The Impact of Technological Change on Low Wage Workers: A Review

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Contents

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I. Background and Major Issues

The relationship between technological change and the earnings of less-skilled workers is one of the oldest issues in economics (Berg 1984). Renewed interest in the link was spawned by labor market trends in the 1980s, including the decline in real wages for younger and less-educated workers, and the sharp increase in the wage gap between college and high school educated workers. At the same time, the introduction of the micro-computer was hailed as a revolutionary event that promised to change the nature of work. Two prominent studies written at the close of the decade Bound and Johnson (1992) and Katz and Murphy (1992) argued that the falling fortunes of less skilled workers were caused by adverse demand shocks, specifically "skill-biased" technological changes induced by the new computer technology. A vast subsequent literature has tended to confirm this basic view.[1] By now it is widely accepted that technological changes have hurt, and will continue to hurt, the labor market prospects for less skilled workers in the United States and other advanced countries. The technological change hypothesis, in turn, has provided a powerful intellectual foundation for a laissez faire approach to policies for aiding less skilled workers.

In this paper we present a critical review of the literature linking technological change to the structure of wages in the U.S. economy. We argue that the evidence for the technological change hypothesis is weaker than many observers have recognized. From a research design perspective we identify two key concerns. First, many studies reason backward from an effect (recent changes in the time series behavior of wage inequality) to a cause. A typical study does not ask "what is the evidence for an effect of this technological invention?" Rather, most have adopted a forensic approach, asking "*why* has wage inequality increased? " In a world where there are many potential causes, some of which are unknown (or ignored), a forensic approach can only eliminate candidate explanations. Even when such an analysis has ruled out all but one of the enumerated hypotheses, the analysis provides at best only limited support for the remaining explanation, since others could be constructed to explain the same set of facts.

A second fundamental problem is that demand shocks are inherently un-

[1] See for example, the useful Spring 1997 symposium in the Journal of Economic Perspectives. See especially Gottschalk (1993), Johnson (1993), Topel (1993). In that same symposium, Fortin and Lemieux (1997) take a different tack and focus on "institutional" explanations.

observable. Shifts in demand can only be measured within a specific structural model of supply and demand. Consequently, to an extent that seems to have been under – appreciated, much of the evidence in favor of (or against) the technology hypothesis is *model–dependent*. Different analysts, often using the same data, have reached different conclusions because they have worked with different structural models. Given the model-dependent nature of the evidence, a convincing case for the technology hypothesis requires an evaluation of the maintained structural model. In reality, these models are over-simplified, and often have other predictions that are inconsistent with key facts. Many of the structural models used in the technological change literature completely ignore the supply side of the labor market, and nearly all abstract from factors like discrimination and frictional imperfections that may have an impact on low-skilled workers. Reliance on simple structural models to infer the effects of technological change has led analysts to downplay or ignore important changes that might otherwise be interpreted as evidence against the technology explanation such as the dramatic rise in female relative wages, or the near constancy of the wage gap between high school dropouts and those with a high school degree.

More generally, we believe that analysts interested in understanding the effects of technology on less skilled workers could usefully adopt an expanded paradigm that explicitly incorporates supply-side considerations, as well as imperfections like discrimination, search frictions, and incomplete information. Indeed, in the broader labor economics literature these factors are often invoked to explain phenomena that have an important influence on the structure of wages, such as industry differentials, firm-size differentials, and the effects of job tenure. A more comprehensive approach seems especially important because low wage workers tend to have many disadvantages: they are younger, less educated, more likely to be minority and/or female, less healthy, live in worse neighborhoods, have few family or friends with good jobs, work in low-wage industries and in smaller firms, and have limited job tenure. While factors beyond simple supply and demand are an important feature of the labor economics literature, they seem to have been pushed into the background by a focus on the technology hypothesis

Maybe it not surprising then that the technology and wages literature has put little emphasis on the search for specific policy remedies that could be used to improve the prospects for less- skilled workers – apart from the need for low-wage workers to upgrade their skills. A "tax on computers" is never seriously discussed as a policy remedy for the problems caused by technology shocks (Johnson 1993). Indeed, the class of models used in the technological change literature would seem to point to policies like reducing minimum wages and lowering welfare payments as natural responses to adverse relative demand shocks. It therefore seems particularly important to understand the limitations of these models, and the robustness of any conclusions about the role of technological change in determining recent trends in the labor market prospects for less skilled workers.

II. Approaches to Measuring the Effects of Technology

It will be helpful to distinguish between two broad classes of approaches that labor economists have used to measure the impacts of skill-biased technological change (SBTC) on the relative earnings of less-skilled workers. In both cases, the focus of the existing literature as been on measuring the effects of exogenous technological changes.[2] One approach, which we call the "model specific" approach, defines SBTC as that part of the variation in relative employment and wages that is left unexplained after accounting for observable changes in the supply or demand for different groups of workers.[3] This approach has two key features which has made it attractive to many analysts. First, it has the potential ability to explain enormous quantities of labor market data from long time periods with very few parameters. Second, (and related) this approach leads to a substantial reduction in the set of "facts" to be explained. For example, in some studies the entire wage structure of the economy at a point in time is summarized by a single number representing the mean wage gap between men with a college degree and those with a high school degree.

[2]Such a focus may be overly restrictive. In Beaudry and Green (2005) and Beaudry and Green (2003) for example, the choice of technology is endogenous and responds to other shocks in the labor market, most notably changes in the relative supply of skilled labor and the price of capital. Outside of the field of labor economics there is a stronger focus on endogenous technological change. Noble (1984), for example, provides an historian's perspective on technological adoption in the U.S., while Berting (1993)presents a sociological perspective on endogenous technology. Sutz (2003) discusses the diffusion of new technology as possible mechanism to reduce inequality in developing countries.

[3]See for example:Levy and Murnane (1992), Katz and Murphy (1992), Juhn, Murphy and Pierce (1993), Bound and Johnson (1992), and Card and Lemieux (2001)

As Autor and Katz (2000) have observed, a serious limitation of this approach is that "strong assumptions about functional forms and substitution possibilities between different [types] groups of workers must be imposed to make this approach feasible". As we explain below, a less transparent but equally serious limitation is that the set of "facts" one chooses to consider are themselves model dependent, sometimes in non–obvious ways.

A second approach to assessing the importance of technological changes is to correlate observed measures of technology with changes in wage structure. While this approach has sometimes been combined with the model–specific approach above, this method in principle is more closely related to traditional notions of research design. Within the limits of the "experiments" nature has provided, one can ask how observed measures of technology are related to relative wages.

The best–known and most influential example of this approach is Krueger (1993), who estimated the wage premium for employees who use a computer on the job, and used the resulting estimates to infer the effect of the spread of computers on the return to education. A substantial literature which we will not review has followed this approach and confirmed that computer-users earn higher wages in many different settings. Apart from the problems associated with the non-random incidence of computer use, the key limitation of this approach is that its relation to the debate on the role of SBTC is unclear. As Autor and Katz (2000) explain:

> The existence of a positive computer wage differential is neither a necessary nor a sufficient condition for the diffusion of computers to have induced a shift in the relative demand for more–skilled workers and to have affected the wage structure. (page 1533)

A variant of the direct approach to measuring the impact of technological change is the case study approach. In section II.B., we discuss several prominent case studies that have documented the changes in employment and wages that occurred following the adoption of a new technology at a single firm or a small group of firms. These studies are helpful in assessing the magnitude of the relative demand shifts associated with the adoption of a specific technology at a specific set of employers. Nevertheless, they do not provide much help in quantifying the overall trend in the demand for less skilled workers. Thus, case studies have mainly served to complement the model-based approaches taken by most previous researchers.

II.A. Model–Based Evidence on the Role of Technology

We begin by reviewing the basic framework underlying the model–based approach to measuring the impact of technology. In practice, this approach proceeds in two steps. In the first step, the labor force is partitioned into a number of discrete skill groups, and data on mean wages and employment for each group is collected from the Current Population Survey or other data sources at several different points in time. These cell means become the "facts" that have to be explained. Next, changes over time in these means are related to each other in a simple supply and demand framework. In the absence of technological change, the model is assumed to be able to fully explain the observed changes in the wages and employment of the different skill groups (i.e., yield an R–squared statistic close to 1). The presence of technological change is inferred by a failure of the model to rationalize the co–movements of wages and employment for different groups over the sample period.

