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Special Issue: *The Effects of Technology and Innovation on Firm Performance, Employment, and Wages*

Bronwyn H. Hall and Francis Kramarz, editors

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Effects of Technology and Innovation on Firm Performance, Employment, and Wages: Introduction

Bronwyn H. Hall and Francis Kramarz

The papers in this issue and the subsequent two issues of EINT were selected from those presented at an international conference on the effects of technology and innovation on firm performance and employment held in Washington, DC, in May 1995, at the National Academy of Sciences. Although the studies are drawn from many different countries, they are united by a common theme and the use of similar methodology and data. Taking advantage of the large micro datasets on firms and their workers that are now available in many countries, they report a series of findings about the consequences of technical change for enterprises and their employees during the recent past.

It is a truism that the last fifteen or so years have seen an apparent increase in the pace of technological innovation (particularly that driven by evolutions in micro-processor technology) in modern industrial firms throughout much of the world and that this change has been accompanied by perceived increases in job insecurity, restructuring of enterprises, and unemployment in many countries. The conference at which earlier versions of these papers were presented was motivated by a desire to document and understand the facts about the association between innovation and the adoption of new technologies by focusing on their effects on both firms and workers at the microeconomic level.

The studies use data from a large range of developed countries, from the G-7 (United States, United

Kingdom, France, Germany, Japan, and Italy) to smaller economies such as Australia, Sweden, Norway, the Netherlands, Taiwan, and Israel. The technology indicators used are R&D investment and the adoption of advanced manufacturing technology for the most part, with a few authors using innovation and patent counts or measures of organizational innovation. The output measures are employment, job creation and destruction, wages, profits, and productivity measures. This issue of the journal includes papers that focus on the consequences of new technology for workers, while the subsequent two issues will contain papers that study the impact of innovation on the productivity and profitability of firms; several of the papers evaluate the effects on both firms and workers.

The first five articles in this special volume examine questions raised by Krueger's (1993) seminal article in which the author demonstrated that computer users were better paid (all things being equal) than non-users. This "fact" has sometimes been used as the main proof of the existence of skill technical bias in modern-day industrial economies. However, as was noted in Krueger's original paper, there are at least two possible explanations for this finding. In the first explanation, that favored by Krueger, workers using computers receive higher compensation because computers make them more productive. The second explanation of higher pay for computer use is simply that it is correlated with unobservable worker characteristics that generate high wages (higher ability, reliability, better knowledge of foreign languages, flexibility, and trainability, etc.). Unfortunately, disentangling these two explanations requires panel data on the same employee at different points in time, which is not currently widely available in many countries.

Some of the articles in this issue directly address this point, although they typically use data on a range of new technologies rather than simply computer use. First, all papers document that workers in developed countries other than the United States (from which Krueger's evidence was drawn) who use new technologies are generally better paid than non-users in the cross-section dimension. To show this, Hildreth, and Entorf and Kramarz use individual level data matched to firm-level data while Chennels and Van Reenen, and Siegel use firm (or establishment)-level information. Hildreth focuses on firm-level correlates of higher pay after the introduction of new technology because he has matched worker-firm data, but only for a single cross-section in time. For each establishment, two workers are interviewed (a new hire and a more tenured worker). This allows him to delve deeper into the factors that might explain higher pay of new technology workers. His investigations lead him to favor rent-sharing by the firm since he finds that rent-sharing is strongest for establishments investing in new process technology. This result holds even when he controls for unobserved differences across establishments (using the fact that he observes more than one worker per establishment) or when he controls for feedback effects from wages to profits using instrumental variable methods.

Also using British plant-level data, this time with no information at the individual worker level but at two different dates, Chennels and Van Reenen demonstrate that plants that use new technologies more heavily pay higher wages. More precisely, they show that unobservable factors in plants are associated with higher probabilities of new technology and higher pay. Then they focus on the endogeneity of the choice of implementing new techniques. That is, does new technology cause higher pay or does higher pay facilitate implementation of new techniques? Their answer is very clear: the second explanation is correct and the first one spurious. Firms with better workers (high unobserved average quality of the workforce) tend to implement modern machines more frequently.

