's contribution is suppressed into the residual estimate of *TFP* and is thus not captured by the *LQ* decomposition.

This scenario is almost certainly correct in some form (more on this in a subsequent section). It is hard to imagine a successful IT revolution supported by a work force in which only 10% had a high school degree (1900), and only 5% had a college degree (1950). A broad advance in the sophistication of technology, as in the IT revolution, would seem to require a fairly broad-based upgrading of the worker skills needed to make effective use of the new technology. An inadequately educated and skilled work force can be a barrier to technical and organizational change. This is widely observed in low-income countries and is the source of development policies aimed at improving human capital via health and education programs.

Lucas' (1988) path-breaking work on knowledge externalities and endogenous growth is particularly important in this regard. The education of one individual provides a flow of benefits whose value can be captured by the individual. The education of a second person generates another stream of direct benefits, but it also interacts with the human capital of the first person to create an externality in which each individual's human capital enhances the value of the other. The total social human capital is greater than the sum of its individual private parts. Using the individual wage as a proxy for the marginal product of education, as in the sources-of-growth model, captures only the private return, and the externality part of the social return is suppressed into the *TFP* residual. A similar argument exists for the creation of social capital through education.

The importance of knowledge capital and technology as a determinant of demand for skills

The neoclassical production function $Y_t = F(K_t, L_t, t)$ presumes an aggregate technology in which aggregate capital is continuously substitutable for aggregate labor along a smooth isoquant. Earlier approaches like activity analysis and choice-of-technique models recognize that movements along an isoqant involved moving from one activity to another, in the process using different types of labor and capital, and different techniques of production.[6] Each type of

[6] Each activity (technique) can be thought of as a mini-production function involving activity-specific capital and labor. In the putty-clay model, there is a fixed-proportions technology for each activity, and the overall (ex ante) production function is the envelope defined by the activities. Substitution of capital for labor, or substitution between low and high skilled workers, involves substituting one activity for another. Within each activity, there are usually a multiplicity of tasks, some running sequentially and others simultaneously. Tasks change from one activity to another. A more complex model of a firm may have several activities running simultaneously.

capital is associated with a worker skill set needed to operate the capital. Think, here, of a few skilled operators equipped with bulldozers versus many manual workers each with a shovel. The choice of techniques depends on the relative price of the various types of capital and labor (and, in more sophisticated versions, on the scale and nature of output). Technical change also matters; think of an innovation that introduces a driverless bulldozer managed by GPS and an IT operator who monitors the result. In all cases, the demand for skills, routine and non-routine, cognitive or non-cognitive, is determined in part by the choice of technique and the requirements of the capital on which they operate. The general supposition is that the more technically sophisticated the machinery and equipment, the greater the sophistication of complementary worker skills, though this is not necessarily the case.[7]

Not all activities within a firm are production related. Workers must be supervised and managed and their wages paid. Customers must be found and satisfied, inventories managed, products designed, finances and legal affairs managed, and a host of other overhead activities undertaken. These activities require different types of employee skills and different types of capital. These employees are often professionals with college degrees and beyond -- lawyers, accountants and financial managers, senior executives, marketers, and scientists and engineers. The capital with which they operate, and in many cases develop within the firm, includes intellectual property, product brands, customer lists and reputation, and management and human resource systems. These categories constitute a firm's intangible capital. These overhead activities are highly knowledge intensive.[8]

These non-production activities are also a source of new processes and products that are the hallmarks of the knowledge revolution. They are the result of R&D and product design and coinvestments in marketing and customer support, and their development is a source of

[7] The introduction of the factory system and assembly line, along with interchangeable parts, routinized many manufacturing processes and replaced high skill craft production with workers with routine skills. However, the IT revolution reverses this trend in many manufacturing processes because it allows for greater customization of product to fit buyer needs. In these cases, routine jobs are replaced by workers with IT skills and the capacity to manage non-routine production plans.

[8] The economic literature on modeling of these activities includes articles by Nerlove and Arrow (1952) for advertising, Prescott and Vissher (1980) for employee and organizational management, Bloom and Van Reneen (2007) for management, and many authors for R&D, but for modeling, see Romer (1986,1990). Lev (2001) is an important source for studying intangible capital activities at the company level.

demand for the highest order of non-routine creative skills. They endogenize the development the innovations that are, in turn, skill-biased in their subsequent application. A key point is that the innovations they produce are not costless or exogenous, as in the formulation of technology and innovation, $Y_t = F(K_t, L_t, t)$, underlying much of the analysis. It is the result of systematic investments in R&D and its co-investments. Another key point is that these investments in intangible innovation have until very recently been omitted from the data used to analyze growth. This omission has the effect of suppressing the sources of innovation into the TFP residual, thereby understating the contribution of the knowledge inputs involved in the innovation process. One consequence is that the full contribution of education and skill-building is understated.

How big might this understatement be? Corrado, Hulten, and Sichel (2005,2009) extended the measurement of intangible capital to the U.S. private nonfarm business sector as a whole. In this formulation, the stock of intangible capital is estimated and added to the aggregate production function as an input, and the corresponding investment is included as an output. This stops short of a full activity analysis treatment of intangibles, but such a treatment would require data about with-in firm activity that are not available. Expanding the conventional aggregate production function to include this kind of capital does, at least, introduce inputs and output closely associated with the knowledge revolution. Three general categories of intangible capital are identified: computerized information, innovative property, and economic competencies.[9] The rate of investment in these intangibles over the period 1977 to 2010 is shown in Figure 3. The rate rose significantly over the period, starting at just over 8% in 1977 and reaching just under 14% by the end of the period. The growth in importance of this type of capital is in stark contrast to the declining rate of tangible capital investment shown

[9] The first category is mainly software, and comprises 13% of the overall intangible investment rate in 2010. Innovative property is a diverse group that includes not only the conventional National Science Foundation (NSF) type of R&D, with its orientation to science and technology, but also other important forms of R&D such as investments in artistic originals (books, movies, and music), development of new financial products, and architectural and engineering designs. Conventional R&D accounts for only about half of the innovative property subtotal and just 18% of total intangible investment. The largest category of intangible capital is economic competencies, divided into brand equity (advertising, marketing, customer support), firm-specific human capital (worker training), and organizational structure, a rather amorphous grouping that includes investments in management and human resource systems, strategic planning, and management consulting.

in the figure, falling from the 11% to 13% range and to around 8% by the end of the period (9.6% in 2007, the last year before the recession). The overall trends are associated with the decision by many companies to move up the global value-chain to higher valued added activities like product design and marketing, and the much-noted decline in tangible capital-intensive manufacturing industry.

When the BLS model is expanded to include intangibles using estimates from Corrado, Hulten and Sichel (2009) and subsequent research, the contribution of intangible capital becomes the largest systematic source of growth in the U.S. business sector over the period 1995 to 2007. The full decomposition is shown in Figure 1b. Intangible capital accounts for 27% of the growth in output per hour and can be thought of as the productivity change arising from investments in knowledge capital (as opposed to "costless" TFP). Another 23% is accounted for by tangible capital, with the majority of the 13% accounted for by information technology equipment and 10% by other tangible capital. When the effects of ITC equipment are added to intangible capital, and then combined with the labor composition effect, it becomes clear that the measured footprint of the knowledge economy is large. Even this may be an understatement, as some part of tangible capital embodies new technology, and the residual productivity category, while something of a black box, contains an unknown amount of output growth from technology diffusion and spillovers.

The inclusion of intangible capital reclassifies a quarter of the growth of private business in the U.S. from the TFP residual – termed by Abramovitz (1956) "a measure of our ignorance" – to growth driven by investments in technology and organizational capability. With it comes an insight into the underappreciation of the skills needed for the formation of intangible capital, which along with the capital itself, were previously suppressed into the pre-intangibles measure of our ignorance. To repeat an earlier remark, it is hard to imagine how investment in innovation (and ITC capital) on this scale and consequence could have occurred with the low levels of advanced education prevailing in the 1950s and 1960s.