It has long been recognized that the choices made by the researcher in both steps have important consequences for the resulting estimates of technological change. For example, in the first stage of their investigation Bound and Johnson (1992) partition the labor force into groups defined by experience, education, and gender. This division is tied to their model–based assumption that men and women with the same education and experience are imperfect substitutes in production. Since the number of women working in each education and experience group rose relative to the number of men, and the relative wages of women also increased, Bound and Johnson (1992) infer that technological changes led to a positive relative demand shock for female labor in the 1980s. [4]

Although researchers may agree that the decision to model male and female labor markets separately is natural and appropriate, it is important to recognize that this decision has a powerful impact on the facts to be explained. When men and women are treated separately, the 1980s emerges as a decade of rapidly rising individual wage inequality. (Katz and Murphy 1992, Bound and Johnson 1992, Levy and Murnane 1992, DiNardo, Fortin and Lemieux 1996, Card and DiNardo 2002, Autor and Katz 2000, Autor, Katz and Kearney 2004). When they are taken together, however, the over-

[4]They clearly acknowledge that there are other possible explanations for this fact.

all rise in wage inequality during the decade is quite modest. Indeed, as shown in Lee (1999), after taking account of changes in the minimum wage there is almost no change in wage inequality in the pooled distribution of men's and women's wages over the 1980s. Moreover, the decision to view men and women as separate factors of production means that any spillover effects between the gender groups will be ignored, or pushed very far into the background.

A similar relationship between the facts to be explained and the choice of model emerges in the recent literature on the evolution of the college-high school wage gap. To understand this point, consider the model developed in Card and Lemieux (2001), which includes as a special case the benchmark specification of Freeman (1976) and Katz and Murphy (1992). In this model, aggregate output y is produced via a CES production function that combines high school equivalent labor at time t (H_t) with college equivalent labor (C_t):

$$y_t = (\theta_{ht} H_t^{\rho} + \theta_{ct} C_t^{\rho})^{(\frac{1}{\rho})} \quad (1)$$

Here the θ parameters measure the efficiency of technology in period t. The key parameter in the model is $\rho = 1 - \frac{1}{\sigma_E}$ where σ_E is the elasticity of substitution between the two education groups.

Unlike Freeman (1976) and Katz and Murphy (1992), Card and Lemieux (2001) explicitly allow imperfect substitution between workers with similar schooling but different ages (or different levels of potential labor market experience). This is accomplished by letting high school equivalent labor and college equivalent labor both be CES sub–aggregates of labor of different age groups.[5] Specifically, Card and Lemieux (2001) assume that

$$H_t = \left[\sum_j (\alpha_j H_{jt}^{\eta})\right]^{\frac{1}{\eta}} \quad (2)$$

$$C_t = \left[\sum_j (\beta_j C_{jt}^{\eta})\right]^{\frac{1}{\eta}} \quad (3)$$

where α_j and β_j are relative efficiency parameters that are assumed to be fixed over time, and $\eta = 1 - \frac{1}{\sigma_A}$ where σ_A is the elasticity of substitution

[5]Imperfect substitution between age groups can be introduced in a number of different ways. Beaudry and Green (2000), for example, use a specification that implies that there are cohort–specific age–earnings profiles for different education classes.

between different age groups with the same education.

Assuming full employment, and that the relative wages of different skill groups are proportional to their relative productivity, one can derive the following convenient expression for the log relative wage gap between college–educated and high school–educated workers in age group j in year t:

$$\log\left(\frac{w^c_{jt}}{w^h_{jt}}\right) = \log\left(\frac{\theta_{ct}}{\theta_{ht}}\right) + \log\left(\frac{\beta_j}{\alpha_j}\right) + \frac{1}{\sigma_E}\log\left(\frac{C_t}{H_t}\right) - \left(\frac{1}{\sigma_A}\right)\left[\log\left(\frac{C_{jt}}{H_{jt}}\right) - \left(\frac{C_t}{H_t}\right)\right] + e_{jt} \quad (4)$$

where e_{jt} represents sampling variation and any other unmeasured determinants of relative wages.

Assuming that the relative numbers of workers with college and high school education in a cohort do not change once the cohort enters the labor market, the ratio $\left(\frac{C_{jt}}{H_{jt}}\right)$ is fixed for a given cohort. Thus equation (4) partitions the college-high school wage gap for different age groups in different years into four components:

1. A time effect: $\log(\frac{\theta_{ct}}{\theta_{ht}}) - (\frac{1}{\sigma_E} - \frac{1}{\sigma_A})\log\left(\frac{C_t}{H_t}\right)$
2. An age effect: $\log\left(\frac{\beta_j}{\alpha_j}\right)$
3. A cohort effect: $\left(\frac{1}{\sigma_A}\right)\left[\log\left(\frac{C_{jt}}{H_{jt}}\right)\right]$
4. A residual component: e_{jt}

In this framework, technologically induced relative demand shocks are identified as the component of the trend in the college-high school wage gap that remains once the effects of aggregate supply have been factored out. [6]

Although this model represents only a small departure from the benchmark specification used by Freeman (1976) and Katz and Murphy (1992), the introduction of imperfect substitutability between different age groups with the same education has a potentially important effect on the facts to be explained. The benchmark model assumes that $\frac{1}{\sigma_A} = 0$, and therefore implies that the cohort effects are ignorable. The benchmark model therefore

[6] The aggregate supply effect is $(\frac{1}{\sigma_E} - \frac{1}{\sigma_A})\log\left(\frac{C_t}{H_t}\right)$.

asserts that the facts to be explained are merely a function of the regression coefficients on a set of dummies that can be depicted as:

$$\log w_{a,s,t} = f\left(\text{Age} \bigotimes \text{Education} \bigotimes \text{Year}\right) \qquad \dagger$$

where $\log w_{a,s,t}$ is the mean log wage of a worker in age group a, schooling level s in year t. Such a framework is at the heart of the facts helpfully laid out in Levy and Murnane (1992).

The model in Card and Lemieux (2001) by contrast can be depicted as:

$$\log w_{a,s,t,c} = f\left(\text{Age} \bigotimes \text{Education} \bigotimes \text{Year} \bigotimes \text{Cohort}\right) \qquad \dagger\dagger$$

From the textbook omitted variables analysis, the set of facts generated from equation (†) will be the same as the facts generated by equation (††) only if these cohort effects are orthogonal to the age, education, and year effects. It is widely recognized, however, that this is not the case, especially with changes in cohort size induced by the "baby boom." For example, in their review of the standard earnings regressions, Heckman, Lochner and Todd (2003) find "important differences between cohort based and cross–sectional estimates of the rate of return to schooling" and that "in the recent period of rapid technological progress, widely used cross–sectional applications of the Mincer model produced dramatically biased estimates of cohort returns to schooling."

This sensitivity of structural models is not not an argument against the use of such structural models. Indeed, one surprise in Card and Lemieux (2001) is how *well* such a simple model can rationalize a large number of wage differentials for the U.S., Britain, and Canada over many years, once proper consideration is given to the role of cohort–specific supplies of college educated labor. As a matter of research design, however, we believe that a structural approach is better suited to testing hypotheses about the effect of *observed* factors (such as cohort–specific supply effects) than as a method for identifying the effects of technological change, since ultimately any misspecification or error feeds into the residual, and will become part of the estimate of technological change.

II.A.i Constant or Accelerating Technology?

Whatever the choice of model, the effect of technology is pinned down by imposing a specific time pattern for technology, usually by restricting the time series pattern of the relative technology term in equation (4), $\log\left(\frac{\theta_{ct}}{\theta_{ht}}\right)$. There are two different assumptions common in the literature. The first assumes that the relative technology effect follows a linear time trend:

$$\log\left(\frac{\theta_{ct}}{\theta_{ht}}\right) = \delta t,$$

with $\delta > 0$ under the assumption that technological changes are skill–biased.

An alternative assumption – sometimes called the "accelerationist" hypothesis – asserts that there was a trend break in the pace of technological change at some time during the 1980s (say, coincident with the introduction of the personal computer), implying:

$$\log\left(\frac{\theta_{ct}}{\theta_{ht}}\right) = (\delta + D\gamma)t,$$

where D is a dummy indicating the post break period, and γ is a parameter reflecting the faster pace of technological innovation in the later period.

The two alternative specifications have different implications for the role of exogenous technology in affecting the wage structure. The "constant trend" version suggests that although technology plays a role in determining relative wages, there is nothing particularly remarkable about the new technologies that developed in the 1980s and 1990s. Rather, these technologies should be interpreted as part of a steady stream of innovations over the recent past. The accelerationist view, by contrast, suggests that the pace of technological progress was faster in the 1980s and 1990s than in previous decades, and that recent inventions such as the microcomputer and the Internet represent a quantum break from the past. Unfortunately, in the absence of direct measurement of technological change, or even of an exact date for the timing of any acceleration, it has proven difficult to distinguish between these alternative specifications (see Borjas and Ramey (1995)).

II.A.ii The Facts When Workers of Different Ages are Imperfect Substitutes.

