Adapting to Automation

Jack Karsten, David Parkes, and Gardner Swan
International Science and Technology Policy Capstone
Elliott School of International Affairs
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Table of Contents

Executive Summary

Adapting the American workforce to an automated economy is a complex process. Tech-savvy workers will be well positioned to use productivity enhancing technologies, and through the use of those technologies they will induce further changes to the structure of the economy. The rate at which these changes come about is uncertain, based both on the rate of technological progress itself, as well as the rate at which firms are able to successful adopt those technologies. Given the complexity of the issue, the Neo-Luddite response of blaming technology for disruption is understandable, but it is also unwise.

Automation is a historical phenomenon dating back to the Industrial Revolution and beyond. Within the past fifty years, computers have increased in power to the point of replacing humans in cognitive occupations. So far, capital has displaced human labor without causing mass technological unemployment. Entirely new job categories have arisen to employ displaced workers as a result of rising incomes and new methods of organizing labor. However, this process is neither instantaneous nor automatic. To facilitate the reorganization of capital and labor, the American workforce will need new skills to adapt to new technologies.

The policy presented in this paper targets skills acquisition within traditional education as well as during a career. Department of Education grants would establish model technology centric high school-community college partnerships. Industry mentorships incentivized by tax breaks will ensure that students draw connections between technology in the classroom and the workplace. Department of Labor grants would expand successful skills training programs and establish new ones based on local skills needs. Training programs in the same sector will partner with each other and with industry to standardize curricula for skills courses. To encourage industry participation, businesses that invest in workforce training will receive tax credits.

This set of straightforward policies addresses both the roots and branches of a complex issue. A technology-centric education system will create a 21st century workforce capable of managing dynamic technological systems. Increasing the variety and accessibility of skills courses will provide workers with a means of learning how to implement new technologies in the workplace. Working in the capacity of technology system managers will give workers the necessary perspective to recognize opportunities for yet more productivity enhancing innovations.

As these technology systems change and demand new skills from workers, the policy we propose offers workers the opportunity to quickly adapt and obtain those needed skills. Through the changes brought about by this policy, American workers will be transformed into lifetime learners. Workers will be able to acquire new competencies, and develop complementary skill sets that emerge as a result of technological change.[1]

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1 MacCrory, Westerman, Alhammadi, & Brynjolfsson (2014).

Introduction

Gone are the days when education meant entering school as a young child and leaving at age eighteen, ready to progress into a good, stable job. Although productivity growth has increased the standard of living for nearly all Americans,[2] income inequality has risen for nearly half a century, with income correlating to educational attainment.[3] Occupations that once sustained the broad American middle class have been disrupted by technological progress, manifested in automation, outsourcing, and trade. As technological progress continues apace, a growing chorus has asked whether technology benefits or hurts the American worker.[4] Framed differently, we ask how the American workforce can adjust to take advantage of continued technological improvements and contribute to economic growth.

Automation has historically benefitted the American workforce by contributing to productivity growth, and thereby growth of the economy. But benefits do not accrue effortlessly throughout the population as manna from heaven. Longstanding policy choices such as the establishment of land grant universities, compulsory education, and the G.I. Bill facilitated the growth of an industrial economy with a highly skilled labor force. The work of labor unions during the 20th century substantially shifted the gains from economic growth to a wide swath of the population, creating a strong middle class. Unfortunately, these policies do not appear to be keeping pace with structural changes in the economy.[5]

The long term stability of the economy requires that workers have marketable skills throughout their careers. The displacement of workers by technology creates an uncertainty about the length of time any skill set is marketable. Writing in the 1930s, economist John Maynard Keynes predicted the "discovery of means of economizing the use of labor outrunning the pace at which we can find new uses for labor."[6] Although this prediction has not yet come to pass, automation could have a profound effect on employment in the coming decades. A study by Carl Benedict Frey and Michael A. Osborne estimates that 47 percent of American occupations are at high risk of computer substitution in the next twenty years.[7] Even if an equal number of new jobs were created as a result of the productivity gains from computerization, the structure of the economy would look significantly different. The U.S. system for retraining workers displaced by technological change is unprepared to deal with this level of upheaval.

In the long run, the workers that benefit the most from automation are those with skills that complement computer automation. These skills involve abstract thinking, social interaction, and other areas where computers still perform poorly. [8] High-skill professions from doctors to

2 Rose (2014).
3 Goldin and Katz (2008). Rothwell (2015) points out that the discussions of extreme income inequality focusing on the top 1% of earners misses out on the significant variance of incomes and education within the 99%.
4 For example, Brynjolfsson & McAfee (2014). For a list of further examples see Miller & Atkinson (2013).
5 Marchant, Stevens, & Hennessy (2014).
6 Cited in Frey & Osborne (2013).
7 Ibid.
8 Autor (2014).

designers will see their productivity increase as computers quickly complete their repetitive and time consuming tasks for them. Training a workforce for computer-complementary skills through traditional education takes time, however. Higher skill professions require additional years of higher education, creating a lag between discovering a need for skills and the arrival of a high-skilled workforce. By the time one cohort of educated workers finishes their training, the pace of technology change may have already made other skills obsolete. Education will undoubtedly play a large role in preparing a future workforce to adapt to the realities of automation, but flexibility is needed so that training can keep up.

While earlier waves of automation replaced many low-skill jobs, computer automation is increasingly reducing demand for middle-skill jobs, creating a polarized labor force. Computers create a gap between high-skill jobs that complement computer automation and low-skills jobs where automation is not cost-effective. Between these two groups lie jobs that computers can now do quicker, cheaper, and more accurately than humans. In their study, Frey and Osborne evaluated each occupation's probability of computerization by asking "can the tasks of this job be sufficiently specified, conditional on the availability of big data, to be performed by state of the art computer-controlled equipment?"[9] Job seekers and policy makers should ask a similar question when considering career choices or trying to reduce unemployment.

Changes wrought by the continuing advance of technology require a new approach to diffuse the benefits of growth throughout society. The policies, skills, and political forces of the 20th century cannot be relied upon in the high-tech economy of the 21st century. Automation is progressing beyond the realm of substituting capital for routine manual labor, as machines become increasingly capable of performing complex tasks. But automation retains the potential for broadly beneficial economic outcomes, if a new set of smart policies is implemented with that goal in mind.

In this report we propose a set of policies that will enable firms to adopt productivity enhancing technologies, while also making workers more adaptable to the demands of technological change. Our policies accomplish these dual goals by addressing the technology skills of the overall U.S. labor force, starting at the high school level and continuing throughout workers' entire careers. Through these policies, workers can effectively transition into managers of systems of technology.

9 Frey & Osborne (2013).

Background of the Issue

Definition of Terms

In discussing the effects of automation or computerization of labor, it is necessary to understand what is meant by those terms. In the broadest sense, automation is the substitution of capital for labor.[10] Computerization is more specifically the replacement of human labor by computers. The replacement need not, and in most instances should not be a direct matching of human tasks to machine tasks.

Automation and Innovation

The Rethinking Problem

Productivity boosting inventions can originate in a variety of ways, from an individual having a "Eureka!" moment in a garage, to a coordinated team of professionals developing a new product or process over time. However the invention occurs, economically significant productivity gains will only occur once the invention becomes an innovation,[11] diffusing throughout the market as firms and individuals adopt the technology.