The Growth in Non-Cognitive Skills

The sources-of growth analysis records the contribution of various factors, including the changing composition of the labor force. How has the skill composition actually changed? The growing importance of non-routine skills can be seen in Figure 4, which shows an updated version of these results from Autor and Price (2013), based on the seminal contribution of Autor, Levy, and Murnane (2003) and reproduced in the 2013 OECD Survey of Skills study (PIACC). This figure compares the proportion of the labor force employed in occupations that made intensive use of non-routine cognitive tasks versus the percentage of the labor force employed in occupations intensive in routine activities. The former increased significantly while the latter declined. The similarity of these patterns with the cross-over in rates of intangible and tangible capital is unmistakable: the demand for the skills needed to function in an increasingly complex task environment coincided with a surge in investment in creating that environment.

The 2013 OECD *Survey of Adult Skills* also addresses the issue of cognitive skills. Some 166,000 adults aged 16-65 were surveyed in 24 countries and sub-national regions, and the results were classified into six levels of proficiency in literacy and numeracy. Test scores ranged from zero (the lowest proficiency) to five. Occupations were grouped into four categories according to average scores along with the change in employment by each over the period 1998 to 2009, and the results are shown in Figure 5.[10] The highest scoring occupations saw employment increase by more than 20% over the period, while employment in the next to highest and the lowest was essentially unchanged. The employment share of occupations with next-to-lowest skills, however, experienced a 15% decline. These patterns suggest a hollowing out of the skills distribution consistent with other evidence for the U.S. alone. They also reinforce the message of the preceding figure that the relative demand for more complex cognitive skills has increased in recent years.

[10] The occupations with the highest average scores are those with scores at, or above, the upper half of Level 3 for literacy and numeracy; the next-to-highest have average scores from the lower half of Level 3 for literacy and numeracy; the next-to-lowest have average scores in the upper half of Level 2; and the lowest average scores are in the range at or below the lower half of Level 2.

The PIACC study also tracks the evolution of employment shares by level of education. The results are shown in Figure 6, and they indicate that the occupations with the highest (tertiary) education levels expanded while the mid- and low-education occupations contracted. The pattern is consistent with the preceding two figures and points to the growing importance of higher-order cognitive skills and the education through which many of these skills are acquired. This point is reinforced by Eden and Gaggl (2014), who report that the income-share of non-routine labor increased at the expense of routine labor, and that there is a wage premium for non-routine labor.

The Importance of Non-cognitive Skills

Technical and conceptual cognitive skills are important worker attributes, but they are not sufficient by themselves. They must be effectively applied in the work place, and a good work ethic has long been recognized as an important factor in determining economic success. The recent literature has also focused on the demand for non-cognitive ("soft") skills, which include characteristics like self-discipline, perseverance, attentiveness, dependability, orderliness, and persistence in the pursuit of long-term goals. Deming (2015) argues that the labor market increasingly rewards social skills, and that jobs with high social skill requirements have shown greater relative growth throughout the wage distribution since 1980. One factor he cites is the difficulty of automating human interaction. Another factor is that a worker with significant deficits in these characteristics is unlikely to be a productive employee in most jobs despite the possession of superior cognitive skills. Deming also observes that the strongest employment and wage growth has occurred in jobs that require high levels of both the hard cognitive skills and the soft social skills. In her work on the topic, Lundberg (2013) finds that non-cognitive skills are important for academic success.

III. Education and the Supply of Skills

Educational Attainment, Outcomes, and Expenditures

The growth in educational attainment of the American population over the last century has been remarkable and has coincided with a century of sustained technological innovation

and skill demand. It was not until the late 1960s that workers with at least a high school degree became a majority of the work force. Over the post-World War II era, the proportion of persons over 25 with college degrees went from around 5% in 1950 to 30% in 2010. Two-thirds of high school graduates went on to college in 2012 according to the BLS, up from 50% in 1975. These statistics indicate a major transformation in the human capital of the U.S. population and workforce.

The dramatic increase in schooling was matched by a large increase in annual real expenditures per student over the period 1960 to 2011, from around $3,000 to $11,000. The investment rate in public education increased steadily over the course of the 20th Century, from around 1% of GDP to just under 6% in the late 1970s. It has fluctuated around this level until the Great Recession, but has fallen under 5% since then. When private spending is added to public outlays, the combined direct investment rate in education in 2011 was nearly 7%. U.S. spending on education is second only to Switzerland, according to OECD data for 2008, but the U.S. is by far the leader in tertiary education.

These expenditure data omit an important additional resource devoted to education – the time spent by the students who could otherwise be working. Figure 7 shows Ramey and Francis' (2009) estimates of the average hours per week spent in formal education for *all* individuals ages 14-17 and 18-24.[11] Over the course of the 20th Century, average hours spent in formal education quadrupled for individuals ages 14-17 and rose eight-fold for individuals ages 18-24. These changes reflect both increases in enrollment rates and increases in the hours spent per enrolled student. We estimate that the dollar value of the foregone work hours equals 1.6 percent of GDP.[12] Thus, accounting for the foregone wages raises total education investment to around 8.5% of GDP. [13]

[11] Hours spent in formal education include both time spent in class and at home studying, and are averaged over the entire year (including summer vacation). For a description of the methods and assumptions used to create these estimates, see Ramey and Francis (2009).

[12] We can estimate the dollar value as follows. We first create annual hours spent on formal education by multiplying the weekly average hours by 52 weeks. We then assume the federal minimum wage of $7.25 as the opportunity cost of time for teenagers without a high school degree and $10 as the opportunity cost of a high school graduate (based on payscale.com for individuals with little experience). With 17 million individuals

While the increase in U.S. educational attainment over the last century has been impressive, years or hours of schooling are not the only dimension that matters. The quality of education also matters, and performance of the American educational system is not strong in this regard. The test scores of American high school graduates have not improved much in recent years, despite increasing amounts of money spent on their schooling and significant grade inflation. Moreover, the 2013 National Assessment of Educational Progress (NAEP), a "report card" on the math and reading skills of some 92,000 American 12th graders, found that only 26% scored in the proficient or advanced range in math, and only 37% in reading. These outcomes are a cause for concern when thinking about the preparation necessary for success in higher education and the skill development required by the emerging knowledge-based economy. Equally disturbing is the finding that 35% of 12th graders scored in the lowest proficiency category, "below basic", in the math assessment and 25% in reading. It is hard to give the primary and secondary education system a high grade based on this report card.

The "report card" for tertiary education is somewhat better, though still mixed. A 2011 survey by the PEW Research Center found that some 74% of those respondents who had graduated from a four-year college said that their education was "very useful in helping them grow intellectually"; 69% thought it helped them "grow and mature as a person"; and 55% say it was a helpful preparation for a job. These are the perceptions of those who actually have graduated. In the general population, 57% did not think that higher education gave good value for money. The perception of the higher education sector is colored by several high visibility issues: rising tuition costs and the issue of affordability, the associated issue of large and growing student debt burdens, lengthening times-to-graduation, and lower graduation rates.

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between the ages of 14-17 and 30.7 million between the ages of 18-24, the total dollar cost adds up to $281.5 billion per year.

[13] The 8.5% rate of investment in education appears low when compared to the capital investment rates in Figure 3. However, the latter are shown as a fraction of nonfarm business GDP, expanded to include intangibles. When those estimates are expressed as a fraction of full GDP ex intangibles, the comparable investments rates are approximately 10% (intangibles) and 6.5% (tangibles). Moreover, these are gross rates of investment, not net rates adjusted for depreciation. The depreciation rate of education is low given the long life time of the human in which the capital is embodied, where the depreciation rate of knowledge is generally reckoned to be quite high due to obsolescence, and tangible capital is somewhere in between (around 15% for machinery and equipment and 3% for structures).