Table 1 from Card and Lemieux (2001) presents estimates of the log wage gap between college and high school workers in different age groups and in different time periods for the U.S., Canada, and the U.K. The three countries

Table I: College–High School Wage Differentials by Age and Year

	Age range						
	26–30	31–35	36–40	41–45	46–50	51–55	56– 60
A.United States							
1959	0.136	0.268	0.333	0.349	0.364	0.379	0.362
	(0.007)	(0.007)	(0.008)	(0.011)	(0.013)	(0.016)	(0.021)
1969–1971	0.193	0.272	0.353	0.382	0.360	0.378	0.371
	(0.013)	(0.015)	(0.015)	(0.016)	(0.018)	(0.022)	(0.028)
1974–1976	0.099	0.225	0.310	0.355	0.366	0.369	0.363
	(0.012)	(0.014)	(0.017)	(0.018)	(0.019)	(0.020)	(0.028)
1979–1981	0.111	0.180	0.265	0.281	0.336	0.349	0.355
	(0.011)	(0.012)	(0.015)	(0.017)	(0.017)	(0.018)	(0.021)
1984–1986	0.275	0.315	0.324	0.378	0.402	0.433	0.401
	(0.012)	(0.012)	(0.014)	(0.017)	(0.020)	(0.021)	(0.025)
1989–1991	0.331	0.410	0.392	0.395	0.381	0.357	0.461
	(0.012)	(0.013)	(0.014)	(0.015)	(0.018)	(0.022)	(0.025)
1994–1996	0.346	0.479	0.482	0.443	0.407	0.384	0.421
	(0.014)	(0.014)	(0.015)	(0.017)	(0.017)	(0.023)	(0.030)
B. United Kingdom							
1974–1977	0.172	0.323	0.267	0.338	0.340	0.371	0.455
	(0.026)	(0.034)	(0.046)	(0.049)	(0.057)	(0.059)	(0.086)
1978–1982	0.103	0.173	0.267	0.278	0.259	0.325	0.331
	(0.020)	(0.022)	(0.034)	(0.032)	(0.040)	(0.047)	(0.056)
1983–1987	0.193	0.154	0.300	0.234	0.292	0.330	0.420
	(0.022)	(0.025)	(0.029)	(0.039)	(0.048)	(0.054)	(0.064)
1988–1992	0.272	0.304	0.306	0.284	0.292	0.392	0.393
	(0.025)	(0.029)	(0.031)	(0.035)	(0.047)	(0.049)	(0.075)
1993–1996	0.306	0.369	0.352	0.318	0.325	0.285	0.337
	(0.032)	(0.032)	(0.037)	(0.038)	(0.046)	(0.066)	(0.095)
C. Canada							
1980	0.095	0.182	0.256	0.297	0.291	0.393	0.366
	(0.012)	(0.014)	(0.017)	(0.024)	(0.028)	(0.031)	(0.035)
1985	0.115	0.214	0.279	0.263	0.327	0.356	0.433
	(0.014)	(0.014)	(0.015)	(0.018)	(0.026)	(0.030)	(0.035)
1990	0.146	0.253	0.263	0.279	0.297	0.337	0.349
	(0.011)	(0.011)	(0.012)	(0.013)	(0.018)	(0.023)	(0.031)
1995	0.151	0.304	0.299	0.271	0.297	0.285	0.320
	(0.012)	(0.012)	(0.013)	(0.014)	(0.015)	(0.020)	(0.034)

Standard errors are in parentheses. The elements of the table are as follows:

United States: the table entries are estimates of the difference in mean log weekly earnings between full-time individuals with sixteen and twelve years of education in the indicated years and age range. Samples contain a rolling age group. For example, the 26-30 year old group in the 1979-1981 sample includes individuals 25–29 in 1979, 26-30 in 1980, and 27-31 in 1981.

share many similarities, including relatively similar education systems and relatively low rates of institutional intervention in the wage determination process. Moreover, employers in all three economies have adopted computers and other advanced technologies at about the same pace. Contrary to the impression conveyed by much of the recent literature, however, the data in Table 1 do not seem to show evidence of a ubiquitous increase in the returns to skill since 1980, even in these three countries. Figure 1 plots an admittedly selective subset of the college high school wage gaps by age and country that underscore this point.[7]

A close examination of the wage differentials in Table 1 suggests some amendments to the "facts" for which technological change has been proposed as an explanation:

1. **The increase in the college–high school wage differential is not ubiquitous across countries and age groups.**

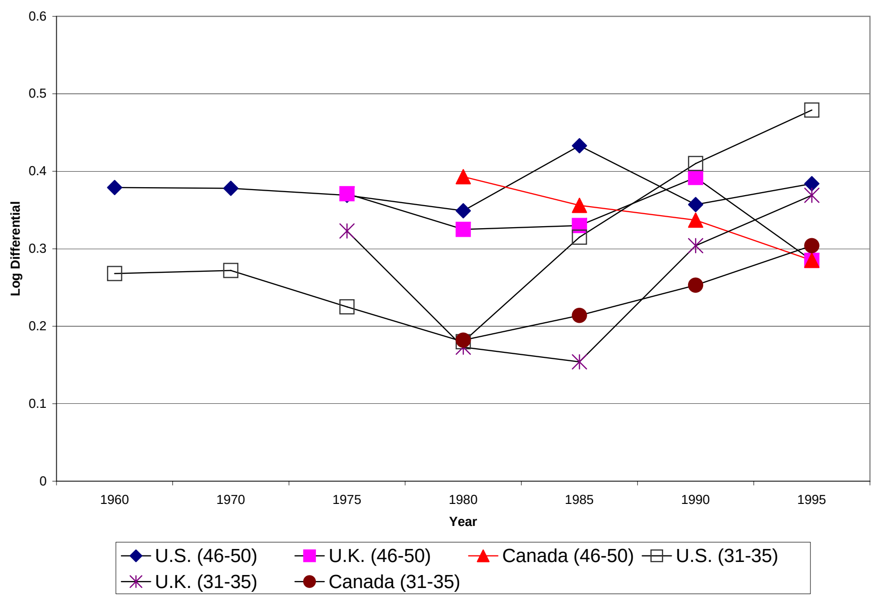
   In the UK, a model based technology story needs to explain why there has been a (sometimes substantial) *drop* in the college–high school wage premium for men over the age of forty over the period 1974–1996. For men aged between the ages of 56 and 60, for example, the college–high school differential fell from 0.455 to 0.337. For men between the ages of 40 and 45, the differential in the gap fell from 0.338 to 0.318. Such facts are not impossible explain with an important role for skill biased technological change, however, it does suggests some caution in in assuming that an increased college high school gap is a ubiquitous feature of economies that have seen important changes in technology.

   In Canada, the story is similar with the college–high school wage differential for men 41–45, 51–55, and 56–60 falling over the period 1980–1995.

2. **The increase in the college–high school wage differential is**

[7]The lack of ubiquity in rising education-related wage gaps across OECD countries has been noted by others. Nickell and Bell (1996) assemble data for a sample of 8 OECD countries from 1971–1993 and observe that "the key facts are that in Britain and the United States there has been a large fall in the relative wages of the unskilled from 1980 onward and that falls of this magnitude are not apparent in any other country." Card, Kramarz and Lemieux (1999) and Nickell and Bell (1996) observe that the lack of movement in the skill differential in most of the OECD *can not* be easily explained by a systematic increase in the unemployment rates of the unskilled in those same countries.

Figure 1: Selected College High School Gaps by Age and Country



concentrated among younger workers in the US, UK, and Canada.

Here the increase the college–high school wage differential has been quite striking. It appears that estimates of the trend in the "overall" college–high school wage gap have been driven by increases in the gap for younger workers.

3. **Even in the U.S., the patterns for workers over the age of 35 do not seem to show continuous rises in wage differentials over the 1980s and 1990s.**

   A general description of the patterns for U.S. workers in Table I is that college–high school wage gaps were roughly constant during the 1960s, fell during the 1970s, rose sharply in the mid 1980s, and then grew more modestly or not at all afterward. The fact that much of the change in college–high school workers has affected younger workers, and has had comparatively little effect on older workers argues against viewing these developments as consistent with a ubiquitous increase in the relative wage of college graduates.

   As noted in Card and DiNardo (2002), from the vantage point of the late 1980s, the rapid increase in the overall high–school wage differential in the early 1980s did seem anomalous, given the constant or falling differentials over the previous decades, and rather large increases in the supply of college educated workers. Indeed, from that vantage point, the supply and demand plus technology framework strongly suggested a further rapid expansion of college-high school wage differentials in the 1990s. For instance, in one particularly clear discussion about the implications of a broad class of supply and demand models Bound and Johnson (1992) noted:

   > It is interesting to speculate about what the results imply about the course of relative wages in the future. Given a continuation of the increase in the relative demand for highly educated labor, wage differentials by education are likely to continue to increase unless there is a sharp rise in college attendance and completion rates. Such an increase does not appear to be likely in the near future . . . in the absence of drastic changes in educational policy at all levels. Bound and Johnson (1992) (page 389).

While this seems to be the right prediction given the basic model, it was not borne out by subsequent events. Indeed, many measures of inequality were fairly stable, or increased only modestly, over the 1990s.[8]. Obviously, the slowdown can be rationalized by assuming that there was a deceleration in the pace of technological change relative to the 1980s, or that other factors emerged to obscure the underlying trend in technology.