For diffusion to occur, management must recognize the benefits of the invention, and labor must be trained or hired to use the new technology. Recognition of this sort requires *rethinking* the firm's production process in a way that optimizes the benefits of the new technology.[12] Rethinking in this context can be defined as the reengineering of a production process, or the redesign of a product, so as to optimize the gains from automation.

Since humans and machines generally do not look, move, or act alike, the work done by machines should not merely attempt to copy the work done by humans. The rethinking problem is compounded by the fact that the managers familiar with a product or production process and the engineers responsible for a new technology may not overlap or even communicate with each other. Recognizing machine-work as a suitable substitute for human-work is not a trivial task. In order to solve the rethinking problem, managers must think more like engineers, and engineers must think more like managers.

Firms lacking the knowledge base necessary to rethink will face uncertainty as they attempt to estimate the benefits of technology adoption. Because the initial investment in new technology

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10 Although the process of automation may include the creation of new labor in the form of engineers and programmers that develop the automated system, these are generally a different class of laborers than those whose labor has been automated.

11 For a broader discussion of the definition and dynamics of innovation, see Ch. 1, The nature and importance of innovation, in Greenhalgh & Rogers (2010).

12 This problem was first identified by John Diebold (1952), who wrote "Automation can often be achieved only by *rethinking*."

generally requires significant upfront costs, this uncertainty may obscure the potential long-term gains and emphasize the short-term risks. In such cases, firms will be less likely to adopt productivity boosting inventions effectively. As a result, those firms will experience suboptimal growth.

Rethinking remains a central bottleneck for firms attempting to realize gains from productivity boosting inventions. This bottleneck is one of the reasons why historical predictions of widespread technological unemployment – unemployment caused by substitution of capital for labor – have not come to fruition.[13] Even when an invention is capable of displacing workers, the rethinking bottleneck imposes costs, be they capital costs, re-training costs, or simply the costs associated with the risk of new methods. Rethinking may require bringing in outside consultants, hiring engineers or programmers, or shifting employees from production to rethinking tasks. While the adoption of technology may have long-term benefits, these upfront costs can be a hurdle that is too high for most firms. Nevertheless, the prediction of technological unemployment has not gone away, and has in fact strengthened in recent years.

Solving the rethinking problem will lead to major structural changes in the workforce, according to a recent model proposed by researchers Carl Benedict Frey and Michael A. Osborne. Their model for estimating the computerization of occupations in the U.S. labor market found that 47 percent of total U.S. employment is at “high risk” of replacement by machines.[14] Of particular note, this model treats the effect on skilled employment in a way that is substantially different from the classical effects of substitution of capital for labor. It posits that adding technology to a process hollows out the middle-skill positions from the workforce.[15] Importantly, this model only predicts the probability of computers being technically capable of meeting the skill demands of the occupations specified, not the market risk of computers being adopted for those occupations. The technological capabilities of modern computers and other machinery are rapidly expanding, but it is the rate at which these technologies are adopted that determines their benefits and their disruptive effects.[16] Thus the problem of rethinking remains central.

In order to encourage productivity growth, the U.S. needs to craft policies that remove the bottleneck of rethinking. At the same time, by removing this bottleneck, the U.S. could create rapid changes to the structure of the economy, changes that could result in unfavorable outcomes for many workers. To avoid this problem, the U.S. should develop a set of policies that enable firms to engage in the process of rethinking, while simultaneously equipping workers with the flexibility and adaptability to thrive alongside widespread automation and computerization.

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13 Akst (2013) provides a useful history of faulty predictions of technological unemployment.

14 Frey &and Osborne (2013).

15 Lewis (2011) finds that historical data from the manufacturing sector supports arguments that capital substitution eliminates the lowest skill occupations while complementing middle-skill occupations.

16 As an example, Tom Bonkenburg, an expert on robotic systems in distribution, states that only fifteen percent of warehouses are mechanized, and five percent are fully automated. Bonkenburg indicates that both costs and technology are a current impediment to adoption, but advances in autonomous vehicles may soon spark more widespread automation (Cooke, 2014).

Automation of Routine Processes

The computer is an example of a General Purpose Technology (GPT), an innovation that enables other innovations. Computers, defined by Alan Turing as the "universal machine," are GPTs with applications in virtually any human activity.[17] Other GPTs include steam power and electricity, which allowed for new production methods during the Industrial Revolution. Unlike previous GPTs, computers replace mental rather than physical labor. In addition, economist Timothy Bresnahan notes that a "GPT could be disembodied knowledge", such as the knowledge behind the factory system or mass production. Disembodied knowledge, in the form of software, has supported many of the innovations in computing that substitute for machines for human labor.

Solving the rethinking problem requires abstract thought. Workers and managers cannot simply view a system as it is – they must envision a system as it could be. They must know how to develop an improved process. Abstract thinking is also an area where humans continue to excel over computers. An algorithm can churn out new combinations of old ideas, but only with well-defined criteria. Given this fact, we would expect humans to specialize in abstract tasks as computers automate the more routine ones. This expectation is confirmed by the data in the figure below, which shows that the share of employees in routine labor dropped for both college graduates and workers without a college degree since 2007, while the share of workers in abstract labor increased slightly for degree holders.[18] This trend shows that occupational category is just as important as educational attainment in determining job security.

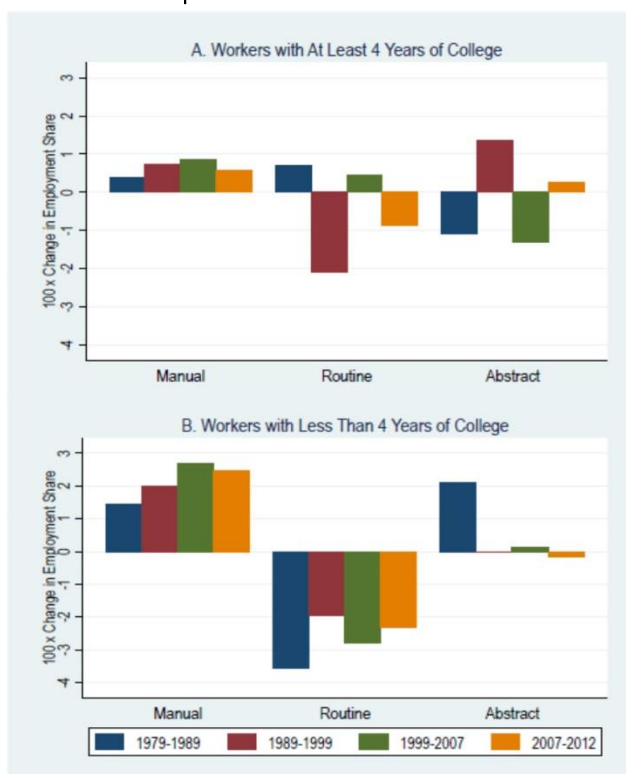

Fig. 1: Changes in employment shares in broad occupational categories, 1979-2012: Workers with and without a four-year college degree; Source: Autor (2014).