Issues in High Education

The difficulty in any assessment of the problems with "college" is that "college" is not a homogenous entity. Institutions of higher education range from two-year colleges to graduate and professional schools; they include public and private not-for-profit institutions as well, and those that operate for-profit and free on-line entities; they also include research universities and liberal arts colleges, professional schools, and those aimed at vocational development. These institutions differ significantly in many dimensions, including mission, selectivity, graduation rates, and tuition. The degree of selectivity varies greatly even among four-year, degree-granting institutions. According to the 2013 College Board assessment, the most selective of these accept one applicant in four, and account for 2% of schools and 4% of undergraduates (in other words, high "selectivity" essentially means admitting a quarter of those that apply). The next tier accepts between 25% and 50% of applicants, and accounts for 3% of schools and 16% of students. At the other end of the selectivity scale, almost a quarter of the student population is in the 22% of institutions with acceptance rates of 90% or more. A majority of students are in schools that accept between 50% and 90% of applicants. This diversity of options is an important factor in allowing two-thirds of high school graduates to go on to college, and these data do not include the two-year institutions that in 2011 accounted for some 40% of all (and 28% of full time) undergraduate enrollments.

This diversity and flexibility does come at a cost since graduation rates fall monotonically with the degree of selectivity. The graduation rate for the small number of highly selective schools was 88% in 2011, and 70% in the next tranche of schools admitting 50% or less. This rate falls to 45% when 90% or more are accepted and 31% in schools with no application criteria.

The high and rising cost of college is one of the most visible issues in the debate over the future of higher education. According to the College Board, tuition rates have outstripped the rate of general inflation for many years, increasing from an inflation-adjusted index of 100 in 1983-84 to 331 in 2013-14 in public four-year institutions, and from 100 to 253 in private institutions,. This increase imposes a burden on students and their families, and there has been a particular concern that low-income students may be rationed out of the college market, or at

least the upper and middle echelons of selective schools. However, these statistics refer to gross tuition. Many students qualify for government and other grants and benefits, and net tuition is in many cases considerably lower. College Board data for 2007-2008 suggest that net tuition was only about half the published rate for full-time, full-year, students at four-year institutions, and that this fell to 40%, 32%, and 12% as institutions became progressively less selective in their admissions (the majority of students were in the 40% class). Even lower net tuition can be a problem for lower-income students, but much of grant-in-aid effort is targeted to this group. The College Board study reports that, in 2011-12, the net tuition paid by dependent students whose family income is in the lowest quartile of the income distribution is effectively zero for both two- and four-year institutions.

As tuition has risen, so have some student debt burdens. A White House report shows that debt burdens have increased significantly since the onset of the Great Recession, and now tops well over $1 trillion (DPC/CEA (2014)). The DPC/CEA report also indicates that 71% of those graduating with a bachelor's degree have incurred some level of debt in 2014, and that this debt averages $29,400 among this group (or around $21,000 for graduates as a whole). Other evidence suggests that the distribution of the debt burden is skewed. The study by Akers and Chingos found that median debt was only about half of the average level in 2009, and Monge-Naranjo (2014) reports that 43% of students beginning postsecondary education in 2003-04 did not borrow, and another 25% had debt less than $10,000 in 2009. At the other end of the distribution, only 7% have debt greater than $30,000 and 2% $50,000 or more. Of the latter, the majority had graduated with a Bachelor's degree.

Rising debt burdens and increasing gross tuitions are not independent events. They reflect a two-way interaction in which rising tuitions lead students to take on more debt, but government subsidies also lead some institutions to raise their "sticker" prices. The latter is a familiar result in tax (and subsidy) incidence theory, in which supply and demand elasticities affect the degree to which taxes or subsidies are shifted from one side of the market to the other. Lucca, Nadauld, and Shen (2015) take this simultaneity into account and estimate that the pass-through effect of subsidized loans on gross tuition is about 65 cents on the dollar, and 55 cents for Pell Grants; unsubsidized loans are found to have a weaker effect of about 30%.

The financial burden on students increases to the extent that student loan and grant subsidies are shifted to institutions.

Around 40% of total student debt is from graduate and professional school debt (Delisle (2014)). College Board estimates suggest that students at this level receive fewer benefits that lower net tuition (though they do exist), so a rising burden of debt may pose a significant financial constraint on the development of some of the highest non-routine cognitive skills for many people.

The average versus marginal return to education

The large average wage premium attached to a college degree has been documented by Goldin and Katz and others. The magnitude and trend in the average premium is shown in Figure 8, which also shows that most of the increase in the premium occurred from the 1970s to the late 1990s, and that it has slowed since then. This slowdown has been offset by a premium for post-graduate degrees, so the total higher education premium has continued to rise. Moreover, the average premium for undergraduate degrees is not shared equally across majors. Numerous studies have found that those majors requiring the strongest technical and quantitative skills commanded the largest premiums. *Payscale* data on the starting wage of graduates in 32 majors in 2009 suggests that technical subjects like electrical and mechanical engineering, computer science, economics, finance, accounting, statistics, and mathematics command significant wage premia (Coelho and Tung (2012)). Graduates in these subjects were also the likeliest to be in jobs that require four-year degrees (McKinsey).

Can all the two-thirds of high school gradates who currently go on to some form of post-high school education be expected to earn the average premium, in light of the 2013 NAEP report card in which only 37% of the graduating seniors tested were found to be proficient or advanced in reading and only 26% in math? The answer given by James Heckman is a qualified "no". In an interview with Megan McArdle about whether going to college was worth the expense, he replied "Even with these high prices, you're still finding a high return for individuals who are bright and motivated," but, "if you're not college ready, then the answer is no, it's not worth it." This conclusion is backed by econometric analyses that find that average and

marginal returns diverge, and the divergence depends on student characteristics (e.g., Carneiro, Heckman, and Vytlacil (2010)). Moreover, it is not just the cognitive skills that matter, the non-cognitive soft skills matter as well and perhaps more so (Heckman, Stixrud, and Urzua (2006), Lundberg (2013)).

The implication of this problem for some college graduates with Bachelor's degrees can be seen in Figure 9, taken from the paper by Abel and Deitz (2014a). This figure compares the median real income of those graduates with the income of those in the 25 percentile income over the period 1970 to 2013. It shows that median-income degree holders have been consistently and significantly higher than those of the lowest quartile, though they have increased only slightly from the mid 1980s to the onset of the Great Recession. The remarkable point, however, is that the lowest quartile incomes of college graduates only marginally outperformed (if at all) the median incomes of high school graduates.

The college readiness problem is evident in the data on college student retention and time-to-degree problems, and in studies of the need for remedial courses at the college level (a recent NCSL report stated that among first-time undergraduates, "studies have found anywhere from 28 % to 40% of students enroll in at least one remedial course" (Bautsch (2013)). Moreover, less than half of students at four-year institutions actually graduate in four years. According to NCES data, the four-year graduation rate is around 40%, and after six years, only around 60% have graduated (NCES Table 326.10). As noted, graduation rates tend to increase with the selectivity of the institution.

While the wedge between average and marginal returns to college education may reflect a number of factors (bad luck in finding the right employment match, or idiosyncratic personal issues), the work of Heckman and colleagues suggests that it is due in part to a deficit in cognitive and non-cognitive skills.[14] These deficits are doubtless a factor in the finding in surveys of college graduates that they felt unprepared for the demands of the workplace (30% in the McKinsey survey), and that employers tended to agree. One implication of this analysis is that the skill content of the marginal B.A. degree is less than the average, and an increase in such degrees does not necessarily mean a proportionate increase in skills. This is important for

[14] See also Schoellman and Hendricks (2014).

analyses that use educational attainment as a proxy for skills. Another implication, in conjunction with the deficits reported in the 2013 NAEP, is that efforts to raise the national non-cognitive skill base via increased college education might better be aimed at increasing college readiness at the primary and secondary levels of education.