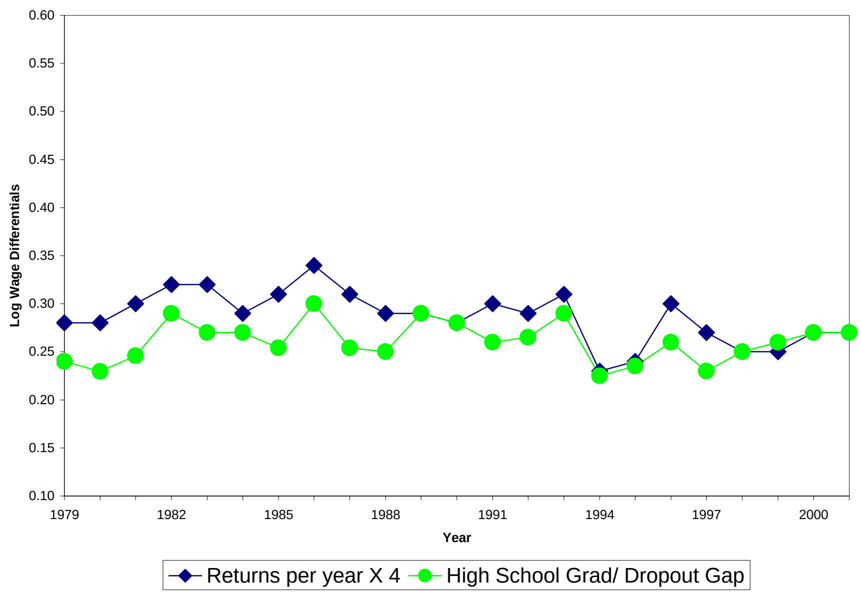
II.A.iii What About The Bottom of the Education Distribution?

Much of the inequality literature has focused on interpreting trends in the wage differential between college and high school workers. In part, this reflects the influence of Freeman (1976), who first proposed a supply and demand framework for analyzing trends in the college wage premium. In part, it also reflects the legacy of Mincer (1976), who specified a linear relationship between log earnings and years of schooling. According to Mincer's specification, the wage gap between college and high school workers is proportional to other education-related wage gaps in the labor market, so there is no loss in generality in focusing on the college premium. During the 1980s and 1990s, however, the relationship between earnings and years of schooling became more convex. In addition, analysts have begun to make a distinction between inequality trends among higher wage workers and trends for lower wage workers. In particular, Autor et al. (2004) have emphasized the divergence in trends in inequality for the "upper half" of the wage distribution (between the median and 90th percentile of wages) and the "lower half" (between the median and the 10th percentile).

Surprisingly, the technology and wage inequality literature has paid little or no attention to the relative wages of people with less than a high school education. Nevertheless, in thinking about the implications of technological change for less skilled workers, it seems particularly important to understand the trends for people with below-average levels of education. Based on trends in the college-high school wage premium, one might have expected that the

[8]See Mishel, Bernstein and Boushey (2002), for example. One potentially important issue which we ignore in our discussion is the overhaul of the Current Population Survey in the mid 1990s. See Polivka (1996),Polivka and Rothgeb (1993), and Cohany, Polivka and Rothgreb (1994) for a description of the changes and their effects on measurement. While there seems to be evidence that the redesign affected the *level* of wages, it is not clear what effect (if any) it had on measures of inequality. See Bernstein and Mishel (1997) and Lerman (1997) for different viewpoints.

Figure 2: The High School – Dropout Gap and the Returns to School



wage gap between high school dropouts and those with a high school diploma would have also risen during the 1980s and 1990s. Figure 2, however, tells a different story. The figure plots two measures: the mean log wage differential between high school graduates and dropouts, and the average return per year of schooling among those with 12 or fewer years of schooling, multiplied by 4.[9] Since 1979, the wage premium for high school graduates relative to dropouts has fluctuated in the range of 25 to 30 percent, with a modest rise in the early 1980s and more or less steady declines since then. By contrast, the similarly measured college high school gap was 50 percent higher in 2000 than in 1979.

The framework of equation (4) suggests that it is important to control for differences in the relative supply of high school versus dropout labor in

[9]These wage gaps refer to the hourly earnings of men age 18-64 in the 1980-2002 March Current Populations Survey (CPS), and are estimated from models that include controls for a cubic in potential experience and dummies for black race and Hispanic ethnicity.

order to interpret the trend in the relative wage differential. Using data on education shares in the 1980 and 2000 Censuses reported in Card (2005), we estimate that the log relative supply of high school labor relative to dropout labor increased by about as much as the log relative supply of college labor relative to high school labor. Arguably, then, in the presence of uniformly skill biased technical change, the high school–dropout wage premium should have risen by about as much as the college–high school premium. The remarkable stability of the high school–dropout premium provides further evidence against the ubiquitous technical change hypothesis.

II.A.iv Implicitly Model Based Evidence – Residual Inequality

Since Juhn et al. (1993) it has become standard practice to decompose wage inequality into two components – one which relates to observed measures of skill, such as age and education, and a second that relates to unobserved skills. Empirically, unobserved skill is defined as the difference between the observed wage and the part of wages that can be predicted by observed skill factors: i.e., as the residual component of earnings. Special emphasis is often given to an analysis of time series trends in variance of the residuals from a standard human wage equation (so-called "within inequality"). For example, Levy and Murnane (1992) study trends in residual wage inequality for U.S. workers in the 1970s and 1980s, Goldin and Margo (1992) use similar methods to study changes in inequality before 1940, Machin (1996) applies a parallel analysis to recent trends in the U.K., and Gottschalk and Smeeding (1997) study trends for a large set of countries.

Although inspired by the formal model of wage determination developed by Juhn et al. (1993), most of the literature has treated the analysis of residual wage inequality as an accounting exercise, rather than as a model–dependent procedure, and has treated the measured trend in residual inequality as one of the important "facts to be explained."[10] As Goos and Manning (2003) have observed, "a small industry has been established based on the premise that wage inequality has risen very markedly among 'identical' workers and has been building theoretical explanations of this 'fact'."

As in the case of education-related wage differentials, we believe that casual readers of the technology literature may have missed two important points. First, there has not been a ubiquitous rise in residual wage inequality

[10]Indeed, Levy and Murnane (1992) argue that the upward trend in residual wage inequality is the single most important unresolved puzzle in the wage inequality literature.

across all skill groups and in all developed economies.[11] Second, as has been clearly demonstrated by Lemieux (2004), estimating the trend in residual wage inequality is not a "model free " exercise. Rather, the trend depend critically on a number of choices, including the choice of data set to measure wages and the specific procedure adopted to adjust for changing skill characteristics of the labor force.

To understand Lemieux (2004)'s analysis, it is helpful to begin with an overview of the standard procedure for measuring trends in residual wage inequality. Although the exact implementation varies somewhat, a simple representation of current practice is to begin with a simple wage equation:

$$\log w_{it} = \alpha_t + X_{it}\beta_t + \epsilon_{it} \tag{5}$$

where w_{it} represents the wage of individual i observed in period t, α_t is a constant, X includes a vector of standard human capital variables (Mincer 1974) such as education, age, gender, etc., and β_t is a coefficient vector. The covariates are taken as measures of skill. Standard practice treats the residual from equation (5) as the product of a one–dimensional measure of the unobservable ability of individual i and a time varying "price" of skill:

$$e_{it} = p_t a_i, \tag{6}$$

although it should be noted that when the dependent variable is the logarithm of wages, this naming convention is potentially confusing.

For a single time period, a convenient measure of the importance of unobservable skill in explaining wage inequality is

$$\sigma^2(1 - R^2)$$

where σ^2 is the variance in log wages and R^2 is the usual measure of the proportion of variance in wages that is explained by the observed skill variables (X). Equation (6) implies that the variance of unobserved wage inequality in period t is $p_t^2\text{Var}(a_i)$, where $\text{Var}(a_i)$ denotes the cross-sectional variance of the unobserved ability component. Assuming that the distribution of unobserved ability is a constant over time, a rising value of the residual variance $\sigma^2(1 - R^2)$ implies that there has been a rise in the return to unobserved ability.

[11]See Gottschalk and Smeeding (1997) for a helpful review.

An obvious limitation of this framework is that any conclusion about the trend in residual wage inequality is likely to depend on what observable skill components are included as controls. Using data for the U.K., for example, Goos and Manning (2003) find that including a longer list of job quality characteristics has an important impact on the facts about residual inequality. Indeed, once they control for job conditions they find that the previously documented rise in residual inequality in Great Britain disappears. Goos and Manning (2003)'s finding also raises an interesting question: Should residual wage inequality be defined after controlling for both supply and demand side characteristics, or only the former?