The same type of question is posed by Entorf and Kramarz, and a similar answer is given. Entorf and Kramarz use the 1987 supplement of the French labor force survey. For all workers, information is collected on technology use at that date as well as retrospective information on technology introduction. The data is a panel with information available for the same workers in 1985 and 1986. Thus it becomes possible to perform wage regressions controlling both for individual worker effects and for unobserved differences across the employing firms. As in other countries, they find that new technology workers are compensated more highly than other workers in France. However, they also show that these workers were already better paid before using new technologies. Thus their conclusion is similar in spirit to Chennels and Van Reenen's: the introduction of new machines does not cause wages to rise by very much, but workers (and firms) who use modern techniques are more able (have unobservable characteristics that are more highly rewarded) than non-users. Note that this result, although not that favored by Krueger, is also found by Doms, Dunne and Troske (1997) and Di Nardo and Pischke (1997), although neither of these two sets of authors have precisely the data which allows for control of unobserved worker and firm characteristics completely. Entorf, Gollac and Kramarz (1996) come closer to the using adequate data (using the 1993 supplement of the survey used by Entorf and Kramarz) and obtain the same answer as Entorf and Kramarz. However, wage inequality in France has increased less during this period than in the United States and United

Kingdom, so that the possibility remains that the absence of wage effects when computers are introduced may only be due to the French wage-setting institutions. It would be desirable to pursue this question further as worker-establishment datasets become more widely available.

Siegel takes a slightly different approach to measuring the existence of skill-bias technical change: using detailed labor force composition data drawn from a survey of U.S. manufacturers located in Long Island, New York, and a model that incorporates both the adoption decision and the employment decision, he finds that firms adopting technology tend to reduce their employment overall while shifting their labor force toward more highly skilled workers. In his case, changes in cost shares of skilled workers tend to track the changes in numbers, which suggests that the wages of skilled workers do not rise. Adoption itself tends to increase with both R&D intensity and size of the adopting firm. The latter result is expected if there are fixed costs of adoption but the former implies that use of new technology requires in-house technical competence as well.

The remaining papers in this issue focus on the employment effects of innovation, with often conflicting results. Blanchflower and Burgess (Britain and Australia), Pacelli, Rapiti, and Revelli (Italy), and Regev (Israel) find a positive correlation between firm-level employment growth and indicators of innovative activity, while Klette and Forre (Norway), in common with Siegel (United States) find that slight evidence that adopting new technologies or being an R&D firm is associated with declines in employment. When comparing these results, it is useful to keep in mind that the authors use a variety of indicators for "innovativeness": Blanchflower and Burgess, and Siegel focus on the technology adoption decision, Pacelli et al use spending per employee on R&D and innovative capital investment in the industry to which the firm belongs, and Regev uses a composite technology index composed of measures of labor quality, capital equipment vintage (which is related to adoption of new technology), R&D spending per employee, and the share of R&D employees as a proxy for innovativeness. Klette and Forre use R&D intensity and presence in a high technology industry as indicators of the innovativeness of Norwegian establishments; neither of these appears to be associated with net job creation, and in fact, R&D firms create fewer jobs than non-R&D firms in the later part of their period (the last ten years). They also find that there is a higher turnover of jobs in these firms; this result is echoed by Boeri and Bellman using German data and the use of advanced technology as an indicator of innovativeness.

Some of the differences in results among these papers can be attributed to differences in methodology and the choice of technology indicator. For example, Blanchflower and Burgess examine the impact of the introduction of new technology on employment growth and profitability in Britain and Australia in the 1990s and find some evidence that the introduction of new technology is associated with higher employment growth, at least in larger establishments. Because of the nature of the survey with which they are working in Britain, they are able to distinguish between effects associated with new technology and those associated with organizational changes. They find that the introduction of new technology is followed by employment growth for both manual and non-manual workers in British establishments by about 3 percent per annum, while introducing new work practices or organization lowers job growth by 2-3 percent per annum. The fact that both changes often go hand in hand may explain why their results on job growth are somewhat different from Siegel's; note that the negative effect is concentrated among manual rather than non-manual workers, which is consistent with Siegel's results. It may be necessary to qualify their conclusion that job growth and new technology are complements and not substitutes slightly: skilled jobs and new technology are complements while unskilled jobs and new technology may be substitutes. This is not a new finding (for example, see Griliches 1969 and Bound and Johnson 1992), but it is helpful to find confirming evidence using microeconomic data from a variety of industrialized countries.

As the preceding papers have shown, innovation and the adoption of new technologies and even methods of organizing work have indirect consequences for workers in the affected firms, both in their current jobs (via wages and the probability of continued employment) and in potential future jobs (through shifts in demand toward skilled labor and the ease with which they will find a new job on separation). However, in most industrial economies, the motivation behind the decision to innovate is more directly related to the expected effects on the profitability and productivity of the innovating firm. Some of the papers in this issue (e.g., Regev, Hildreth) touch on this topic, and the papers from this conference that appear in the subsequent two issues of this volume focus directly on firm-level outcomes of the innovation process.