IV. Is There a Gap between the Supply and Demand for Skills?

The supply and demand for skills

The last 35 years have seen a significant increase in both educational attainment and the premium for advanced education. By implication, there has been an increase in the reward for, and quantity of, the skills needed in the transition to a knowledge economy. But one point that emerges from the literature reviewed above is that education and skill building are not equivalent, and it is therefore worth looking at the current state of the national skills base in light of the growth in educational attainment.

The results of the 2013 OECD Survey of Adult Skills provides a snap shot of the skill distribution of adults aged 16-65 in 24 countries , who were (as noted) classified into six levels of proficiency in literacy and numeracy with test scores ranging from zero to five. These data were used to construct Figures 5 and 6, and they can also be used as an inventory of skills by level of proficiency. The results are shown in Figures 10a and 10b, which shows that 35% of the U.S. population surveyed scored at numeracy levels 3, 4, 5, with a much smaller 9% in the top two levels. The literacy numbers are somewhat better, 48% and 12%, but more than half the population is at basic levels or below. The U.S. trails the OECD average in both literacy and numeracy, although cross-national comparison are complicated by differences in economic and demographic structure (see the Carnoy and Rothstein (2013) critique of the OECD's PISA results).

The "problem solving in technology rich environments" dimension of the survey is of particular relevance for the issues of this paper. Only 31% of those surveyed in the U.S. scored in the top two categories, about the same as for the OECD as a whole. Of even greater concern is the problem-solving proficiency of the age cohorts 16 to 24 and 25 to 34: only about 40% of both cohorts placed in the top two levels versus 50% in the OECD. The youth are (presumably)

the most computer-literate cohorts and the ones whose technology-oriented skills are critical for sustaining the growth of the knowledge economy through much of the century. Other deficits are also apparent in the OECD data. Just over 50% of the most educated adult cohorts - those with a *tertiary* education -- scored in the top two levels of problem solving skills (about the same as the OECD average). The corresponding score for those identified as being in the highest skilled occupations was 48% for the U.S. versus 50% for the OECD. These are presumably the non-routine skills of the knowledge economy, and half of America's college-educated and skilled cohorts are in some degree of skill deficit.

How does this stock of skills match the corresponding demand? This is not an easy question to answer directly, but the PIACC survey does show data on wage differentials by literacy score. The median hourly wage was approximately $12 for the lowest proficiency levels, $15 for level 2, $19.50 for level 3, and $26 for the highest levels. It is also worth noting that a high literacy score did not guarantee a high wage rate. The variance in the distribution of wages at the top level was such that the 25th percentile wage at this level was *lower* than the 75th percentile wage of the lowest literacy levels. Another demand-side indicator, the rate of unemployment, was also favorable to the higher literacy levels. According to the PIACC survey, "on average, about 57% of those individuals who score at or below Level 1 are employed, 7% are unemployed, and the remaining 36% are inactive. Among the most proficient individuals, who score at Level 4 or 5, 79% are employed, about 4% are unemployed, and 17% are inactive" (page 227). The survey also notes that the effects of skills and education on unemployment seem to be somewhat separate (see also Hanushek, Schwerdt, Wiederhold, Woessmann (2013)).

Other indirect evidence comes from the BLS May, 2014, O*ccupational Employment Statistics* survey by occupation, which shows that just over 20% of total employment was in the managerial, professional, and engineering categories, with an average hourly wage of around $35. These are categories generally demanding a high non-routine skill level, roughly corresponding to PIACC levels 5 and 4, and the top half of level 3 (23% in the numeracy inventory and 38% in literacy). Another 10% of employment was in service occupations with an average wage of around $20. These proportions are roughly in accord with the PIACC skill

decomposition. Other evidence comes from the BLS study *Education and training outlook for occupations, 2012–22*. According to this report, 3% of those employed in 2012 were in occupations that typically require a Ph.D. or professional degree for entry, 2% in Master's degree occupations, and 18% in occupations that typically require a Bachelor's degree. Another 10% were in occupations requiring less than a Bachelor's degree but more than a high school degree.

Is there evidence of a skill gap?

Employer-based surveys tend to suggest that there is a perceived gap, but other observers have read the available evidence as suggesting that whatever skill deficit may have existed in the past, the current labor market situation is now rather different. Beaudry, Green, and Sand (2013) argue that, since 2000, the demand for high cognitive skills has undergone a reversal, while the supply of higher education workers has continued to grow. As a result, higher-skilled workers with college degrees have moved to jobs that traditionally have not required a college degree. Abel and Deitz (2014b) also find that the demand for jobs requiring a college degree has slowed significantly, while jobs not requiring a college degree have continued to increase. This provides qualified support for the Beaudry et. al. thesis with their finding that the fraction of new college graduates "underemployed" in non-college jobs has increased somewhat, but Abel and Deitz also report that the fraction is sensitive to recessions and, in any event, has precedents in the early 1990s (see also Abel and Deitz, and Su (2013)).[15] On the other hand, they also report that a crowding down effect occurred since 2000 within the ranks of the underemployed. The fraction of this group with "good" non-college jobs – jobs whose average salary is $45,000 – has declined from around 50% of the underemployed cohort of recent graduates to the mid-to-high 30s (Figure 11).

[15] One of the open issues in the skills debate is the nature of this kind of underemployment. One possibility is certainly that the supply of skills has outstripped the demand. There are two other possibilities, however, one of which is "upskilling": jobs that did not traditionally require a degree in a less technological environment now require higher levels of cognitive skills. The other is what might be called the "Heckman effect": that it is not just an increase in the quantity of college graduates that drive underemployment, but an increase in the marginally qualified college graduates entering the job market. All three possibilities may be in play.

These various strands undermine, or at least do not support, the idea of a major skills gap in the U.S. work force. Economic orthodoxy suggests that prices should adjust to extinguish the gap between supply and demand for skills, and the Goldin-Katz explanation of the college wage premium suggests just that. However, while growth in the premium for a Bachelor's degree has slowed in the 2000s, the premium for graduate and professional degrees continues to rise.

What, then, of the many employer surveys that report the perception of skills shortages? Cappelli (2014) examines "the claims associated with complaints about the supply of skills in the US", and argues that "The evidence they present as well as evidence from other sources suggests little merit to their claims (page 2)." He concludes that **"**Overall, the available evidence does not support the idea that there are serious skill gaps or skill shortages in the US labor force. The prevailing situation in the US labor market, as in most developed economies, continues to be skill mismatches where the average worker and job candidate has more education than their current job requires (page 46)." On the other hand, employers are not the only ones worrying about the inadequacy of skills coming into the labor market. Surveys show that a significant fraction of recent college graduates seem to believe they are underprepared for the world of work (e.g., McKinsey (2013), Bentley (2014)).

The conflicting views on skill deficits may be due, in part, to the imprecise notion of "deficit" itself. To the economist, a deficit is an inability to hire workers with the needed skills, that is, as a market supply and demand gap. This situation should create skills premia that increase to the point that they extinguish the gap, though perhaps slowly (as with the education premia). Another interpretation might see the problem as being about the general preparedness of the pool of new applicants from which a selection must be made, a more macro concern about the ability of the graduates who are actually hired to contribute to the firm.[16]

[16] This may be a particular problem for the acquisition of the soft skills that employers identify as important, which are closely related to individual personality traits. A graduate's soft skills may only become apparent after being hired, and may be harder to spot beforehand (creativity, diligence, grit). This makes it hard for these skills to be accurately priced in the entry-level job market.

Another factor arises from a reduced propensity for employers to invest in on-the-job training. If workers are less likely to stay with one employer for their entire career, the employer may be less likely to give them training that is portable to other employers. The latter may then perceive a skills problem when they hire this segment of the work force. [17]

How does a continuing advance in technology affect the future skill gap?