Although issue of what controls to include in the wage equation is probably of first – order importance, we will assume that such a problem does not exist and instead examine the inherent difficulties with such analyses even if the models are correctly specified.[12]

To explain the problem with much of current practice, it will be helpful to take a special case with a single binary covariate. Accordingly, restrict the wage equation to:

$$\log w_{it} = \alpha_t + \beta_t C_{it} + \epsilon_{it} \tag{7}$$

where $C_{it} = 1$ if worker i at time t has a college degree, and zero if not (i.e., for high school educated wokers). Let $\overline{C}_t$ represent the fraction of workers with a college degree in year t. Then

$$\text{Var}(\epsilon_{i,t}) = (1 - \overline{C}_t)Var(\epsilon_{i,t}|C = 0) + \overline{C}_t Var(\epsilon_{it}|C = 1)$$

This simple decomposition illustrates that the residual variance of wages at any point in time is a weighted average of the residual variances within skill groups. Over time, two things can happen: the fraction of workers in different skill groups can change; and the residual variance of wages within any given group can change. If the error component in wages is heteroskedastic, then a shift in the skill composition of the labor force can lead to a change in the overall residual variance, even when there is no change in dispersion within skill groups.

[12] Note that changes in survey instruments and processing procedures are likely to lead to changes in residual inequality that have no economic content. For example, over the past 20 years the fraction of people with allocated earnings information in the Current Population Survey has risen significantly.

Unfortunately, the assumption of homoskedasticity in wage regressions is decisively rejected for the U.S. for data as far back as 1940 (See Lemieux (2005a) and Heckman et al. (2003) for helpful reviews.) Moreover, there is a large and established theoretical literature arguing that heteroskedasticity should be a pervasive feature in wage regressions. In the standard human capital framework due to Mincer ((1974)), for example, residual variance first falls with experience and then rises after the "overtaking point" of about 10 years. [13] Similarly, (Becker 1975)'s well-known model of comparative advantage in schooling choice leads to the prediction that the residual variance in wages will be higher for better-educated workers (Mincer (1997)). [14]

To illustrate the implications of heteroskedasticity for interpretations of residual inequality, imagine that in both education groups the residual wage component can be decomposed into the product of a return and an unobserved ability, and that the return to unobserved ability, p_t, is the same in both groups. Then the overall variance in residual inequality can be written as:

$$\mathrm{Var}(\epsilon_{it}) = p_t^2 \left[\mathrm{Var}(a_i|C=0) + \overline{C}_t \left\{\mathrm{Var}(a_i|C=1)) - \mathrm{Var}(a_i|C=0)\right\}\right]$$

Assuming that $\mathrm{Var}(a_i|C=1)) > \mathrm{Var}(a_i|C=0)$, this implies that a rise in the fraction of the labor force with a college degree will lead to an increase in overall residual inequality even when p_t is constant.

What is required to make a valid inference about the trend in the return to unobserved ability becomes clear from writing down the ratio of the residual variance at two points in time.

$$\frac{\mathrm{Var}(\epsilon_{i,t+1})}{\mathrm{Var}(\epsilon_{it})} = \frac{p_{t+1}^2 \left[\mathrm{Var}(a_i|C=0,t+1) + \overline{C}_{t+1} \left\{\mathrm{Var}(a_i|C=1,t+1) - \mathrm{Var}(a_i|C=0,t+1)\right\}\right]}{p_t^2 \left[\mathrm{Var}(a_i|C=0,t) + \overline{C}_t \left\{\mathrm{Var}(a_i|C=1,t) - \mathrm{Var}(a_i|C=0,t)\right\}\right]}$$

Lemieux's observation is that even if the distributions of unobserved ability are constant within education groups over time, the ratio is an admixture of the changes in the price of skill $\frac{p_{t+1}}{p_t}$ and a "composition effect" – changes

[13]This phenomenon arises because different individuals invest in on the job training at different rates in Mincer's model.

[14]Many other theoretical channels would be expected to generate higher residual variance in wages for older and better educated workers, including on-the-job learning and differences in in school quality

in the "weights" $\overline{C}_t$ over time. Lemieux's (2004) solution to the problem is to keep the weights fixed at either the base period, or the end period. Remarkably, when he does so, the puzzle posed by Levy and Murnane (1992) nearly disappears – composition adjusted residual inequality is stable in the 1970s, shows a modest rise in the early 1980s, and is constant or even falling after the mid 1980s, much like the time trend in the college high school differential.[15]

While this approach is a natural one, one might be uncomfortable with the assumption that the conditional variance in unobserved skill within cells remains constant. Unfortunately, there is no way to pin down both the change in the price of unobserved skill and the variance in unobserved ability simultaneously. Moreover, as both Lemieux (2004) and Autor et al. (2004) observe, the time series path of residual inequality is somewhat sensitive to choice of data sets and the use of end-of-period versus beginning-of-period weights to standardize the distribution of observed skills. For example, the trend in residual inequality is bigger in March CPS (where wages are typically computed by dividing annual earnings by annual hours) than in the CPS Outgoing Rotation Group files (where hourly wage rates are reported directly by a majority of workers, and are estimated from weekly or monthly earnings and hours for others.) Lemieux (2004) argues that at least some of the faster rise in the March CPS is attributable to increasing measurement error. This argument is downplayed by Autor et al. (2004), who nevertheless acknowledge that most of the rise in residual wage inequality in the late 1980s and 1990s is explained by rising dispersion in the upper half of the residual distribution. To the extent that one's focus is on workers in the lower half of the distribution, this would seem to suggest that technology-induced increases in the return to unobserved skills are not particularly important.

Given the critical model–dependence of any decomposition of residual wage inequality, and the large number of alternative explanations for movements in within cell inequality (including measurement error, choice of job characteristics, etc.) we are not sanguine about the potential for such an analysis to reveal much about the returns to unobserved ability in the economy, or to inform policy makers about the importance or unimportance of technological explanations for the wage outcomes of workers at the bottom

[15]Lemieux's (2004)analysis also helps to resolve another problem, which is how to reconcile the apparently steady rise in returns to unobserved ability with falling and rising returns to education over the 1970-2000 period. See Acemoglu (2002) for further discussion of this problem.

of the U.S. labor market.

II.B. Case Study Evidence on the Role of Technology

Some of the most compelling evidence for the role of technology in affecting the employment prospects of traditionally low wage workers comes in the form of case studies. While the approaches taken are too varied to summarize, they mostly involve a detailed evaluation of the changes in employment, wages, skill requirements, and conditions of work at a single firm or group of firms following the adoption of a new production technology. Interestingly, there is a long history of case studies that focus on the effects of technology on the structure of wages and employment. In response to concerns about "automation" in the mid 1950s, for example, the U.S. Bureau of Labor Statistics (BLS) commissioned a set of plant level case–studies in industries such as petroleum refining and electronics (Mark 1987). An underlying motivation for the case–study literature is the age old concern that modern technology will make certain types workers "redundant." [16]

If there is a common theme from the case study literature, it is that improvements in technology do not lead to long term unemployment. Both the BLS case studies of the mid 1950s, and those conducted by the same agency in the mid 1980s predicted that employment growth would keep up with increases in the working age population, regardless of new technology. Clearly, these predictions have been borne out. As regards the changes in the mid 1980s, the BLS did observe that new technologies seemed to lower the demand for specific types of skills (manual dexterity, physical strength for materials handling, and traditional craftsmanship) (Mark 1987) although other technologies appeared to have led to an *increase* in the demand for low–skilled labor, including relatively unskilled clerical work.

II.B.i Case Studies of SBTC

Some of the more recent case study literature has concerned itself specifically with the SBTC hypothesis. (See Handel (2003) for a particularly careful review of a number of recent case studies.) A prominent example is the study by Fernandez (2001), which utilized longitudinal data on employment and wages from a unionized food processing plant from before and after

[16]Manning (2004) refers to this as the fear of a "science fiction" technology, and notes that such concerns ignore the insights of a supply and demand framework.

the introduction of new machinery in the late 1980s. Fernandez specifically argues that his case study provides a "natural experiment" that opens up the "black box" of new technology:

> While all previous empirical studies of the phenomenon infer an exogenous demand-side shift in the labor market, the workers at this company experienced such a shift in a dramatic way. As such, this study provides an exceptionally clean setting in which to observe the key processes alleged to be operating in the skill-biased technological change account of growing wage inequality. Since this company endeavored to keep all its workers through the change in technology this study also avoids the main threat to validity in extant skill-bias studies, that is, the problem of self-selection of people into jobs for which their skills complement the technology. Past studies have run the risk of attributing observed wage changes to the use of the technology rather than to the individual factors that led the person to the job in the first place.

With some qualifications, Ferndandez views the results of his study as consistent with a role for SBTC in increasing wage inequality. Although average real wages were relatively constant there was an increase in wage dispersion at the firm – much of this attributable to the hiring of three additional (and highly paid) maintenance electricians.[17]. Interestingly, despite the substantial change in technology, apart from electricians the change in inequality was *lower* within the firm than in the local market for similar workers. In particular, wages for the least skilled workers at the firm fell less quickly than wages for similar workers in the local labor market. Fernandez also documents an increase in skill requirements at the firm, although this increase was typically "absorbed" by the workers and led to no increase in the typical amount time it took to be trained.