Rate of Technological Change

Computing power doubled roughly every two years during most of the latter half of the 20th century, through a process known as Dennard scaling. Dennard scaling, closely associated with the more commonly known Moore's Law, describes the relationship between computing power and transistor size. Although this regular rate of improvement

17 Turing (1937).
18 Autor (2014).

ended in 2004, computing technology continues to improve.[19] Computer performance growth has transformed the world, but it has not produced the expected growth in productivity over most of the last half-century that many technological optimists expected.[20] It is beyond the scope of this paper to give a full accounting of the reasons that computing power has not increased productivity growth as much as predicted. The fact that it has not, however, appears to be consistent with our formulation of the rethinking problem – technology gains do not often translate into productivity gains without rethinking production.

Trying to predict specific technology developments of the future, even the relatively near future, is typically a fool's errand. Future improvements may come from the exploitation of parallel processing, the ability to compute entirely new types of algorithms using quantum computers, a reinvigoration of Dennard scaling through room-temperature spintronics, or through sensors and processors embedded throughout the physical world in the Internet of Things. New economic opportunities may spring from one technology or an unpredictable combination of new technologies. In order to exploit these opportunities, firms must have workers with the competency to adopt, combine, and use new productivity enhancing technologies.

The physical limits of silicon-based technologies create substantial uncertainty regarding the future growth rate of computing power. As such, it is unclear whether the technical predictions of Carl Benedict Frey and Michael A. Osborne will occur over the span of ten years or one hundred. Either way, betting on technological stagnation as a solution to the U.S. economy's problems is a losing proposition.[21] Instead, fostering a workforce capable of rapid adaptation to new technologies and the adaptation of existing technologies to new uses should be a key goal of U.S. education and workforce development policy. It is therefore crucial to understand the effects of technological change on skill needs.

Effects of Technology on Workforce Skills

The adoption of automation technologies often results in changes in the skill mix of occupations, or in the reclassification of occupations altogether if the type of work is substantially transformed. Harry Braverman argued that a key element of automation, the substitution of capital for labor, was degrading work by limiting workers to narrower functions that were cut off from a holistic understanding of the production process.[22] Conversely, Paul S. Alder has argued that while automation indeed changes the skill demands of occupations, it

19 Shalf (2014).

20 The failure of computers to produce expected productivity gains is known as the Solow Paradox in the academic literature, after a 1987 remark made by economist Robot Solow. For a more recent discussion of the phenomenon, see Acemoglu et al. (2013).

21 In order to avoid technological stagnation in the face of looming uncertainty, the U.S. needs to increase investment in basic research, as discussed in Miller & Atkinson (2013).

22 Braverman (1974). Moreover, Braverman critiqued the rather myopic categories by which occupational skill level was judged as not truly reflective of the actual skill content. While Braverman did not explicitly object to technology, he saw its effects as primarily deskilling with respect to the majority of labor.

demands skills that require "more training, higher levels of responsibility, more abstract tasks and goals, and greater functional interdependence."[23] To some extent, both of these analyses are true, and depend on management's willingness and ability to train and utilize human capital. When management invests in retraining workers, their skills are upgraded. When management does not make that investment, skills are degraded.

The upgrading or degrading of skills contributes to job polarization. The economists Maarten Goos and Alan Manning define job polarization as "the falling relative demand in the "middling" jobs that have typically required routine manual and cognitive skills"[24] This polarization is partially explained by skill-biased technology change (SBTC), where "high-skilled workers will benefit from a technology, while low-skilled workers will suffer a loss of demand leading to lower wages and higher unemployment."[25] Workers with technology-enhanced skills will see their productivity and wages grow while workers with technology-substituted skills will lose their jobs to lower cost technology.

At first glance, SBTC seems to be a zero-sum game where skilled worker gains come at the expense of unskilled employment. Automation is more productive than the workers it replaces, however, leading to higher overall output. High-skilled workers will gain more than the losses of low-skilled workers, giving society a net gain. Nevertheless, the apparent transfer of income from low to high-skill workers makes SBTC politically problematic.

Skill-biased technology change improves upon previous explanations for the relationship between technology and employment. The "lump of labor" or "Luddite" fallacy mistakenly assumes that "with increased productivity, employers would continue to produce a constant output with fewer workers, rather than expanding their output from a given workforce."[26] Not raising production after a productivity gain would forego economic profits that a competitor would soon capture. By not selling more output at a lower price, a Luddite producer would soon go out of business. When technology threatens to replace workers entirely, however, the Luddite fallacy becomes more relevant. SBTC allows an employer to expand output and shrink their workforce simultaneously, having the same effect as the Luddite fallacy from a displaced worker's point of view.

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23 Alder (1988).
24 Goos and Manning (2007).
25 See Ch. 10, Technology, wages, and jobs, in Greenhalgh & Rogers (2010).
26 Ibid.

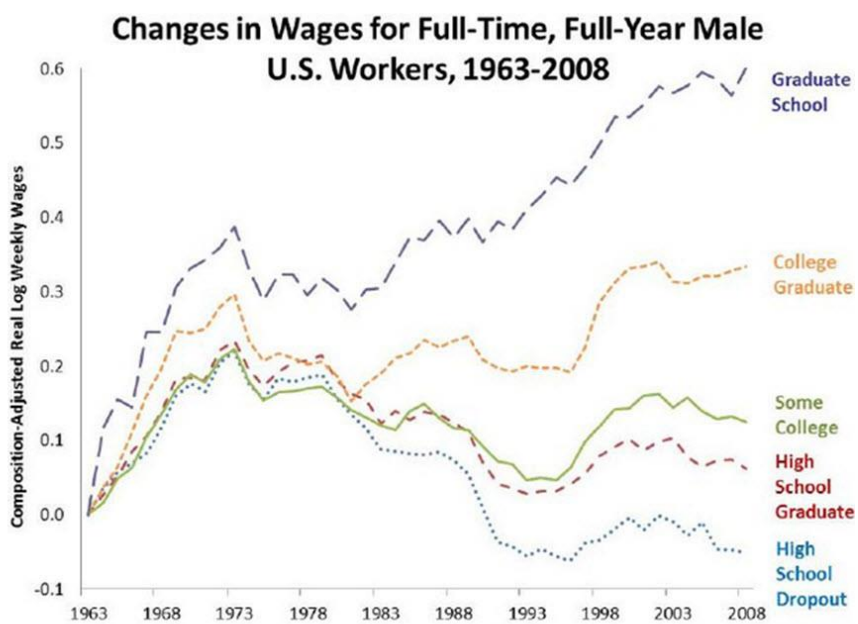

Fig. 2: Wages have increased for those with the most education, while falling for those with the least; Source: Brynjolfsson & McAfee (2011).

Looking at net job losses alone paints an oversimplified picture of SBTC. While the demand for unskilled labor falls, the demand for high-skilled labor increases. Workers that possess the skills to use new technology will see their wages increase along with their productivity, which will increase the incentive for other workers to acquire more skills. Economists Christine Greenhalgh and Mark Rogers note that increased demand for higher skills extends beyond the service sector to “manufacturing firms, where there is a rise in demand for workers who can design innovative products or supervise sophisticated production technology.”[27] Labor in all sectors will have to become more sophisticated in order to match the increasing complexity of capital such as computers.