Projections of future skill needs require an assessment of the future path of technology, and there is substantial disagreement on this point. The position taken by Gordon (2012) is that the information technology boom has largely played out, and that the future technology environment is unlikely to be as dynamic as the recent past. In this world, the demand for higher-order skills would presumably not increase much. An alternative view is advanced by Brynjolfsson and MacAfee (2011), who argue that the continued evolution of robotics and artificial intelligence will create a very dynamic technological future in which intelligent machines increasingly dominate the work place. However, this scenario does not necessarily mean an increased demand for higher-order skills, because there are countervailing expansion and substitution effects. As the use of advanced information technology expands, so does the demand for complementary worker skills, other things equal. But, they are not equal. As artificial intelligence becomes more powerful, it increasingly substitutes for high-cognitive skill workers. This is the Big Blue problem - most complex non-routine skills, even those possessed by a Grand Master chess player, can be mastered by a sufficiently powerful machine. Ultimately, even college professors may be replaced.

Advances in technology are also likely to affect the supply side of the market for education and skills. Information technology has already had an impact on the classroom, as for example, with Powerpoint lecture presentations, course websites and chat rooms, and electronic course management. There are also large amounts of information available outside

[17] Respondents to the 2013 Adecco survey of business executives agreed that worker training was important. Of those 92% who thought there was a skills deficit, 89% said that corporate apprenticeships or training programs could help with the skill gap problem. However, 42% also thought that the great barrier to in-house programs was development cost. Private businesses have an incentive for in-house skill development only up to the point at which marginal benefits justify the cost.

the classroom, from internet search engines and databases. However, the core model of instruction still involves a teacher instructing a class, which meets at a prescribed time and place. Progress through the educational process is based on instructor evaluations, supplemented more recently by broader examinations. In the future, this fixed time-place classroom model of group instruction may be replaced by a more flexible system that allows students to master material at their own speed and in ways more consistent with their individual learning styles and abilities, and that proceeds at a time and place more convenient and accessible. Tailoring instruction to the needs of the individual student could pay large dividends for the student population as a whole, and be of particular value in increasing the accessibility of a good education to underserved segments of the population.

Advances in IT have made a more flexible model possible, but it is a disruptive technology that requires significant changes in existing models and infrastructure. A more flexible IT model may not require the expensive overhead of the core classroom model, but the transition involves a major commitment of resources and IT-related skills. And, the experience to date with massively open online colleges shows that a transition from the *status quo* is not a simple matter. On the other hand, the education industry cannot expect to hold itself apart from the disruptive IT revolutions that are sweeping other industries, particularly those that trade in knowledge.

Immigration is another important source of skills. A study by Orrenius and Zavodny (2013) reported that 27% of immigrants had at least a college education in 2011, approximately equal to the share in the population as a whole. Moreover, the study by Wadhwa et. al. (2007) found that around one-quarter of the engineering and technology companies started in the U.S. from 1995 to 2005 had at least one key foreign-born founder. Immigration has been an important source of high-end skills in the past and can be expected to continue as an important source in the future.

V. Education Premia and Income Inequality

Our focus has thus far been on the success of the education system in supplying the skills need in a progressively more technology-saturated economy. What of the ability of the

education system to deliver an improved standard of living to a broad range of workers? How the gains from growth are shared is at least as important for the sustainability of growth in a democratic society. The problem with the technology boom is that the gains and losses have not been shared equally. This is the well-known "labor force polarization" problem (Autor, Katz, Kearney (2012), Autor (2014), Levy and Murnane (2013). According to Jaimovich and Siu (2012), the employment share of non-routine cognitive occupations increased from 29% to 39%, the share of non-routine manual occupations increased from 13% to 19%, while the shares in routine cognitive skill occupations *decreased* from 58% to 44%. The latter represents occupations in the middle of the skill range, and the loss of mid-level job skills is also the loss of many mid-wage jobs.

The employment problem is exacerbated by the size of the average college wage premium. Occupations with non-routine cognitive skills also tend to those with higher levels of education attainment, and the combination of large wage premium and an increasing share led to the income polarization seen in Figure 2. The simulation by Hotchkiss and Rio-Avila (2014) found that a large share of wage inequality is due to educational inequality. They report that when education and age are held constant at their 1994 levels, the real wage per hour in 2013 is close to its 1997 level. They go on to report that education accounted for 60% of the overall inequality, as measured by the Gini coefficient.

Thus, while education may be part of the solution in providing necessary skills, it also appears to be part of the problem of growing income inequality. The prescription might seem to be "more college", but two-thirds of high-school graduates already go on to some form of higher education. At the same time, the demand for highly educated and skilled worker seems to be flattening, raising the question of how a significant increase in supply could be absorbed at the prevailing average wage premium. A growing literature also suggests that the marginal returns realized by many college graduates are substantially less than the average, and that many may end up in jobs with skills that do not require a Bachelor's degree. There is also the college readiness problem among those not currently going on to college. College entry for this cohort without first addressing their readiness invites failure. A look at the NAEP report card suggests that more attention needs to be focused K-12 education in order to improve the

prospects of going on to college and prospering, and to improve the income and skills of those who do not.

Moreover, formal education is not the only dimension of the income-skill development problem. As Cappelli observes, "The standard classification of job requirements into 'knowledge, skills, and abilities' reminds us that education, which has served as a proxy for skills in most discussions, only maps onto part of the "knowledge" category, leaving the other attributes of job requirements out of the picture. There are many important reasons for being concerned about education, but seeing it as the equivalent of skill is certainly a mistake (page 51)." He goes on to argue that "One of the unfortunate consequences of using education as the proxy for skill has been to see schools, the providers of education, as the mechanism for dealing with skill problems and leaving training and on-the-job experiences out of the story (page 51)." Worker training (and retraining), apprenticeships, and vocational education are also important sources of skill development, particularly in the middle skill areas most severely impacted by technological obsolescence and globalization.

To amplify this point, the 2013 study by Rothwell reports that a college degree is not necessarily needed for a STEM job. He finds that 20% percent of all 2012 jobs require a "high level of knowledge in any one STEM field," and that half of these STEM jobs are "available to workers without a four-year college degree." The 2015 article by Nisen points to the importance of preparation in productivity software, like spreadsheets, in order to prepare people for middle skill jobs.

Allowing young people to realize their potential is an essential goal of the education system. One problem in achieving this goal is that socioeconomic status is an important determinant of educational access and outcomes. This point is driven home by Carnevale and Strohl (2010), who report that those in the highest SES cohort have a significantly higher college graduation rate than those with lower SES after controlling for SAT-equivalent scores. Those in the highest SES cohort with SAT-equivalent scores in the highest range (1200-1600) had graduation rates that were twice as high (around 80%) as those in the two lowest SES cohorts who scored in the same range. This SES gap is present at every level of SAT-equivalent performance, suggesting a built-in advantage for students coming from upper-middle and

upper class backgrounds. A variant of this finding is found in the PIACC survey, which reports that the level of parental educational attainment has a significant effect on problem solving skills in technology-rich environments.. The number of books at home is another variable often used as an SES indicator (e.g., Carnoy and Rothstein). Indeed, higher SES parents expend great effort in insuring these children do well in the "rat rug race" (Ramey and Ramey (2010)). The Carnevale and Strohl finding suggests that this may lead to a distortion in the allocation of talent in the educational process, a distortion that is both inequitable and costly to society, because it fails to make best use of the available pool of talent.

VI. Conclusion

As with the technological revolutions that preceded it, the current information revolution involves major innovations in the technology and organization of production. These innovations have increased the importance of firm-specific intangible assets and led to a shift in the demand for non-routine worker skills. We have emphasized the complementarity between the two and offered it as an explanation of why conventional growth analyses accord so little importance to educational attainment as a source of economic growth, even though the knowledge disseminated through schooling is clearly so important for the emergence of the Knowledge Economy. When intangible capital is included as a source of growth in the conventional model, its contribution is seen to be almost four times larger than that of labor composition. However, the contribution of intangibles would almost certainly have been smaller without the shift in skills needed to operate that capital.