Fernandez is quite clear in defining the counterfactual for his study as the changes that might have occurred at the plant in the absence of the technological change. Despite this clarity, we are sympathetic with the argument made by Handel (2003) that it remains unclear whether the evidence points toward SBTC as an important causal factor in explaining wage changes. One

[17]This hiring patterns is not unexpected. Woodward (1965)describes case studies from the late 1950s that illustrate the complementarity between highly skilled maintenance workers and more advanced machinery.

particular source of ambiguity is the role of the latest (i.e., post-1981) technologies in the changes made at the plant. It is unclear what fraction of the upgrading was driven by new technology and what fraction simply reflecting the process of periodically updating the machinery and processes at the plant. Moreover, the single plant research design is silent on the issue of whether the technological changes experienced at the plant are typical of the changes experience at other plants in the industry, or represent an "upper bound". Finally, plant level case studies don't really tell us whether the employment changes observed at the plant are large enough to have an impact on the overall labor market. Put differently, even if we adopt the view that such change is pervasive and of recent origin, it would seem to require a great deal more data than is available to assess the importance of such change for the trends in the aggregate wage structure.

A related concern with a firm level case study is the potential selectivity of the firms that actually implement new technology. An interesting line of case study research (Maurice, Sellier and Silvestre 1984), for example, puts a great deal of emphasis on the question: why do firms adopt the technology that they do? In their comparison of petrochemical plants in Germany and France, Maurice et al. (1984) observe that although the menu of technological opportunities were the same for the French and German companies, and they were producing identical commodities, firms in the two countries had very different patterns of wage inequality. While it is impossible to do justice to the argument they make, they view the difference as partially attributable to differences in the structure of educational/skill inequality in the two countries generated by different historical traditions about investments in schooling and job specific skills.

Another compelling case study that supports a role for SBTC in the evolution of the structure of wages is the study by Autor, Levy and Murnane (2002). This study carefully describes the changes that occurred at "Cabot Bank" following the introduction of "check imaging" and Optical Character Recognition (OCR) equipment that photographed and read the amounts on checks written by the bank's customers. One feature that makes the case study particularly interesting is that "the technology and the organization of work had been remarkably stable before the changes . . . studied" Autor et al. (2002). Using an interpretative framework developed Autor, Levy and Murnane (2003), Autor et al. (2002) document that the changes were skill-biased, specifically that "the introduction of image processing and OCR software led to the replacement of high school graduates by computers in the deposit processing department, thereby increasing the share of bank employees who had more formal education."

Like Fernandez' study, the study is helpful in understanding how specific technological innovations lead to shifts in firm-level demand for different skill groups. Nevertheless, as in Fernandez' study, the interpretation of the timing of the investment by Cabot Bank is unclear. On one hand, Cabot Bank implemented the new technologies in the mid 1990s, about a decade after the most important rises in wage inequality in the overall labor market. On the other, OCR technology and the mechanical processing of checks are relatively old technologies.[18] Indeed, Autor et al. (2002) remark on Bank of America's introduction of Magnetic Ink Character Recognition as an early example of "computers substituting for human labor input." Thus, it is difficult to tell whether the new technology at Cabot Bank was part of a continuing stream of innovations in the banking industry that had been occurring for several decades, or a quantum leap forward that led to an acceleration in the trend in relative demand for different types of workers. When Bank of America launched ERMA (Electronic Recording Machine – Accounting) a press release noted that the new technology would allow 9 bookkeepers to do the work of 50.(Fisher and McKenney 1993).

II.B.ii The Limits of the Case Study Evidence

We have not enumerated many of the traditional critiques of case study evidence, in part because they are so well–understood. A core criticism is that a case study approach can never establish causality. [19] On the other hand, a weakness of the traditional labor economics focus on causality is that even when we have reliable estimates of the causal effect of a particular policy, we may have little understanding of why or how the policy works. In this light, a useful feature of case studies is that they can help provide insights into the mechanisms that actually relate technological choices to relative demand shifts.

A second core concern about case studies is generalizeability. There is no denying that workers in most industries perform different tasks than they did 50 or even 20 years ago – in many cases because the technologies they

[18]See Schantz (1982).

[19]See Shadish, Cook and Campbell (2002) for a discussion of what they label "intensive qualitative case studies." They conclude that "case studies are very relevant when causation is at most a minor issue."

use today did not exist. Nevertheless, Appelbaum, Bernhardt and Murnane, eds (2003) have argued that the effects of new technology are context specific, and highly dependent on factors like managerial discretion and product market competition. Consequently they conclude that "technology has had quite different effects on the tasks that workers perform and the skills required; in a surprising number of cases, there is little effect at all." In view of this conclusion, the evidence from individual case studies has to interpreted carefully, and balanced against other quantitative evidence on general trends in the market as a whole.

A final concern is that although recent case studies like Fernandez (2001) and Autor et al. (2002) provide compelling examples of the impacts of recent technological changes, there is no way to contrast these examples to the changes that were happening in earlier decades. Goldin (1998) provide evidence suggesting that the process of skill biased technological change dates back to at least the early part of the twentieth century. In light of that evidence, a persuasive case for the unusual role of skill biased technology in the 1980s and 1990s would seem to require a careful comparison of the impacts of new technology before 1980 to the impacts in the most recent decades.

III. Trade versus Technology, Trade and Technology, or Something Else?

So far we have focused our discussion on the potential effects of technological change on the labor market prospects for low-skilled workers. The leading alternative explanation for rising wage inequality and the fall in the real wages of low skilled workers in the 1980s is trade. Although a comprehensive review of trade theories is beyond the scope of this essay, some remarks on the interactions between trade and technology explanations are in order.

In common with technological explanations, the timing of changes in trade flows is not easy to reconcile with a large role for trade in explaining rising wage inequality. Although imports drew rapidly over the past decade, the big reduction in the absolute and relative wages of low-skilled workers occurred in the 1980s, during a period of only modest expansion of trade.[20]

[20]Imports as a fraction of GDP were 6.4% in 1979, 7.8% in 1985, 8.5% in 1990, 10.6% in 1995, 15.0% in 2000, and 15.9% in the last quarter of 2004 (Economic Report of the President, 2005, Table B-2).

Imports from India and China, which now attract widespread attention from academics and policy analysts, were at relatively low levels in the 1980s. Indeed, throughout the 1980s imports from Japan were routinely cited as a leading source of concern for U.S. policymakers.[21] As with technology, it is important to resist the temptation to explain trends in the 1980s with factors that only emerged in 1990s.

Although there is a substantial literature on the possible effects of trade on the absolute or relative wages of low-skilled workers in the U.S., a cursory read of the literature shows a remarkable level of **disagreement** over the actual impacts of trade. Bound and Johnson (1992), Borjas, Freeman and Katz (1992), Krugman (1993), Lawrence and Slaughter (1993), and Krugman (2000) argue that the quantitative impacts of trade are small. Other researchers, including Wood (1995), Borjas and Ramey (1995), Feenstra and Hanson (1996), Leamer (1998), have argued that the impacts are potentially larger.

As emphasized by Krugman (2000), a key reason for the disagreement is the absence of a credible and "model-free" research design for evaluating the impact of expanding imports. In absence of such a research design, there are significant disagreements between researchers over the correct model of world trade (Leamer 1998), the correct model of industry competition in developed economies (Borjas and Ramey 1995, Neary 2002), the correct model of the sources of expanding imports (for a clear statement of some of the alternatives see Krugman (2000)), and the correct model of intermediate versus finished goods imports (Feenstra and Hanson 1996) Most of the existing studies are accounting exercises that use a particular model to derive the fraction of the trend in the absolute or relative wages of low skilled U.S. workers that can be explained by expanding trade under the assumptions of the model and ignoring other potential explanations for the same facts.

Our reading of the literature is that trade–based explanations for rising wage inequality rely on "model based evidence" to an even greater extent than technological explanations. Not surprisingly, then, it is unclear whether the the central question 'Is it trade or technology?" can be resolved. What constitutes "evidence" on the role of technology under the assumptions of the highly simplified models used in the literature on SBTC is inadmissable as evidence when viewed through the lens of trade theoretic models.

[21] See for example Lincoln (1990), Lawrence (1993), and the set of papers in Krugman (1991).

To illustrate, consider the "model specific" approach to assessing the role of technology which we discussed in section II.A.. In this approach SBTC is defined as that part of the variation in relative wages left unexplained by changes in relative employment in a (country–specific) supply and demand model. Most of the existing studies of the effect of trade are based on variants of the Hecksher-Olin (HO) framework. According to this model, trade in goods or services provides a powerful force that tends to equalize wages of different skill groups across different countries. In its purest form, the HO model implies that the wage structure in any one country is *independent* of the relative supplies of different types of labor in that country. If one adopts the pure form of the HO model, however, the entire exercise of inferring technological change from the part of the covariation in relative wages and relative employment that cannot be explained by a (country-specific) demand-supply model is nonsensical. Put a different way, systematic variation between relative wages and relative employment within a country is a requirement for the usual SBTC explanation of widening wage inequality but constitutes evidence against the underlying modeling framework used by many trade economists.