Disparities in productivity growth are borne out in wage data from the past fifty years, using educational attainment as a rough proxy for skill.[28] High school graduates earnings in real terms have stayed relatively flat, while wages for dropouts have decreased. Meanwhile, wages for college graduates have increased dramatically, and wages for graduate degree holders even more so. Wage differentials have only grown larger over time as businesses invest more money in information and communication technology. These trends are likely to continue in the future, further increasing the premium for higher education. Responding to the challenges of SBTC will require expanding access to education so that fewer workers fall into lower wage categories.

Skills Gap

Concurrently with the technology induced change in occupational skills, U.S. firms have consistently identified a difficulty in hiring workers with necessary high-tech skills.[29] These claims have generated substantial debate as to whether a skills gap truly exists, or whether

27 Ibid.
28 Brynjolfsson & McAfee (2011).
29 Although he disputes the premise, Charette (2013, sidebar) details recurrent proclamations of skill shortages throughout the 20th century.

firms are rather unwilling or unable to pay the requisite wages to attract such high-skill talent.[30] In spite of the vigorous debate, this issue allows for both possibilities at a sufficiently high level – workers may lack certain essential skills, while some industries may not be able to offer competitive wages to stimulate acquisition of those skills.

Conflating current unemployment with a perceived lack of skills would be an oversimplification of structural dynamics of the economy, and could exacerbate a future skills gap. Many unemployed workers lost their previous jobs because changing technology made their skill sets obsolete. Furthermore, the skill requirements of unfilled jobs change frequently with technological advancements and organizational improvements. Unemployed workers may have skills, but not the right skills, and it may be unclear to them which skills they need in order to be valuable in the labor market. Designing a system to match workers to skilled jobs must be flexible enough to accommodate rapid changes in skills requirements.

Skills mismatch results from a number of factors, including the high cost of training workers on the job.[31] Businesses would prefer to hire an experienced worker with the necessary skills who can start immediately rather than hire and train an entry-level worker. The company must pay an unproductive employee during training in addition to paying an opportunity cost of lost revenue that an experienced employee would have generated over the same time period. Additionally, another employee must train new hires, drawing further resources away from production. After a new employee is trained, a company cannot always prevent the trainee from leaving the company before the investment in training has paid off. Businesses need better incentives to train new workers, or new workers need alternative ways to receive job training.

Workers and employees must agree on equitable cost sharing agreement for training. Currently, businesses that train their employees bear enormous costs, while businesses that demand a college degree shift the cost burden on to their employees. The cost of a four-year college education has grown at triple the rate of inflation since 1972, saddling many graduates with massive student debt.[32] Lowering the cost of skills training in both time and money would allow workers to acquire the skills they need without assuming massive amounts of debt.

The skills mismatch problem is further exacerbated by wages that are inflexible relative to other production costs. In the manufacturing sector, wages for labor are often set by contract for a long period of time while the prices for raw materials fluctuate with the market. When the market price for a final product goes down or raw input prices go up, a manufacturer must pay existing workers the same wage and cut costs by lowering the wage for new hires. Many new and displaced workers refuse to work for the market wage because they have either previously received a higher wage or they cannot afford to take the market wage. Expanding skills courses

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30 For example, *ITIF Debate: Is There a Stem Worker Shortage?* (2014). See also Davidson (2012); Hemphill, Lillevik, & Perry (2013); Charette (2013).
31 Hemphill, Lillevik, & Perry (2013).
32 Gordon (2014).

could make the labor market more flexible by reducing both the cost in time and in money of skills education for new workers.

Skills mismatch also depends on the geographic distribution of industries. Because physical capital and labor are not perfectly mobile, an employer may struggle to find local workers with the desired skills but cannot afford to relocate their operations to an area where these skills are in abundance. The same situation would apply to some workers who cannot find jobs where they live. Skills courses provide a way to develop local talent without forcing either businesses or workers to relocate. Expanding partnerships between employers and local training programs would ensure that more workers are matched to vacant jobs.

A slow rate of increasing educational attainment relative to technological improvement may account for some of the skills mismatch. While computing power improved dramatically in the second half of the twentieth century, educational attainment increased very slowly over the same period of time.[33] In contrast, educational attainment increased at a faster rate in the beginning of the 20th century as high school education was made compulsory in the United States (see Fig. below). At the same time the rate of educational attainment has slowed, the returns to higher education have also increased, with incomes for high school graduates and dropouts have remained stagnant. Researchers Lawrence Katz and Claudia Goldin described this phenomenon as the "Race between Education and Technology" in their book on the subject.[34] As technology replaces skilled labor, even more education may be needed to stay competitive in the labor market.

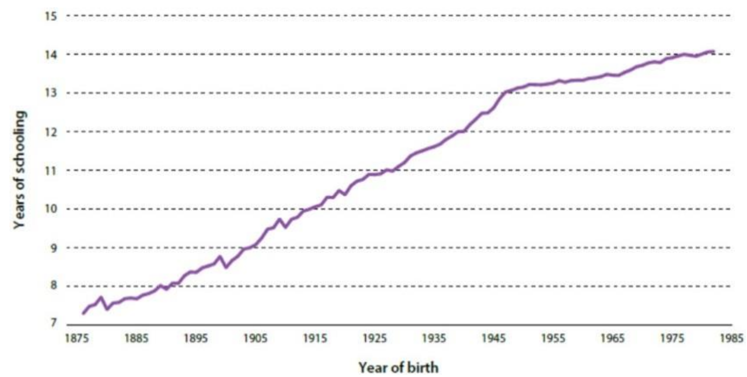

Fig. 3: Years of schooling at age 30, by birth cohort, 1876-1982; Source: Goldin & Katz (2008), published in Kearney, Hershbein, & Boddy (2015).

It is beyond debate that most Americans' lives intersect with advanced technologies on a daily basis, both in the workplace and in their private lives.[35] Workers need the ability to use and understand technologies, both individually and as pieces of a larger system. This skill is crucial and applies not only to the workforce, but to the individual's ability to take part in the modern marketplace. In order to take advantage of the opportunities afforded by technology, the American workforce must be flexible and able to acquire new skills rapidly. To do so will require a solid foundation in technology based education.

33 Goldin and Katz (2008).
34 Ibid.
35 Purcell & Rainie (2014).

Background for the Policy

Education for the 21st Century

All-STEM-for-Some vs. Some-STEM-for-All

A workforce capable of managing systems of technology and adapting to technological change requires a technology based education. The issue of technology education intersects with an ongoing debate – whether all students require substantial science, technology, engineering, and math (STEM) education in order to be successful in the workforce. Previous work by Robert D. Atkinson and Merrilea Mayo argues that neither the needs of students nor the needs of the economy are well-served by a STEM for All approach.[36] Instead, Atkinson and Mayo advocate an All STEM for Some approach. In this approach, students with substantial talent and interest in STEM subjects may be recruited to attend STEM-focused schools, or participate in STEM-specific programs within larger schools.