We have also pointed to the tension between the positive role of skills in the process of growth and their role in creating a less equal distribution of income. It is increasingly evident that the economic gains from the information revolution have not been equally shared, and that the wage premium for higher education and higher-level cognitive skills are important factors behind the labor market-polarization problem. If this polarization persists, a backlash may pose significant constraints on the evolution of the information revolution. The test score and skill inventory data reviewed in this paper are not encouraging on this point, revealing, as they do, significant educational and skill deficits in the population as a whole.

However, this is a static view of the problem. In his 1955 AEA Presidential Address , "Economic Growth and Income Inequality," Simon Kuznets advanced a more positive view of the problem. He argued that the income inequality that characterized the early stages of the Industrial Revolution dissipated as the revolution matured and the benefits broadened out to the population as whole. He generalized this idea into the hypothesis that "long swings" in income inequality is associated with sudden technological changes in economic structure. In the Kuznets dynamic model, both the supply and demand for various skills are endogenous over the full path of adjustment to a technological revolution.

Jeremy Greenwood applies this long-swing idea to the information revolution in his 1997 book, *The Third Industrial Revolution*. Because it is so germane to the current labor-market polarization problem, it is worth quoting at length:

"Clearly, everybody today is better off because of Britain's Industrial Revolution, but this was not true in 1760. So what about [today's] short run? Skilled workers will fare better than unskilled ones, but this disparity will shrink over time for two reasons. First, as information technologies mature, the level of skill needed to work them will decline. Firms will substitute away from expensive skilled labor toward more economical unskilled labor. As this happens, the skill premium will decline. Second, young workers will tend to migrate away from lowpaying unskilled jobs toward high-paying skilled ones. This tendency will increase the supply of skilled labor and reduce the amount of unskilled labor, easing pressure on the skill premium. Moreover, the wealthy will do better than the poor in the short run because the introduction of new technologies leads to exciting profit opportunities for those with the wherewithal to invest in them. These profit opportunities will shrink over time as the pool of unexploited ideas dries up. On average, the old have more capital to invest than the young. Thus, young, unskilled agents will fare worst in the short run. But in the long run, the rising tide of technological advance will lift everybody's boat."

This is a happier picture than the one painted by the NAEP National Report Card and the PIACC Survey of Adult Skills.

In the Kuznets-Greenwood world, technology becomes more familiar as it matures. It also adapts to become more user friendly. In the process, learning curves become less steep and thus more accessible to a broader segment of the work force. Broad-based education and training play a major role in reshaping the learning curve. This has important implications for the design of school curricula at the primary and secondary levels, including vocational education, and for a broader emphasis on skill-building through non-school apprentice

programs and training. Tertiary education is also important, with perhaps a greater emphasis on the quantity and quality of vocational subjects. A greater focus on the quality of four-year college degrees is similarly important, but the evidence suggests that attempts to increase the quantity must contend with the college-readiness problem and the fact that the marginal return is already well-below the average return for many students. If the Kuznets long-swing is to lift all boats, it is important to insure that everybody has a boat that will float.

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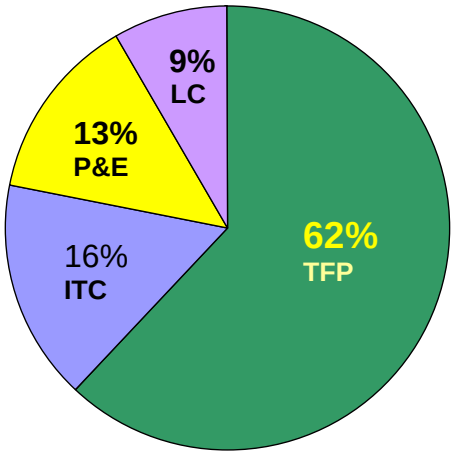


FIGURE 1a
without intangible capital

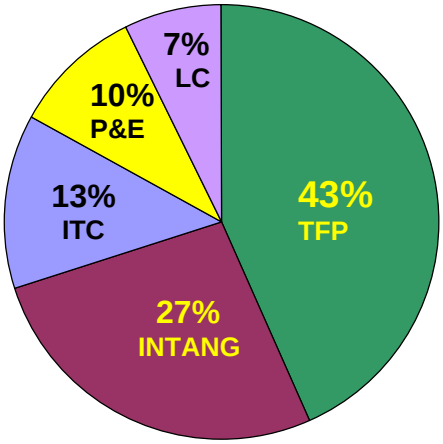


FIGURE 1b
with intangible capital

Sources of the growth in output per hour in the U.S. business sector, 1995-2007
Source: Corrado and Hulten (2010, 2011)

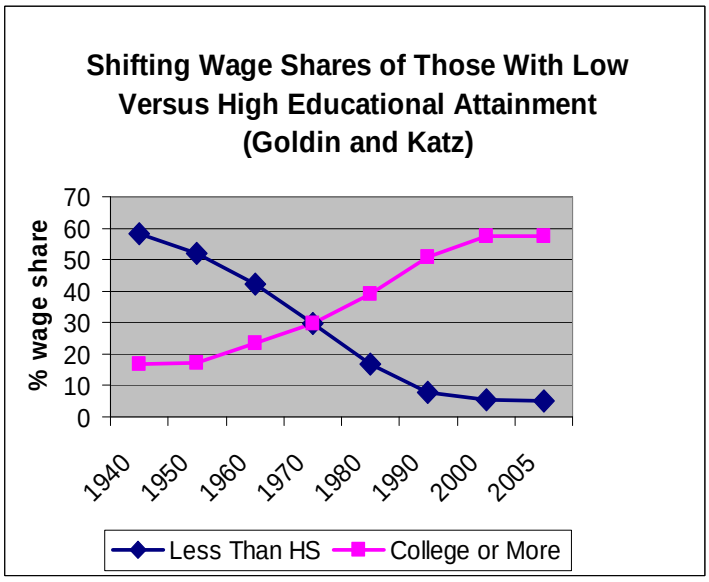


FIGURE 2
Changing Wage Shares, 1940 to 2006
Goldin And Katz (2007)

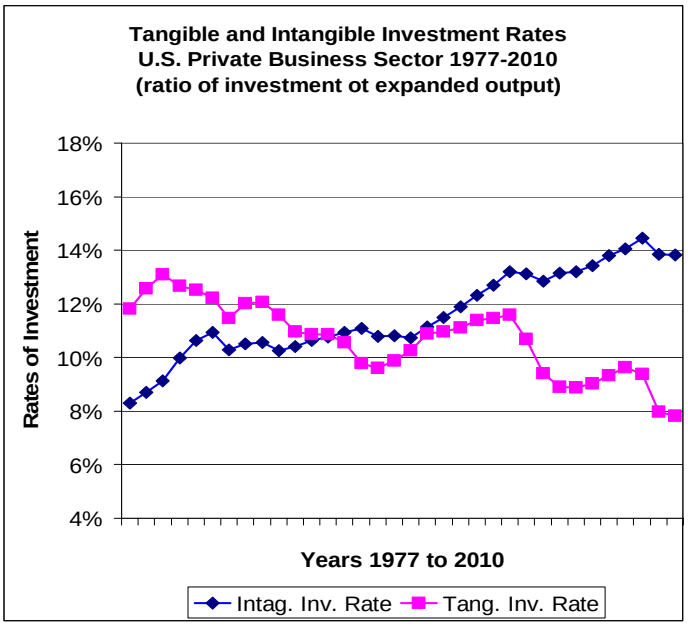
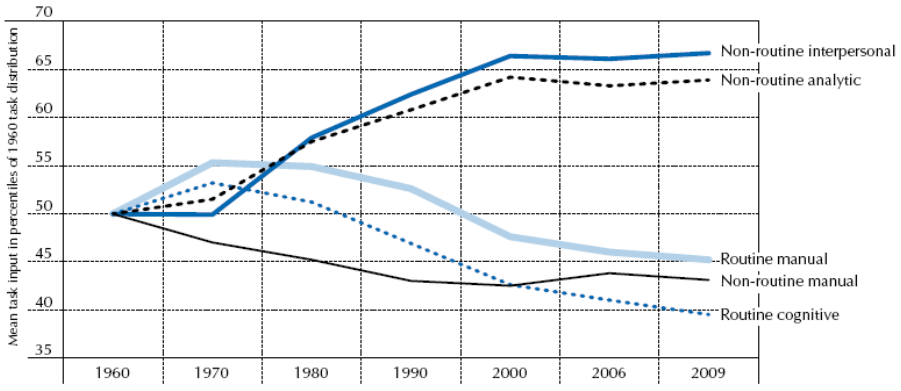