Bartelsman, van Leeuwen and Nieuwenhuijsen study the adoption of advanced manufacturing technology (AMT) and its effects on employment and productivity in Dutch firms. Like Siegel, they find that AMT adoption rates rise with firm size, and also with the capital-labor ratio. Firms that use

AMT have higher average 6-year growth rates of both total factor productivity and employment. McGuckin, Streitwieser, and Doms perform a similar analysis for United States establishments. Because of the longitudinal nature of their adoption data, they are able to study the adoption process in somewhat more detail, documenting its variation across technologies, and the fact that adoption of a particular technique is not necessarily an absorbing process for a plant. In a slightly different conclusion from Bartelsman et al, they find that establishments using advanced technologies exhibit higher productivity levels, but that the causality is likely to run both from technology to productivity growth, and also from productivity growth to the use of advanced technology.

Using a unique data set that matches the functioning of workers within the firm with characteristics of the firm, Greenan and Guellec examine the correlation between firm organization, as represented by the level of communication within and outside the firm and the level of technical and hierarchical constraints on workers with the technological performance of the firm. They find that the “flatter” organizational form, with more communication and less hierarchy is positively correlated with the technological skill level of both the workers and the firm. The consequences of these changes for productivity are somewhat ambiguous: although firms undergoing organizational innovations involving high levels of communication on the shop floor, heavy technical constraints on workers, and changes in capital equipment (such as might happen with the installation of a lean production system) have higher associated productivity growth, when the innovation was “global,” that is, it involved new and innovative products as well, and perhaps more autonomous workers, the productivity effects were not detectable. Given the nature of product innovations and the failure of most price indices to adjust for quality change, this result is perhaps not that surprising. A firm that is undergoing a radical restructuring in output markets as well as internally might not be expected to exhibit productivity growth as conventionally measured.

Motohashi also investigates the correlation between the innovative strategies of over 10,000 Japanese manufacturing firms and their productivity performance. He finds that R&D is more skewed toward larger firms in Japan than in the United States, but that patents per R&D dollar are higher for smaller firms. However, he points out that as in U.S. data (see Bound et al 1984), this result is suspect because of the inherent selectivity in sampling smaller firms for R&D spending and the prevalence of informal R&D arrangements in smaller firms. Although total factor productivity at the firm level is correlated with indicators for R&D and patents used or invented, even controlling for industry, especially for food, drug, machinery, electrical machinery and electronics firms, the conventional production function methodology (using the logarithm of R&D to explain productivity) yields insignificant (or negative) results. It is important to note that because R&D is included in the other inputs to the production function also, this finding implies only that there is no additional return to R&D beyond that expected from spending of other types.

Crepon, Duguet, and Mairesse use data on French firms to address a similar set of questions as Motohashi, but with a simultaneous equation model that integrates the processes generating innovation output from R&D and productivity from innovation output, and controls for the measurement problems induced by the fact that not all firms do R&D and for the fact that the innovation output measures are counts (patents) or qualitative measures (innovation sales). They find rough proportionality between size, R&D, and innovation output. The latter result implies that including observations with zero R&D spending and/or zero patent counts while controlling for the selectivity of R&D reverses the findings of Motohashi and Bound et al that smaller firms have a higher patent productivity. They also find that productivity at the firm level is positively correlated with innovation output measures such as patents and the shares of sales due to innovative products as well as with the innovation input measure, R&D capital. This finding remains even when they control for capital intensity and skill differences and particularly when they use an econometric estimation method that corrects for the inherent selectivity in innovation data (not all firms do or report either R&D or patents).

Several papers in this volume document the export orientation of R&D-intensive firms, especially in small developed economies. For example, Regev finds that technology-intensive firms in Israel are more involved in external trade and show net job creation. Uniquely among the authors in this volume, Aw and Batra explore the use of frontier production function techniques to estimate the relationship between investments in technology, firm efficiency or productivity, and participation in export markets. Their technology variables are the usual R&D spending variable plus the expenditure on "know-how," that is, expenditures on foreign technology licenses, experimental equipment, travel costs for personnel, and books. They find that these two variables are highly correlated and essentially measure the same thing, the technological orientation of the firm, and they correlate them with measures of technical efficiency obtained by frontier techniques. When they classify firms into high technology and other using these variables, they obtain the rather interesting result that technical efficiencies are the same for large, high technology firms whether or not they export, but that exporters are more efficient than non-exporters among the group of small firms with no technology investment. That is, the high technology firms behave as though they are on the same frontier whether or not they export, whereas low technology firms have two efficiency frontiers, with the one for exporting firms outside that for firms that only sell in the domestic market.