The All STEM for Some approach can be seen as the vanguard of dealing with changing skill needs in industry. STEM workers tend to earn more than other comparable workers, and the knowledge-intensive industries that employ STEM workers tend to innovate at a higher rate than other industries.[37] There is no question that STEM education plays a crucial role in stimulating future growth, but it is not the only role.

Despite its outsized influence on economic growth, the STEM labor market makes up only about five percent of the total number of jobs in 2010.[38] Meanwhile, Carl Frey and Michael Osborne estimate that nearly half of American occupations are at high risk of computer substitution.[39] While high performing STEM students form the vanguard, the bulk of the workforce outside of STEM fields will need to increasingly incorporate the “T” – technology. Otherwise, the existence of a small segment of highly specialized STEM workers and a large population of STEM-illiterate citizens will not produce optimal growth over the long term.

21st Century Skills

As technology changes the skill composition of occupations, a shift occurs in the knowledge that workers need.[40] In an environment of rapidly changing technology, identifying the skills that young students must learn is a major challenge. The Partnership for 21st Century Learning, a collaboration between federal and state government, industry, and education partners, has introduced the Framework for 21st Century Learning as a means to consolidate goals and best

36 Atkinson & Mayo (2010).
37 NSB (2012).
38 Ibid.
39 Frey & Osborne (2013).
40 MacCrory, Westerman, Alhammadi, & Brynjolfsson (2014).

practices in teaching relevant skills to the workers of tomorrow.[41]

The Framework identifies four learning and innovation skills – the 4Cs: critical thinking, communication, collaboration, and creativity – that students will need to learn in addition to the traditional 3Rs of reading, writing, and arithmetic.[42] The focus on these skills is supported by the increased importance of interpersonal and technology skills and the decreased importance of manual and perception skills for U.S. occupations between 2006 and 2014.[43] These skills are among the least likely to be computerized in the model of Frey and Osborne.[44]

Existing Policies and Proposals

The U.S. has an existing set of policies and programs for educating students in technology, providing students pathways to higher education and advanced skills, training displaced workers, and matching skilled workers to jobs. These policies and programs are briefly discussed here, along with proposed policies to further strengthen America's workforce. Our policy proposal seeks to complement these policies and programs in order to make workers more adaptable to the demands of technological change.

Inclusive STEM-focused High Schools & Early College High School Programs

Over the past decade, a wide range of experimental high school models have sprung up across the United States. Inclusive STEM-focused high schools (ISHS) are a category of STEM-focused schools that do not restrict admissions based on students' prior performance. Early and middle college high schools (E-MCHS) provide students with the opportunity to take college classes and earn college credits alongside their high school curriculum.[45] ISHS and E-MCHS schools have shown marked success in improving outcomes for a diverse body of students, but these schools serve a small minority of the population.[46]

In a study of these programs, the Opportunity Structures for Preparation and Inspiration in STEM study has identified a number of exemplary STEM-focused high schools. These schools have achieved impressive results from a project-based learning model.[47] This type of model is not limited to STEM classes, and could be adopted by both STEM-focused and general curriculum schools.[48] The project-based learning model provides opportunities for students to apply a project- and systems-management approach to their studies.

41 Partnership for 21st Century Learning (n.d.).
42 Ibid.
43 MacCrory, Westerman, Alhammadi, & Brynjolfsson (2014).
44 Frey & Osborne (2013).
45 Barnett, Maclutsky, & Wagonlander (2014).
46 Foroohar (2014).
47 Lynch et al. (2013); Burton et al. (2013); Spillane et al. (2013).
48 Lynch et al. (2013).

Pathways in Technology Early College High School (P-TECH) in New York City is an intriguing example that combines the ISHS and E-MCHS models. A collaboration between the New York City Department of Education, New York City College of Technology, City University of New York, and the IBM Corporation, P-TECH opened its doors for the 2011-2012 school year. Despite its recent arrival on the ISHS scene, P-TECH has garnered a great deal of national attention. President Obama praised P-TECH in his 2013 State of the Union Address,

> "Now at schools like P-Tech in Brooklyn, a collaboration between New York City Public Schools and City University of New York and IBM, students will graduate with a high school diploma and an associate's degree in computers or engineering. We need to give every American student opportunities like this."[49]

P-TECH provides students with an individually tailored pathway to the skills and knowledge they will need in the workforce. P-TECH students graduate in six years with a no-cost associate degree, and will be positioned to secure entry-level positions in STEM fields or continue their studies at a four-year higher education institution. This model includes a close working relationship and formal agreement with a community college, an industry partner or partners, and a six-year sequence of high school and college courses leading to an Associate degree. The school day and year are also extended beyond the traditional schedule to include more individual support for students.

Industry partners in the P-TECH model offer input into the specific skills and curriculum required for tech jobs and provide dedicated staff to spearhead the initiative, including an Industry Liaison position to work with the school. Students participate in an ongoing, sequenced workplace learning curriculum informed by current and future technology standards that includes career goals, mentoring, guest speakers, workplace visits and internships. Each student is paired with a mentor from the school's industry partner, giving the student guidance and support from a real world perspective. With its focus on early college and careers, these elements will prepare students for good jobs at the corporate sponsor and other industry partners.

America's College Promise: Free Community College

On January 8, 2015, President Obama proposed a program to make two years of community college free for all students who maintain minimum performance standards.[50] Federal funding would provide three-quarters of the proposed costs, while states would be expected to provide the remainder of the funding. The proposal as it stands does not address costs beyond tuition, and does not address other structural barriers to access and success for disadvantaged students.[51] Similar proposals have been considered at the state level by Governor Haslam of Tennessee and by the Oregon legislature.[52]

49 The White House (2013).
50 The White House, Office of the Press Secretary (2015, Jan. 9).
51 Scott-Clayton & Bailey (2015).
52 Forrohar (2014).

Free community college is a powerful mechanism to create a workforce with 21st century skills, but it is not independently sufficient. Students need to come to college prepared, both with a solid grasp of prerequisite coursework, and with an understanding of how their choices in course selection will inform their future career path. Community college requires a substantial time investment by students, and therefore may not be the best option for those seeking to quickly gain marketable skills. Conversely, community college is insufficient for training highly skilled professional workers in fields that require substantially longer periods of training, or training on specialized and cost-prohibitive equipment.

Despite its limitations, a community college education leading to an Associate's degree enables students to enter directly into several high-growth technology-related fields. Occupations such as web developers, air traffic controllers, IT support technicians, and medical technicians offer wages above the national average.[53] Community colleges are therefore well-positioned to offer a technology inclusive curriculum that feeds into more specialized training after graduation.

Workforce Innovation and Opportunity Act

The Workforce Innovation and Opportunity Act (WIOA) was signed into law by President Obama in July of 2014, and goes into effect on July 1, 2015.[54] The law replaces the Workforce Investment Act of 1998. The law covers many aspects of workforce development at the state level. States are required to submit a four-year unified strategy for all of their workforce programs. WIOA will also give job seekers more information about the career services available at American Job Centers. Local areas will also use WIOA funds to fill the workforce needs of local employers through the use of incumbent worker training, on-the-job training, and other programs. Overall, WIOA attempts to connect job seekers with the training they need so they can fill vacant jobs and grow the economy.