FIGURE 3
Rates of Investment in Tangible and Intangible Assets
U.S. business sector, 1977-2010
Source: Corrado and Hulten (2010, 2011)

Change in the demand for skills

Trends in routine and non-routine tasks in occupations, United States, 1960 to 2009

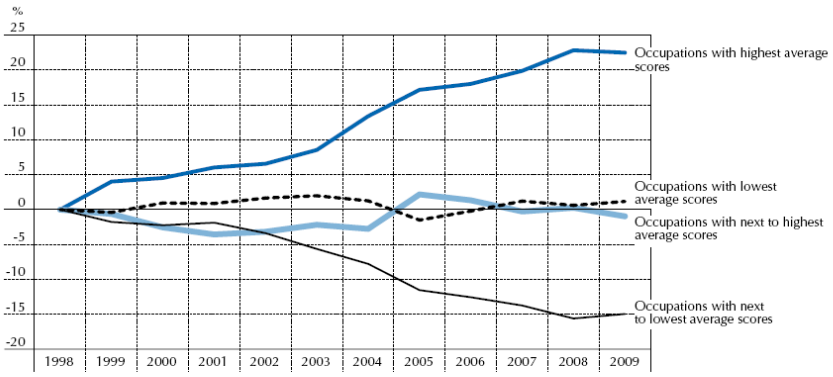


Source: Autor, D.H. and B.M. Price (2013), see Table A1.5 in Annex A.
StatLink http://dx.doi.org/10.1787/888932900308

FIGURE 4
OECD PIACC 2103 Table 1.5

Evolution of employment in occupational groups defined by level of skills proficiency

Percentage change in the share of employment relative to 1998, by occupational groups defined by workers' average level of proficiency in literacy and numeracy



Notes: The Survey of Adult Skills (PIAAC) is used to identify occupations associated with high and low literacy and numeracy scores, and then time series data available from the Labour Force Survey (LFS) Database are used to track changes in those occupations over time. See Chapter 2 of this volume and *The Survey of Adult Skills: Reader's Companion* (OECD, 2013) for an extended discussion describing the literacy and numeracy scales. Only the 24 OECD countries available in the 1998 LFS Database are included in the analysis. Highest average scores are in or near the upper half of Level 3 for literacy and numeracy; next to highest average scores are in or near the lower half of Level 3 for literacy and numeracy; next to lowest average scores are in or near the upper half of Level 2 for literacy and numeracy; lowest average scores are in or near the lower half of Level 2 for literacy and numeracy.

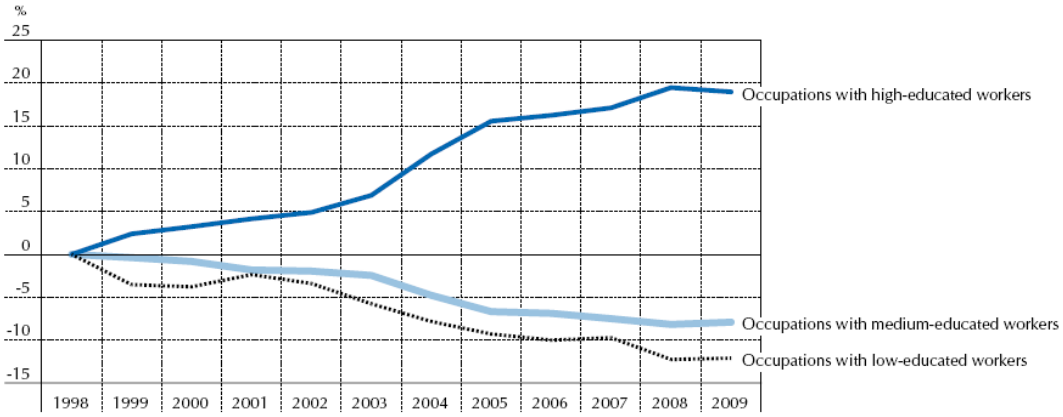
Source: Eurostat, LFS Database; Survey of Adults Skills (PIAAC) (2012). See Table A1.6 in Annex A.

StatLink http://dx.doi.org/10.1787/888932900327

FIGURE 5
OECD PIACC 2103 Table 1.6

Evolution of employment in occupational groups defined by level of education

Percentage change in the share of employment relative to 1998, by occupational groups defined by workers' average level of education



Notes: Only the 24 OECD countries available in the 1998 LFS Database are included in the analysis. High level of education refers to tertiary level or more than 15 years of schooling; medium level of education refers to no tertiary but at least upper secondary education or around 12 years of schooling; low level of education refers to less than upper secondary education or 11 years of schooling. Occupations with high-educated workers: legislators and senior officials; corporate managers; physical, mathematical and engineering science professionals; life science and health professionals; teaching professionals; other professionals; physical and engineering science associate professionals; life science and health associate professionals; teaching associate professionals; and other associate professionals. Occupations with medium-educated workers: managers of small enterprises; office clerks; customer services clerks; personal and protective services workers; models, salespersons and demonstrators; extraction and building trades workers; metal, machinery and related trades workers; precision, handicraft, craft printing and related trades workers; stationary plant and related operators; and drivers and mobile plant operators. Occupations with low-educated workers: other craft and related trades workers; machine operators and assemblers; sales and services elementary occupations; and labourers in mining, construction, manufacturing and transport.

Source: Eurostat, LFS Database. See Table A1.4 in Annex A.