In the recent past there has been a tendency toward internationalization of the R&D done by industrial firms. The reasons for this trend are of particular importance to small R&D-intensive countries. From the perspective of the individual country, it can be good news, reflecting the successful expansion of their multinational corporations into other countries. Alternatively, it can imply either that they are increasingly forced to perform R&D in the large economies because of scale advantages or that these economies are becoming more technically advanced so that it is necessary to do R&D in them in order to stay on the technological frontier by capturing spillovers. In the latter case, the small countries such as Switzerland, the Netherlands, and the Scandinavian countries that have specialized in R&D-intensive industries in spite of their size will find themselves slipping behind technologically as innovative activity is concentrated in large economies.

In his paper, Andersson looks at the determinants of the share of R&D performed in foreign countries for firms in a small R&D-intensive economy, namely Sweden. He considers three determinants of changes in this share: a desire to reduce the costs of transferring technology to production units in foreign countries, an increase in intra-firm trade across foreign boundaries, and technical progress within the firm; he finds that reducing transfer costs of technology and a general increase in R&D intensity are better predictors of the internationalization of R&D than indicators of increased vertical or horizontal integration. By examining the behavior of individual foreign affiliates, he is able to reject explanations that rely on a general tendency of R&D to concentrate in large host countries (such as the U.S. or Japan), or on a shift in the mode of expansion from "greenfield" foreign direct investment to acquisition of ongoing firms. The conclusion is that foreign R&D is more likely to be a substitute than a complement for domestic R&D, and that there is no reason to think that the trend toward internationalization necessarily disfavors a small economy such as Sweden's.

Pulling together the results from these sixteen papers is a daunting task. Although the questions are addressed are quite similar, each of the analyses is unique, reflecting to a great extent the particular policy concerns of the country in question (e.g., exports and internationalization in small open economies like Taiwan and Sweden, unions and work councils in countries where labor institutions are strong like Australia and Germany) and contains a rich set of results that are only touched on in this introduction. However, a few stylized facts about the impact of technical change emerge that are common across several countries.

First and foremost, innovative firms, whether R&D-doing, or simply adopting new advanced manufacturing techniques, shift the composition of their labor force toward more skilled labor and frequently, but not always, increase overall employment as well. In general, it is difficult to ascertain the causality of the latter result: in many cases it may be that firms that are growing for other reasons have incentives to undertake R&D and technology adoption.

Second, the shift toward more skilled labor has often been accompanied by higher wages for skilled labor, although direct causality between use of technology and higher wages at the individual level is difficult to prove. The picture that emerges is one where innovative firms are the ones that are growing, they tend to be more skilled-labor-intensive, and they also tend to have workers that are more able to begin with (after controlling for very rough skill classifications) and that command higher wages. The end result is a positive correlation between growth, innovation intensity, skill intensity, and workers' wages, but without a simple causal mechanism connecting them.

Third, technological innovation and organizational innovation do seem to be followed by increases in productivity in most countries, although there are some exceptions, partly due to lagged response and the difficulty of measuring productivity in a world with rapid technical change. As in the case of technology adoption and wage/employment effects, there is a strong correlation between productivity and advanced technology use, but it is much harder to find concrete evidence of AMT adoption *causing* productivity growth. That is, good performers adopt advanced manufacturing technology, but the consequences are difficult to trace, probably because they take some time to appear, and because they are accompanied by many other changes such as increases in the capital-labor ratio that confound attempts to isolate their effects on total factor productivity in the short term.

Finally, after reviewing the evidence from the 12 economies studied in these papers, the reader may be struck by the fact that in spite of the use of quite different data sources and methods, it is often the case that when one is able to compare the results, they are remarkably similar across countries. The impacts of new technologies on firms and workers is fundamentally a global phenomenon that operates in a similar manner in different countries. Were we to produce an agenda for future work in this area, we would suggest a series of studies using some of the same data that were more directly comparable in methodology and analysis in order to verify this observation and obtain estimates of the relevant coefficients whose magnitudes can be directly compared.

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