TechHire Initiative

The Obama administration announced the TechHire Initiative in March 2015.[55] This program offers $100 million in grant funding to scale up and establish new training programs that focus on technology jobs. The White House chose to focus on the information technology sector because it offers relatively high salaries and it has the highest number of unfilled positions, according to data from the Bureau of Labor Statistics. In addition to jobs at IT companies themselves, many other service industry companies hire IT workers to install, repair, and update critical software systems. The pilot program includes employers in 20 regions with some 120,000 jobs openings, a significant portion of the estimated 500,000 unfilled jobs in the American IT sector.

53 BLS (2013).
54 US Department of Labor, 2014
55 The White House, Office of the Press Secretary (2015, Mar. 9).

One prominent partner for the TechHire Initiative is the Flatiron School, based in New York City. Flatiron offers short courses in website development, smartphone application development, and data science.[56] Their graduates, many of whom lack a college degree, go on to work for major companies like Google, Boeing, and the New York Times. The 12-week program costs $15,000, far less than a computer science degree at a four-year college. The Flatiron School has already partnered with the City of New York to offer tuition-free fellowships to low-income New Yorkers of diverse backgrounds. The Flatiron School serves as a proof of concept for partnerships between employers, local government, and skills training programs.

Cisco Networking Academies

Cisco Networking Academy is an example of a successful employer-run skills program. It began in 1997 as a way to train students to install and maintain infrastructure for a rapidly growing number of computer networks. To scale up the program, Cisco trains its instructors at numerous Regional Training Centers. This "train the trainer" approach dramatically increases the number of certified instructors, who receive Cisco credentials but are not Cisco employees. Instructors currently teach over 1 million students in 9,000 academies in 170 countries.[57] Cisco achieves this level of scale by providing everything instructors need to teach courses, from online curricula to instructional support.

56 The Flatiron School
57 Cisco Network Academy

Statement of Policy

We propose a set of policies designed to improve workers' adaptability and skills for an economy undergoing rapid technological change, and to improve workers' abilities to bring about that same change. These policies start at the high school level, and continue through life-long skills acquisition courses. These policies are designed to enhance worker flexibility, and to enable workers to effective manage technology systems.

Pathways in Technology

Inclusive Technology Early College High Schools

At the high school level, this proposal would offer a complementary approach to the dedicated science, technology, engineering, and math (STEM) high school policies advocated by ITIF in *Refueling the U.S. Innovation Economy*.[58] Without denying the importance of STEM education to the nation's workforce, this policy provides an education for the remaining 95 percent of students who do not pursue STEM careers.[59] These policies expand the ISHS model beyond STEM, to a more generalized Inclusive Technology High School approach. Although technology will be pervasive throughout courses as these schools, technology is not intended to be the focus of the curriculum.

Under the proposed policy, the Department of Education (DoED) would provide grant funding to between four and eight high school-community college partnerships. The purpose of these partnerships would be to develop model programs for schools that incorporate a technology project- and systems-management approach to teaching. The partnerships would be based on successful STEM programs such as P-TECH, but without an explicit focus on advanced STEM curriculum. Rather, this curriculum would integrate technology into the study of traditional or innovative non-STEM subjects through project-based learning. Students would learn to work collaboratively with others and to understand how components are integrated into a system. These 21st century skills will be essential for workers managing technology systems far beyond occupations classified as "STEM."

As is the case at P-TECH, students in these partnership programs would take classes both at the high school and community college level. Dedicated staff would manage the high school-community college partnership and facilitate the transition between high school and community college curriculum. Schools would also provide dedicated staff to monitor and facilitate partnerships with industry.

The targets of the DoED grants would be geographically diverse, allowing a wide range of local

58 Atkinson & Mayo (2010).
59 NSB (2012) notes that only about 5% of U.S. students will eventually pursue careers in STEM fields. It is therefore unnecessary to require an advanced STEM course-load for every student.

needs to be addressed. Each high school-community college partnership would leverage its own local industry partnerships to identify and plan curriculum that incorporates that industry's (or industries') skill needs.

Mentorships and Internships

In order to create incentives for partners, the government would offer a tax credit to companies that allow their high-skilled employees to serve as mentors to students. Mentorships should be based on the P-TECH model, which provides for strong one-on-one engagement with students over the course of their high school (and early college) career. Mentors can provide students with guidance and help students to understand how their curriculum – and the technology used to teach it – applies to their long-term career development. Students armed with this information will be able to make well-informed decisions about what courses to take, and which careers to pursue.

A further tax credit should be offered to companies that take high school students from rural or historically underserved communities as interns. These internships must provide students with an opportunity to utilize their curriculum and 21st century skills in a meaningful way. Internship programs have proven beneficial in some ISHS districts, but scaling these to incorporate schools in rural and underserved areas remains a challenge.[60] By providing a financial incentive to firms via a tax credit, innovative models may be developed that can be scaled once proven successful.

In order to justify these tax credits, the program will set standards for mentorships and internships. Standards for mentors should include a definition of "high-skill" that reflects the ability of the mentor to provide meaningful guidance in a technology-rich environment. Standards for both mentorships and internships must include guidance for the types of interaction and work performed, as well as the time commitment expected of the mentors and students. The incorporation of Internet based collaboration tools may be contemplated, but these should not be used exclusively unless absolutely necessary.

Information Sharing

DoED can encourage schools to adopt best practices by facilitating schools to share information about their success. DoED could either fund a nationwide network, or leverage an existing network, to share information among schools.

Skills Course Accreditation

Many regions and industries have the problem of skill mismatch, lacking workers with needed

60 Burton et al. (2013).

skills and having too many workers with unneeded skills. Skill mismatch is typically a localized problem that could not be solved by a centralized national program. However, the federal government has a role to play in facilitating the formation and growth of local programs. Under this policy, the Department of Labor (DOL) would address skill mismatch by identifying successful skills courses around the country and providing grant funding to replicate their success in other regions with similar needs. Additionally, local governments that identify skills needs in a certain industry would apply for federal funding to establish a new skills course. This distributed approach would place responsibility for implementation in the communities that will benefit most from the skills courses.

Independent skills courses already exist in various forms. Creating a flexible system of training to benefit both workers and employers requires better integration of existing programs and accelerated creation of new ones. To accomplish this task, the DOL would create a national skills course registry that provides an exhaustive list of available training courses. Like a college course catalog, this registry should contain detailed information about the content of each skills course and what certifications are available. This information would allow employers to identify the skills competencies of hires based on the courses they complete. In addition, workers can match employer skills demands for desired jobs with available courses. By specifying the knowledge embodied in each course, a national registry would facilitate the creation of new courses to meet local skills needs.

A national registry would also facilitate a system of peer accreditation for skills courses. Programs within the same industry would partner together with employers to build training curricula around current skills needs. These partnerships would form the basis for peer accreditation organizations that set standards for training in each industry. The credentials offered by accredited training programs would be recognized by all participating employers. This policy would promote these industry partnerships by making accreditation a required goal for grant-seeking programs.