Although the HO framework presents a logical challenge to the existing literature on technological change and wage inequality, the HO model is widely perceived as a failure in describing patterns of inter-country trade (see Neary (2002) for a recent evaluation). Even within the U.S., the HO model's key prediction –that differences in the relative supply of different skill groups will be absorbed by shifts in industry composition – is not very helpful in describing differences across local labor markets. As documented in Lewis (2003), Lewis (2004), Card and Lewis (2005), and Card (2005), for example, intercity differences in the relative supply of education groups are only weakly related to differences in the relative size of industries that use high or low skilled workers more or less intensively. Despite the absence of a correlation between relative wages of less-educated workers and their relative supply (a pattern that is consistent with the HO framework), differences in the relative supply of low-education labor are mainly absorbed by within-industry changes in dropout intensity.[22] This underscores a fundamental

[22]While much of the focus in the trade and wages literature is on the impacts of trade on U.S. workers, similar problems arise when considering the impact of trade with the United States on Canadian labor markets. Lemieux (2005b) tries to assess a weak version of "factor price equalization" following the passage of the North American Free Trade Act and finds that "there has been, if anything, a divergence between the wage structures

problem in evaluating trade-theoretic explanations for the fall in labor market prospects of low-skilled workers. If the basic predictions of the model are rejected within the U.S., it may be inappropriate to put a lot of weight on model-based empirical exercises that assume these predictions are true across countries.

IV. Concluding Remarks

Since the late 1980s, a consensus has emerged that the decline in real wages for low skilled workers in the early 1980s, and the subsequent slow recovery of these wage levels, is explained by skill biased technological change. In this essay we have argued that evidence underlying this consensus is remarkably frail. Much of the evidence takes the form of "proof by residual." After accounting for changes in relative supply, and (in some cases) a modest list of other factors, it is noted that the decline in relative wages of low skill labor remains unexplained. Skill biased technological change is then left as the only plausible explanation for the facts. Given the state of knowledge about how labor markets work, we find this line of argument unconvincing. Moreover, the evidence that emerges from such an exercise is highly model specific. Depending on how the data for different groups are organized, the degree of substitution that is allowed between workers of different genders or ages, and the list of other job characteristics are included in the decomposition, the results can suggest that rising inequality was a ubiquitous phenomenon affecting virtually all workers over the past three decades, or a trend that mainly affected young workers in the early 1980s.

While it seems quite possible that exogenous changes in technology are important factors in the evolution of wage inequality and the trend in wages for low skill workers, our judgment is that the evidence that has been assembled so far falls well short of the standard that labor economists have established in other areas. Moreover, despite an enormous effort involving multiple data sets and sophisticated analysis techniques, the literature has turned up surprisingly few insights into appropriate policy responses. Even if we could agree that technological change accounted for the relatively slow growth in real living standards for low skill workers in the U.S. over the past 30 years, "no technology" is hardly a meaningful option.

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in Canada and the U.S. over the last 20 years. In many cases, however, Canada–U.S. differences . . . are not large relative to regional [Canadian] differences in the wage structure.

Given the innumerable ways that the poor are disadvantaged in the United States, it seems that a continuing narrow focus on the role of technological change is misplaced, and that researchers interested in policy options for improving the fortunes of less skilled workers should look elsewhere. This would appear to be case whether one sees the future as a glass that is "half empty," with "technology tilt[ing] the playing field against less–educated workers" (Levy and Murnane 2004) or "half full" in the sense articulated by Murphy and Welch (2001) "that increase[s] in the disparity in incomes between those with more skills and those with less skills . . . represents a significant opportunity . . . to expand our nation's investments in skills and reap historically high rates of returns on those investments"

References

Acemoglu, Daron, "Technical Change, Inequality, and The Labor Market," *Journal of Economic Literature*, March 2002, *40*, 7–72.

Appelbaum, Eileen, Annette D. Bernhardt, and Richard J. Murnane, eds, *Low–Wage America: How Employers Are Reshaping Opportunity in the Workplace*, New York: Russell Sage Foundation Publications, September 2003.

Autor, David and Lawrence Katz, "Changes in the Wage Structure and Earnigns Inequality," in Orley Ashenfelter and David Card, eds., *Handbook of Labour Economics*, Vol. 3 of *Handbooks in Economics*, Amsterdam: North Holland, 2000, pp. 1463–1555.

Autor, David H., Frank Levy, and Richard J. Murnane, "Upstaris, Downstairs: Computer Skills on Two Floors of a Large Bank," *Industrial and Labor Relations Review*, April 2002, *55* (3), 432–447.

___ , ___ , and ___ , "The Skill Content of Recent Technological Change: An Empirical Exploration," *Quarterly Journal of Economics*, November 2003, *118* (4), 1279–1334.

___ , Lawrence F. Katz, and Melissa S. Kearney, "Trends in U.S. Wage Inequality: Re–Assessing the Revisionists," August 2004.

Beaudry, Paul and David A. Green, "Cohort patterns in Canadian earnings:assessing the role of skill premia in inequality trends," *Canadian Journal of Economics*, November 2000, *33* (4), 907.

___ and ___ , "Wages and Employment in the United States and Germany: What Explains the Differences?," *American Economic Review*, June 2003, *93* (3), 573–602.

___ and ___ , "Changes in US Wages 1976–2000: Ongoing Skill Bias or Major Technological Change," *Journal of Labor Economics*, Forthcoming 2005.

Becker, Gary S., "Woytinsky Lecture, University of Michigan, 1967," Reproduced in Human Capital, Second Edition 1975.

Berg, Maxine, *The Machinery Question and the Making of Political Economy, 1815–1848*, Cambridge, England: Cambridge University Press, 1984.

Bernstein, Jared and Lawrence Mishel, "Has Wage Inequality Stopped Growing?," *Monthly Labor Review*, December 1997, *120* (12), 3–16.

Berting, Jan, "Technological impacts on human rights: Models of development, science and technology, and human rights," in C. G. Weeramantry, ed., *The Impact of Technology on Human Rights: Global Case Studies*, Tokyo: United Nations University, 1993, chapter 1.

Borjas, George J. and Valerie A. Ramey, "Foreign Competition, Market Power, and Wage Inequality," *Quarterly Journal of Economics*, November 1995, *110* (4), 1075–1110.

Borjas, George, Richard Freeman, and Lawrence Katz, "On the Labor Market Effects of Immigration and Trade," in George Borjas and Richard Freeman, eds., *Immigration and the Workforce*, Chicago: University of Chicago Press, 1992.

Bound, John and George Johnson, "Changes in the Structure of Wages in the 1980s: An Evaluation of Alternative Explanations," *American Economic Review*, June 1992, *82*, 371–392.

Card, David, "Is the New Immigration So Bad?," Unpublished Working Paper, Center for Labor Economics, University of California – Berkeley January 2005.

____ **and Ethan Lewis**, "The Diffusion of Mexican Immigrants in the 1990s: Patterns and Impacts," Unpublished Working Paper, Center for Labor Economics, University of California – Berkeley January 2005.

____ **and John DiNardo**, "Skill Biased Technological Change and Rising Wage Inequality: Some Problems and Puzzles," NBER Working Paper 8769, National Bureau of Economic Research, Cambridge, MA February 2002.

____ **and Thomas Lemieux**, "Can Falling Supply Explain The Rising Return To College For Younger Men? A Cohort-Based Analysis," *Quarterly Journal of Economics*, May 2001, *116* (2), 705–746.

—, **Francis Kramarz, and Thomas Lemieux**, "Changes in the Relative Structure of Wages and Employment: A Comparison of the United States, Canada, and France," *Canadian Journal of Economics*, August 1999, *32* (4), 843–877.

Cohany, Sharon R., Anne E. Polivka, and Jennifer M. Rothgreb, "Revisions in the Current Population Survey Effective January 2004," Current Population Survey Technical Documentation CPS-94, Attachment 5, Bureau of the Census, Washington, D.C. 1994.

DiNardo, John, Nicole Fortin, and Thomas Lemieux, "Labor Market Institutions and The Distribution of Wages, 1973-1993: A Semi-Parametric Approach," *Econometrica*, September 1996, *64* (5), 1001–1045.

Feenstra, Robert C. and Gordon Hanson, "Foreign Investment, Outsourcing, and Relative Wages," in Robert C. Feenstra, Gene M. Grossman, and Douglas A. Irwin, eds., *The Political Economy of Trade Policy: Essays in Honor of Jagdish Bhagwati*, MIT Press Cambridge, MA 1996.

