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INTERNATIONAL DIFFERENCES IN THE ADOPTION AND IMPACT OF NEW INFORMATION TECHNOLOGIES AND NEW HR PRACTICES: THE VALVE-MAKING INDUSTRY IN THE U.S. AND U.K.

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ABSTRACT

This paper compares the impact of new IT-enhanced technology on the efficiency of production in the U.S. and the U.K. for one manufacturing industry, valve manufacturing. There is a long-standing question of whether technological change and organizational changes have the same rates of adoption and impact internationally. We have assembled a unique dataset on plants in one narrowly defined industry -- valve manufacturing -- in both the U.S. and U.K to consider whether plants outside of the U.S. gain as much from IT as U.S. plants. We find that, despite differences in the current and historical patterns of institutions in the U.S. and U.K., both countries exhibit comparable patterns of gains to IT at the plant level. The impact of new IT-enhanced technology on the efficiency of production is virtually identical in the two countries. In addition, as a result of the adoption of the new technology, plants in both countries have shifted production to customized products. Finally, we find that, in both countries, the adoption of the new IT-enhanced technology coincides with increases in the skill requirements of machine operators, notably technical and problem-solving skills, and with the adoption of new human resource practices to support these skills.

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I. Introduction

There is now a well-developed body of macroeconomic evidence that information technology (IT) investments are likely to have 'paid-off' with higher levels of productivity growth in industries that invested more heavily in IT in recent years.[1] In our own work (Bartel, Ichniowski and Shaw, 2007) we have provided evidence that documents that plants that adopt new IT are in fact the same ones that increase the customization and reliability of their products and the speed and efficiency of their operations, thereby providing an explanation of what lies behind the macro-level trends. Other researchers have also provided micro-level evidence on the relationship between IT and productivity.[2] An important question is whether plants outside of the U.S. gain as much from IT as U.S. plants. This paper contributes to that literature by providing comparative evidence on the adoption rates and impact of new information technologies (and related HR practices) in the valve industry in the U.S. and U.K. [3]

The microeconomic evidence in this paper is based on data obtained from plant visits and our own detailed survey of plants in the valve-making industry in the U.S. and U.K. By using our own personally designed survey we are uniquely able to identify precise ways in which firms have both adopted and benefited from the investments in IT. Ours is the first study to have detailed microeconomic evidence linking IT, HR, productivity and skill demand for plants in the same industry in two different countries. Our data enable us to address the following questions: Have valve-making plants in the U.S. and U.K. adopted new IT and new HR practices at the same rate? What has been the impact of new IT and new HR on productivity in the two

[1] See Jorgenson, Ho and Stiroh (2003) and Oliner and Sichel (2000).
[2] See Bloom and Van Reenen (2007), Brynjolfsson and Hitt (2000), Athey and Stern (2002) and Hubbard (2003).
[3] See Bloom and Van Reenen (2007) for broader firm-level evidence on the impact and adoption of management practices in which they show differences across the U.S. and U.K.

countries? Has the adoption of new IT influenced skill demand and has this impact differed in the U.S. and U.K.?

Our main findings can be summarized as follows. The plants in the U.K. and U.S. are not identical in their characteristics: the U.K. plants are more unionized, smaller and thus have fewer advanced machines, sell more to wholesalers and less directly to a primary customer. However, in the five years that we follow these plants (1997-2002), they have moved in virtually identical directions, as is evident in the means of the variables and the regression results. We find the following results:

1. While U.S. valve-makers adopted CNC technology earlier than plants in the U.K., by 2002, U.K. plants were just as likely to be using CNC technology as their U.S. counterparts. Over the last five years, in both countries there was pronounced growth in IT technology, new HR practices, and increased skill demand. There has also been nearly identical and substantial increases in the efficiency of production and the customization of the products.
2. The impact of CNC technology on the efficiency of production is virtually identical in the two countries; plants in both countries have experienced reductions in setup times, run times and inspection times as a result of the new information technologies.
3. As a result of the adoption of new IT-enhanced equipment, plants in both countries have shifted production to customized products.
4. In both countries, there is a positive correlation between the adoption of new IT and the adoption of new HR practices.
5. The adoption of new computer-based IT increases the technical and problem-solving skill requirements of workers in both countries and this effect is stronger in the U.K.

These findings lead us to conclude that even though the U.K. has a different history of labor market institutions, small valve-making firms are operating in much the same way in the U.K. as in the U.S. This suggests that plants in both countries have been responsive to similar market pressures following a decline in the price of computerization.

The paper is organized as follows. Section II describes the valve-making production process and the data that we collected in our survey of the industry. Section III compares the adoption rates of new IT and HR practices in the U.S. and U.K. and recent trends in the efficiency of production in the two countries. Sections IV through VI present econometric evidence on the relationship of new IT investments to process efficiency, product innovation, worker skills and employment practices in the U.S. and U.K. Section VII concludes.

II. Survey Data on the Valve-Making Industry in the U.S. and U.K.

In this section, we provide background on the valve-making industry and describe the findings from plant visits that proved critical to the design of an accurate industry survey.[4]

A. *The Production Process and Information Technologies in Valve Manufacturing*

A valve is a metal device attached to pipes to regulate the flow of liquids or gases – such as the flow of natural gas in a heating system, or the control of liquids in a chemical factory. Valves can be a commodity product – as when they control the flow of air in standard air conditioners – or they can be a highly customized product – as when they are built to order for a new chemical plant or a submarine. The production process in valve making is a machining

[4] See Bartel, Ichniowski and Shaw (2004) for a discussion of methods to use for assembling detailed organization-level data.

operation.[5] A simple valve is made by taking a steel block or pipe and completing several processes on one or more machines; such as, etching grooves at each end for screwing the valve to pipes; boring holes at different spots to attach control devices; and making and attaching various devices that control the flow.