In addition to independent skills courses, employers should commit to training their workers instead of simply recruiting workers with the desired experience. In order to create incentives for corporate investment in training programs, Congress should enact a tax credit for businesses that establish training programs for their employees. Again, a condition of the tax credit would be participation in an accreditation organization as well as sharing information with local government. Employers that spend more on training their employees would pay fewer federal taxes. This will encourage businesses and industry to build their own training programs to develop the skills of experienced workers and new hires.

To maximize the flexibility of the skills courses, they should be designed to have credentials that are stackable. According to the DOL's Employment and Training Administration, a stackable credential is "part of a sequence of credentials that can be accumulated over time to build up an individual's qualifications and help them to move along a career pathway."[61] For example, a computer programmer would begin by earning a certification in a specific programming language, and then earn additional credentials in other programming languages as the demands of their job changed. To promote stackable credentials, DOL would preferentially approve grants for skills courses that fit within a sequence. Creating a sequence of credentials allows workers to update their skills over an extended period of time so they can better adapt to changing skills needs.

61 Employment and Training Administration, TEGL 15-10

Analysis

Policy Benefits, Strengths, and Opportunities

The overall strengths of this policy come from building on what works, and from being adaptable to a variety of situations. Although these policies are situated around potential technological disruptions to the structure of the economy, they do not derive their advantage based on a particular technological outcome or timeframe. The policies presented do not prescribe particular technology skills, but rather are adaptable to whatever technological changes occur. This is a crucial aspect of any policy that attempts to address future technology issues, since the future of technology is notoriously hard to predict.

While the motivation for the policies proposed here are economic, the benefits to these policies are not so limited. In a democratic society in which technology is pervasive, making informed, responsible decisions as citizens requires knowledge of how technology works. Technologies affect and are affected by policy, often in very complicated ways. The policies proposed will strengthen America's democracy by developing a technologically informed electorate.

Pathways in Technology

Schools that incorporate technology in a project-based learning approach and engage students with challenging and innovative curriculum have already seen improvements in attendance, test scores, and academic advancement.[62] By building off of working models, the proposed school partnerships may focus on adapting to local area needs and developing innovative technology-inclusive curriculum. There is no need to reinvent the wheel.

Starting small with four to eight schools, a low initial investment can prove successful methods, which can then be scaled and adapted to new locations as warranted. Additionally, this program can be used to target the most at-risk, underserved, and historically disadvantaged segments of the population. In doing so, the industry partnerships and mentoring opportunities can facilitate the strengthening of communities across seldom traversed lines.

Facilitating industry partnerships will offer opportunities to incorporate local industry skill needs into the curriculum. The technology skills learned by students can be tailored to match the skills required for jobs in the local economy. The policy also provides dedicated staff to spearhead the initiative. Incorporating technology throughout each school's curriculum will allow students to learn how systems of technology interact. Through mentorships and internships, these students will be exposed to similar systems of technology used by firms.

By incorporating community college learning into a structured partnership between high

62 Lynch et al. (2013); Burton et al. (2013); Spillane et al. (2013); The Aspen Institute (2015).

schools and community colleges, this policy supports the framework of President Obama's America's College Promise plan. The partnership between high schools and community colleges would allow for a close and careful monitoring of students' achievement and readiness for community college classes. Students only gain the benefit of America's College Promise if they are able to meet performance standards, so it is imperative that students are well-prepared.

Although the proposed policy does not address four year institutions, the enactment of this policy would have spillovers that enable future college success. Graduates from Associate's degree programs wishing to pursue a Bachelor's degree often receive priority for admission to the local state university system. Furthermore, giving students a taste of college-level coursework would allow students to make more informed choices about whether they are prepared for further education. Students who are able to bypass entry-level prerequisite classes at four-year institutions will enjoy substantial cost savings in obtaining their degree.

Skills Course Accreditation

Skills courses offer workers the flexibility they need to adapt to technological disruption throughout their careers. Workers that have already completed their formal education will be able to continue learning new skills as the demands of their jobs change. Furthermore, workers that lack a post-secondary education will have a way to obtain the necessary skills for jobs that utilize new technologies. Skills courses increase job stability for workers whose jobs are at risk of automation.

Skills course accreditation introduces greater flexibility into the labor market. By creating standardized curricula for skills courses across the country, accreditation increases the recognition of skills course credentials. A standardized curriculum outlines a sequence of skills courses that can be completed as they are needed, allowing workers to complete courses on their own schedules. This policy builds upon existing training programs like the Cisco Network Academy and existing policies such as the TechHire initiative.

The proposed training tax credit corrects a market failure for employers that cannot fully appropriate the return on their investment in training workers. According to Robert Atkinson, "firms invest less in training than is optimal from a societal and economic perspective, and it negatively impacts growth and innovation."[63] The proposed tax credit will internalize the economic and societal benefits for an employer that invests in workforce training. The economic growth generated by increased employer training will offset losses in corporate tax revenue.

A robust system of continuing training adds value to workers above and beyond the skills they have already mastered. Workers embody human capital as well as human labor, and upgrading human capital increases the productivity of human labor. Rather than pay workers solely based

63 Atkinson (2015).

on the sum of their past experience, employers can pay workers based on their future learning potential. Skills courses allow workers to continuously upgrade their human capital and reap the rewards of their increased productivity.

Policy Challenges and Threats

Each of the proposed policies brings together several partners. Each of these partners must agree to a common set of goals and standards. Coordinating these partners and reaching consensus on is a significant challenge, as it is for any policy that requires buy-in from multiple actors. That said, the incentives to make these policies successful are strong, as they can achieve positive outcomes for education, industry, and community.

Even with partner buy-in, the outcomes of these policies rely on complex interactions and external factors. For example, the policies proposed here can facilitate the acquisition of needed skills by workers, but they cannot make high-skilled American workers cost-competitive with equally skilled foreign workers earning substantially lower wages. Trade policy and labor policies beyond the scope of education and skill acquisition will be needed to address these external factors.

Of course, no policy can control or predict the future of technological progress. Unexpected breakthroughs may substantially speed up the rate at which technology gains the 21st century skills that were previously considered safe from automation. A rapid growth in artificial intelligence capabilities could render much of the rethinking problem moot, if computers were suddenly able to reengineer processes and products themselves. Conversely, technological stagnation could result in widespread unemployment for reasons wholly different than those predicted by Carl Benedict Frey and Michael A. Osborne.

Pathways in Technology

The main challenge for high school-community college partnerships supported by DoED grants is to develop a sustainable, self-supporting model. Industry partnerships are the backbone of the P-TECH model, and will need to be developed for the schools proposed here. Although industry partners have shown a strong willingness to support STEM-specific schools, those schools only serve a small fraction of the overall community. Building strong partnerships to support a much larger network of schools will be a major challenge, but it is a goal that will benefit industry partners in the long run. By starting small and scaling up, the benefits of these schools to industry partners can be convincingly demonstrated.

Another challenge to expanding the educational models of schools like P-TECH is the avoidance of overly prescriptive curriculum. Although technology will be incorporated throughout the learning experience, students should not feel like they are mainly learning about technology. Instead, students should learn how to leverage technology in order to enhance their educational experience. With inclusive STEM high schools like P-TECH a relatively recent phenomenon, the ability of these schools to meet their goals have not been well documented in the research literature.[64] At present, the successful adaptation of the ISHS model to different curriculum has not been clearly demonstrated.