Fernandez, Roberto M., "Skill–Biased Technological Change and Wage Inequality: Evidence from a Plant Retooling," *American Journal of Sociology*, September 2001, *107* (2), 273–320.

Fisher, Amy Weaver and James L. McKenney, "The Development of the ERMA Banking System: Lessons from History," *IEEE Annals of the History of Computing*, 1993, *15* (1), 44–56.

Fortin, Nicole M. and Thomas Lemieux, "Institutional Changes and Rising Inequality: Is There a Linkage?," *Journal of Economic Perspectives*, Spring 1997, *11* (2), 75–96.

Freeman, Richard B., *The Overeducated American*, San Diego: Academic Press, 1976.

Goldin, Claudia and Robert Margo, "The Great Compression: The Wage Structure in the Unite d States at Mid-Century," *Quarterly Journal of Economics*, February 1992, *107* (1), 1–34.

Goldin, Claudia Dale, "The Origins Of Technology-Skill Complementarity," *Quarterly Journal of Economics*, August 1998, *113* (3), 693–732.

Goos, Maarten and Alan Manning, "Lousy and Lovely Jobs: The Rising Polarization of Work in Britain," LSE CEP Working Paper 604, London School of Economics December 2003.

Gottschalk, Peter, "Inequality, Income Growth, and Mobility: The basic facts," *Journal of Economic Perspectives*, Spring 1993, *11* (2), 21–40.

—— **and Timothy M. Smeeding**, "Cross-National Comparisons of Earnings and Income Inequ ality," *Journal of Economic Literature*, June 1997, *35* (2), 663–687.

Handel, Michael J., "Implications of Information Technology for Employment, Skills, and Wages: A Review of Recent Research," Final Report Project Number P10168, SRI International, Arlington, VA July 2003.

Heckman, James J., Lnace J. Lochner, and Petra E. Todd, "Fifty Years of Mincer Earnings Regressions," Working Paper 9732, National Bureau of Economic Research, Cambridge, MA May 2003.

Johnson, George, "Changes in Earnings Inequality: The role of demand shifts," *Journal of Economic Perspectives*, Spring 1993, *11* (2), 21–40.

Juhn, Chinhui, Kevin M. Murphy, and Brooks Pierce, "Wage Inequality and the Rise in the Returns to Skill," *Journal of Political Economy*, June 1993, *101* (3), 410–442.

Katz, Lawrence and Kevin Murphy, "Changes in Relative Wages, 1963-1987 – Supply and Demand Factors," *Quarterly Journal of Economics*, February 1992, *107* (1), 35–78.

Krueger, Alan, "How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984–1989," *Quarterly Review of Economics*, February 1993, *108*, 33–60.

Krugman, Paul R., *Trade with Japan: Has the Door Opened Wider?*, Chicago: University of Chicago Press, 1991.

—— , "International Trade and American Wages in the 1980s: Giant Sucking Sound or Small Hickup?," *Brookings Papers on Economic Activity: Microeconomics*, 1993, pp. 161–210.

——, "Technology, Trade, and Factor Prices," *Journal of International Economics*, February 2000, *50* (1), 51–71.

Lawrence, Robert Z., "Japan's Different Trade Regime: An Analysis with Particular Reference to Keiretsu," *Journal of Economic Perspectives*, Spring 1993, *7*, 3–19.

—— **and Matthew J. Slaughter**, "International Trade and American Wages in the 1980s: Giant Sucking Sound or Small Hickup?," *Brookings Papers on Economic Activity: Microeconomics*, 1993, pp. 161–210.

Leamer, Edward J., "In Search of Stoper Samuelson Linkages between International Trade and Lower Wages," in Susan M. Collins, ed., *Imports, Exports and the American Worker*, Brookings Institution BI Press Washington D.C. 1998, pp. 141–202.

Lee, David S., "Wage inequality in the United States during the 1980s: Rising dispersion or falling minimum wage?," *Quarterly Journal of Economics*, August 1999, *114* (3), 977–1023.

Lemieux, Thomas, "Increasing Residual Wage Inequality: Composition Effects, Noisy Data or Rising Demand for Skills?," Unpublished Working Paper, University of British Columbia, Vancouver, BC May 2004.

——, "The Mincer Equation Thirty Years after *Schooling, Experience, and Earnings*," in S. Grossbard-Shechtman, ed., *Jacob Mincer, A Pioneer of Modern Labor Economics*, Heidelberg: Springer Verlag, 2005.

——, "Trade Liberalization and the Labour Market," in Thomas Lemieux and Richard G. Harris, eds., *Social and Labour Market Aspects of North American Linkages*, Calgary: University of Calgary Press, Forthcoming 2005.

Lerman, Robert I., "Reassessing trends in U.S. Earnings Inequality?," *Monthly Labor Review*, December 1997, *120* (12), 17–25.

Levy, Frank and Richard J. Murnane, *The New Division of Labor: How Computers Are Creating the Next Job Market*, Princeton, New Jersey: Princeton University Press, 2004.

—— **and Richard Murnane**, "U.S. Earnings Levels and Earnings Inequality: A Review of Recent Trends and Proposed Explanations," *Journal of Economic Literature*, September 1992, *30*, 1331–81.

Lewis, Ethan, "Local, Open Economies Within the U.S.: How Do Industries Respond to Immigration?," Working Paper 04–1, Federal Reserve Bank of Philadelphia, Philadelphia, PA 3 December 2003.

—— , "How Did the Miami Labor Market Absorb the Mariel Immigrants?," Working Paper 04–3, Federal Reserve Bank of Philadelphia, Philadelphia, PA 12 January 2004.

Lincoln, Edward, *Japan's Unequal Trade*, Washington D.C.: Brookings Institution, 1990.

Machin, Stephen, "Wage Inequality in the U.K.," *Oxford Review of Economic Policy*, 1996, *12* (1), 47–64.

Manning, Alan, "We Can Work it Out: The Impact of Technological Change on the Demand for Low–Skill Workers," *Scottish Journal of Political Economy*, November 2004, *51* (5), 581–608.

Mark, Jerome A., "Technological Change and Employment: Some Results from BLS Research," *Monthly Labor Review*, April 1987, *110* (4), 26–29.

Maurice, Marc, Francois Sellier, and Jean-Jacques Silvestre, "The Search for A Societal Effect in the Production of Company Heirarchy: A Comparison of France and Germany," in Paul Osterman, ed., *Internal Labor Markets*, Cambridge, MA: MIT Press, 1984.

Mincer, Jacob, *Schooling, Experience, and Earnings*, New York: National Bureau of Economic Research, 1974.

—— , "Changes in Wage Inequality, 1970–1990," *Research in Labor Economics*, 1997, *16*, 1–18.

Mishel, Lawrence, Jared Bernstein, and Heather Boushey, *The State of Working America: 2002-03*, Ithaca: ILR Press, 2002.

Murphy, Kevin and Finis Welch, "Wage Differentials in the 1990s: Is the Glass Half-Full or Half-Empty?," in Finis Welch, ed., *The Causes* *and Consequences of Increasing Inequality*, Vol. 2 of *Bush School Series in the Economics of Public Policy* Texas A & M University University of Chicago Press Chicago Spring 2001, pp. 360–390.

Neary, J. Peter, "Competition, Trade and Wages," in David Greenaway, Richard Upward, and Katharine Wakelin, eds., *Trade, Investment, Migration and Labour Market Adjustment*, International Economic Association Palgrave Macmillan Basingstroke September 2002, pp. 28–46.

Nickell, Stephen and Brian Bell, "Changes in the Distribution of Wages and Unemployment in OECD Countries," *American Economic Review*, May 1996, *86* (2), 302–308.

Noble, David, *Forces of production. A social history of industrial automation.*, New York: Knopf, 1984.

Polivka, Anne E., "Data Watch: The Redesigned Current Population Survey," *Journal of Economic Perspectives*, Summer 1996, *10* (3), 169–180.

—— **and Jennifer Rothgeb**, "Overhauling the Current Population Survey: Redesigning the Questionnaire," *Monthly Labor Review*, September 1993, pp. 10–28.

Schantz, Herbert F., *The History of OCR: Optical Character Recognition*, Manchester Center, Vt.: Recognition Technologies Users Association, 1982.

Shadish, William R., Thomas D. Cook, and Donald T. Campbell, *Experimental and Quasi–Experimental Designs for Generalized Causal Inference*, Boston: Houghton Mifflin Company, 2002.

Sutz, Judith, "Inequality and University Research Agendas in Latin America," *Science, Technology, and Human Values*, 2003, *28* (1), 52–68.

Topel, Robert, "Factor proportions and relative wages: The supply–side determinants of wage inequality," *Journal of Economic Perspectives*, Spring 1993, *11* (2), 21–40.

Wood, Adrian, "How Trade Hurt Unskilled Workers," *Journal of Economic Perspectives*, 1995, *9*, 57–64.

Woodward, Joan, *Industrial Organization: theory and practice*, first ed., London: Oxford University Press, 1965.