StatLink http://dx.doi.org/10.1787/888932900289

FIGURE 6
OECD PIACC 2103 Table 1.4

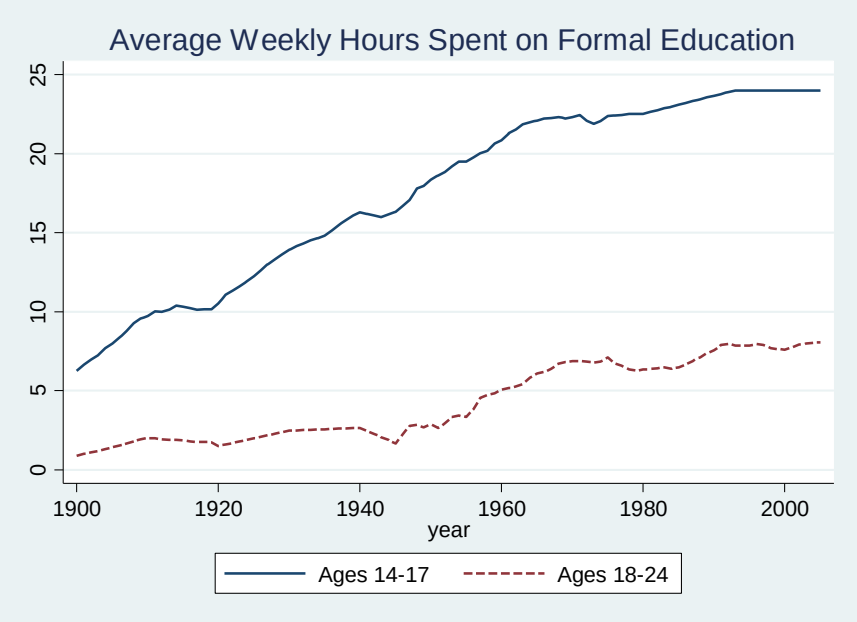
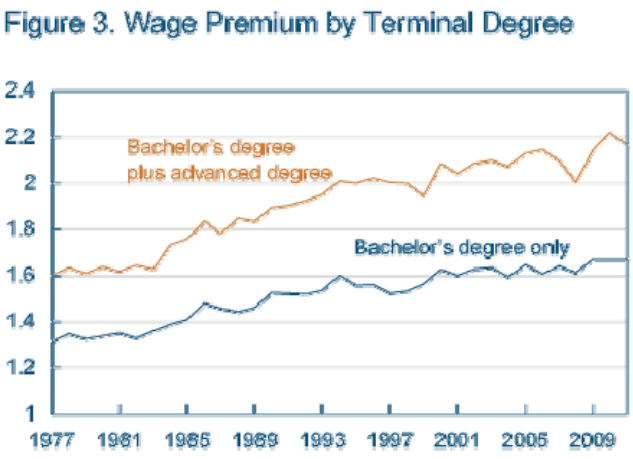
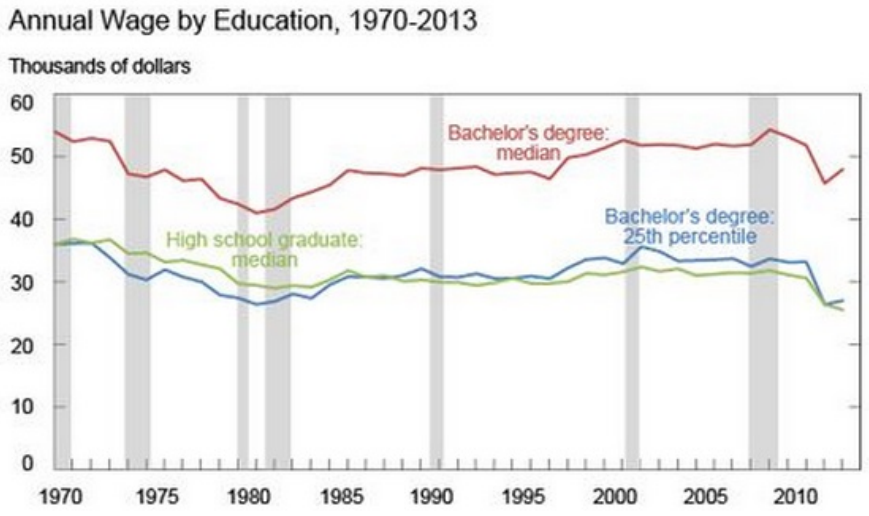


Figure 7
Based on Time Use Estimates from Ramey and Francis (2009)
(Hours include both time spent in class and on homework, averaged over an entire year)



Notes: Premiums are calculated as the ratio of median wages for those with only a four-year degree or those who additionally have an advanced degree, to the median wages of high school graduates. Data include workers who worked full-time (35 hours or more) and for a full year (40 weeks or more).
Source: Census Bureau, Current Population Survey; author's calculations.

FIGURE 8
Abel and Dietz (2014a)



Source: U.S. Census Bureau and U.S. Bureau of Labor Statistics, Current Population Survey, March Supplement; U.S. Bureau of Labor Statistics, consumer price index.

Notes: Dollar figures are expressed in constant 2013 dollars. Shaded areas indicate periods designated recessions by the National Bureau of Economic Research.

FIGURE 9

Annual Median Wage Income of Bachelor Degree Holders Compared to Wage of 25th Percentile Income and High School Degree Income , 1970 to 2013
Abel and Deitz (2014b)

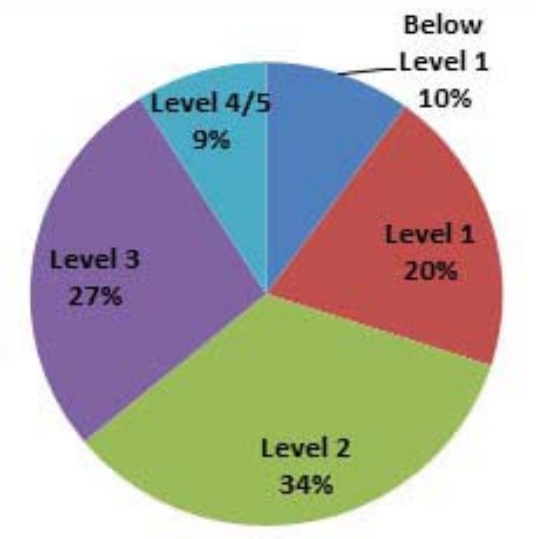


FIGURE 10a

2013 PIACC Numeracy Survey
OECD (2013)

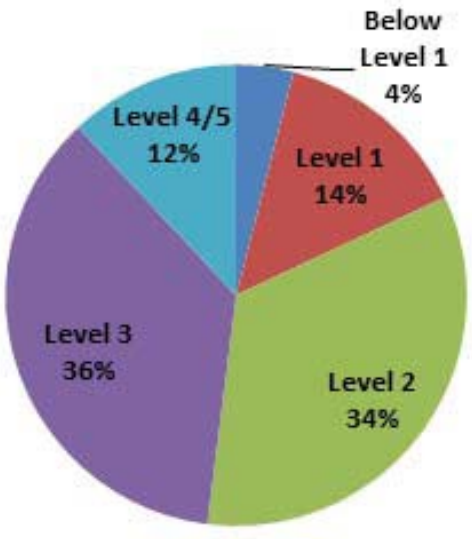


FIGURE 10b

2013 PIACC Literacy Survey
OECD (2013)

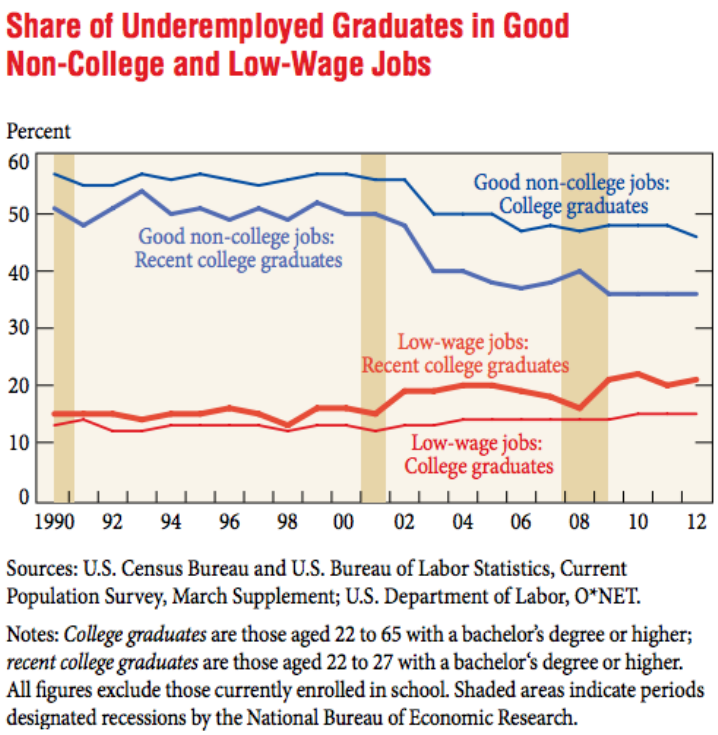


FIGURE 11

Bachelor Degree Graduates in Jobs Not Traditionally Requiring a College Degree
High-Wage Versus Low-Wage Jobs
Abel, Deitz, And Su (2014)