The above two challenges may interact with each other, if industry partners are only willing to participate on the condition that they are able to prescribe curriculum. Although the skill needs of industry are a driving factor in the development of this policy, industry needs cannot be allowed to supersede the academic needs of students. Not every student will want to work for the industry partners of these schools, and students should not feel unduly pressured to do so.

Other policy considerations that will need to be addressed include state and municipal requirements on seat time or hours of instruction. Aside from the challenge of recruiting effective teachers, there are implications for those teacher contracts given the P-TECH model's school day are longer than the standard K-12. Additionally, credit accumulation may look different for students who want to apply to a four-year post-secondary institution at the end of their fourth year of P-TECH. In this case, there are questions regarding how P-TECH students' unique situation will affect access to scholarships and other opportunities for financial aid. These aspects of the policy can be dealt with in a variety of ways, but should be carefully considered in order to maximize benefits.

Finally, the model proposed in this policy simply will not work in certain circumstances. Schools that are too distant from any significant industry will be unable to leverage partnerships to achieve the desired gains. There are no easy solutions to dealing with schools in these areas. Despite this limitation, the policy presented here will provide substantial benefit to the vast majority of the nation's school districts.

Skills Course Accreditation

Successful skills course programs require cooperation of a number of stakeholders in government, industry, and training. Incorporating a large number of stakeholders increases the complexity of establishing and operating these programs. Successful programs depend on local governments accurately assessing skills needs in their region. Industry actors must continually agree to skills training standards as technology advances. Skills course programs must uphold industry standards to maintain their accreditation. These complex interactions among stakeholders will lead to uneven outcomes unless programs are properly monitored and evaluated.

This policy does not provide for the stability of stakeholders themselves. Government funding is subject to shifting political priorities. Likewise, corporations that fund training programs are subject to the booms and busts of the business cycle. Independent skills course programs will

64 Lynch et al. (2013).

compete to attract trainees and their tuition dollars, and some will fail to reach sustainable levels of enrollment or funding. Skills course accreditation does not address any associated political or market risk.

While this policy attempts to help workers adapt to technology change, it will not help all workers avoid technological displacement. Strong social safety nets are needed to provide for those workers that do not benefit from the availability of skills courses.

Conclusion

Adapting the American workforce to structural changes in the economy is a complex process. Tech-savvy workers will be well positioned to use productivity enhancing technologies, and through the use of those technologies they will induce further changes to the structure of the economy. The rate at which these changes come about is uncertain, based both on the rate of technological progress itself, as well as the rate at which firms are able to successful adopt those technologies. Given the complexity of the issue, the Neo-Luddite response of blaming technology for disruption is understandable, but it is also unwise.

Automation is a historical phenomenon dating back to the Industrial Revolution and beyond. Within the past fifty years, computers have increased in power to the point of replacing humans in cognitive occupations. So far, capital has displaced human labor without causing mass technological unemployment. Entirely new job categories have arisen to employ displaced workers as a result of rising incomes and new methods of organizing labor. However, this process is neither instantaneous nor automatic. To facilitate the reorganization of capital and labor, the American workforce will need new skills to adapt to new technologies.

Our policy targets skills acquisition within traditional education as well as during a career. At the high school level, a small number of DoED grants would establish project based learning programs at geographically dispersed schools. These programs would integrate technology into the teaching of different disciplines so that students instruction into how these technologies are used. Industry mentorships incentivized by tax breaks will ensure that students draw connections between technology in the classroom and the workplace.

After students have joined the workforce, they will continue to learn new skills throughout their careers. Our policy offers DOL grant funding to expand successful skills training programs and establish new ones based on local skills needs. Training programs in the same sector will partner with each other and with industry to standardize curricula for skills courses. To encourage industry participation, businesses that invest in workforce training will receive tax credits. Increasing the variety and accessibility of skills courses will provide workers with a means of learning how to implement new technologies in the workplace.

In response to the problem of technology-driven structural change in the economy, we have proposed a set of straightforward policies that cut to the heart of the complexity. A technology-centric education system will create a 21st century workforce capable of managing dynamic technological systems. Working in the capacity of technology system managers will give workers the necessary perspective to recognize opportunities for yet more productivity enhancing innovations.

As these technology systems change and demand new skills from workers, the proposed policy offers workers the opportunity to quickly adapt and obtain those needed skills. Through the changes brought about by this policy, American workers will be transformed into lifetime learners. Workers will be able to acquire new competencies, and develop complementary skill sets that emerge as a result of technological change.[65]

Going forward, these programs contained in our proposed policy will need monitoring and evaluation to determine their success or failure. This is especially important given the complexity of interactions between technological, economic, and social factors. Future policies will address the complexity issues that arise from implementing skills education and training programs. In the meantime, governments at the local, state, national level should hire graduates of these programs in order to set a positive example for the rest of industry. Finally, policymakers should seek out and emulate successful skills training programs outside of the United States. These next steps will maximize the benefits of our policy and minimize its drawbacks.

65 MacCrory, Westerman, Alhammadi, & Brynjolfsson (2014).

Appendix

It is often remarked that the pace of automation has been increasing in recent decades. It is difficult, however, to find clear data justifying this conclusion. Rather, it seems as though commenters have a tendency to conflate the regular doubling of computing power known as Dennard scaling with the actual implementation of automation. But as discussed in this paper, the technical ability to automate a system means nothing if the technology is not recognized and utilized. Thus, to the extent that an increasing rate of automation may introduce significant workforce disruptions, it is necessary to have clear metrics that point to a rate of automation.

The Bureau of Labor Statistics (BLS) in the Department of Labor tracks economic data on hundreds of job categories in the U.S., and thus the BLS is a natural home for tracking the automation rate. The effects of automation on any particular job category are dependent on a significant number of economic factors, such as the substitutability of capital for labor, the rate of substitution, the behavior of the overall economy at the time of substitution, the elasticity of demand for the good or service produced, etc. Furthermore, the effects on occupational categories may include changes in wages, skills, and employment numbers, without any necessary correlation between the three. Thus, tracking should incorporate a variety of models.

At present, BLS does not collect data on jobs that are eliminated specifically due to automation or computerization.[66] In order to facilitate accurate data collection, the Worker Adjustment and Retraining Notification (WARN) Act should be amended to include a voluntary provision, whereby employers are encouraged to notify the Department of Labor when workforce reductions are perceived as a direct or partial result of labor automation adopted within the past five years. By making this data reporting voluntary, companies will not be substantially burdened or discouraged from adopting productivity enhancing technology.

Data collected in this manner should not be overvalued. Since the link between technology adoption and labor force reductions is anything but clear cut, firms' perception may not accurately reflect the role that technology adoption played in their decision. Combined with other analysis of BLS data,[67] this data could help to reduce wildly speculative claims about the effects of automation, and help to guide policymakers in forming well-reasoned policies.

66 Mathiason et al. (2014).

67 Such as MacCrory, Westerman, Alhammadi, & Brynjolfsson (2014), whose analysis should be repeated periodically in order to track changing occupational skill mixes.

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