IT and Capital Machinery. Thirty years ago, the reshaping of the steel pipe or block would be done on a work bench by a highly skilled machinist using manual tools. Today, much of valve making is highly automated with new computer-based IT features embedded directly in valve making equipment. The central piece of equipment in the valve making production process is a *computer numerically controlled (CNC) machine* that lines up the block on the pallet of the machine and automatically drills and chips in the proper places based on directions entered into the machine's operating software.[6] CNC machines are now in widespread use in the industry, as will be shown in our data below.

As information processing technologies improve, greater computing power is embedded directly into newer CNC machines, computing power that can reduce setup-time substantially and to a lesser extent reduce runtime. Because the computing power is intangible (or embedded in the capital), only descriptive field research can reveal the source of the IT gains. Therefore, we offer numerous examples to explain the IT gains.

The key IT element of the CNC machine is in the CNC *controller*, or box that controls the machine, and thus is most able to reduce the setup-time. The controller tells the machine exactly what to do to make each particular valve – where to cut, how deep, the angle of the cut, the diameter, how many times to cut, how to move the steel to re-cut, etc. Improvements in

[5] Other processes are welding and assembly of multiple machined parts and final packaging and shipping.
[6] CNC machines were predated by numerically controlled (NC) machines in which fixed computer programs for a given run, originally input on tape, controlled the action of machines during that run. Manual, NC, and CNC machines of different vintages all still exist in the industry, but sophisticated CNC are now dominant.

software go hand-in-hand with setup time reduction. More precisely, after 1998, CNC were equipped with 'fusion control' that is much easier to program and much easier for operators to understand (more 'conversational') and this control technology 'became standard in 2003' for new vintage CNC machines.[7] While the 'computerization' in the CNC label began when the CNC machines were introduced in the 1970s, at that time the CNC was controlled by computer tapes that were programmed off-line by computer programmers and fed to the machine for the operator to run. Today, the 'computers' in the CNC machines are controlled and programmed by the operators, and are dramatically faster and cheaper.

The computerization of the CNC has also reduced the run-time of the machines when they are doing the cutting and drilling, though to a lesser extent than setup reduction (since runtime is ultimately limited by how fast you can cut steel). The cost reduction for controllers has enabled CNC to add 'axis' capabilities: a 5-axis CNC machine tool can drill holes into a valve at several different angles (or axes) while a 3-axis CNC machine tool would require the valve to be manually repositioned within the machine tool for each new drill angle. Thus, computerization has directly enabled the machine to increase the number of axes on which it can operate, and this has directly reduced the run-time (and setup-time) and increased the flexibility of the machine. There have also been advances in the IT component of CNC controllers that allow the controller to use its computing resources more efficiently. An example is "curve interpolation," which allows CNC machine tools to create smooth curves on a valve instead of having to approximate curves using a large number of linear cuts. This reduces the software program size, which decreases the amount of memory needed to perform a given task, thus lowering setup-time and run-time.

[7] As stated by the chief operating officer of a plant that we visited.

Overall, increases in computing power improved the capabilities of CNC machines considerably. Operators can now program a modern CNC machine more easily through much simpler software interfaces, and each machine can now perform a much wider variety of tasks on the block of steel. *Most important for our empirical work below, plant managers and engineers demonstrated how investing in technologically more capable CNC machines leads to a reduction in the number of CNC machines needed to produce a given product.* For example, in 1980 a typical product at one plant required seven machines; by 2002 that same product would be made on two more advanced CNC machines. The only way that the same product can be produced on fewer machines is if the quality of the CNC has improved through the purchase of new CNC machines that are IT intensive. Thus, when the number of CNC machines falls over time, CNC quality must be rising (according to our experts).

A second technology, *flexible manufacturing systems* (FMS), coordinates machining operations across different CNC machines. To implement FMS, a separate computer is installed and hooked up to the control boxes on the CNC machines so that the FMS system can control the coordination of the production tasks across different CNC machines. By coordinating across machines, it clearly reduces setup-time – setup instructions are given directly to the machines it is coordinating when the production of a valve requires multiple machines. FMS also does a better job of optimizing which part of the valve should be produced on which CNC machine. In addition, FMS also reduces runtime. The FMS also typically monitors the machine tools themselves (that are in the CNC) using its centralized data. The coordination process reduces the number of tool changes that are required as it allocates jobs across CNC machines, and it reduces the cost of calibrating each cutting step, which increases cutting accuracy and speed and thus reduces run-time.[8]

Finally, plant tours and interviews identified new IT-based advances that have reduced the time it takes to inspect valves in the quality control process. Each dimension of a complicated valve often must be produced to an accuracy rate of 1/1000 of an inch, so inspection is a critical part of the production process. For many years, inspection was done with hand-measuring devices, which was very time-consuming. Over the last several years, *automated inspection* machines have been introduced which use a laser probe technology, so that the operator touches each surface (interior, exterior, holes, etc.) of the valve with a probe that develops a three-dimensional picture and measures all dimensions and automatically compares measurements to the desired specifications.[9]

Another technology that is becoming more common in valve making plants is *three-dimensional computer-aided-design* (3D-CAD). This is a constantly advancing IT method for turning customers' valve specifications into a specific design, thereby reducing the time that elapses from order placement to design presentation to the customer.

Thus, during our site visits and interviews, managers routinely identified as important sources of improved operational efficiency one or more of the following three specific technologies – advances in the capabilities of the CNC machines themselves through the use of more advanced controllers; flexible manufacturing systems (FMS) that coordinate the operations of multiple machines; and new automated inspection equipment. All three technological

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[8] Note also that plants that implement FMS are also likely to put higher quality control boxes on their CNC machines, which reduces setup time and runtime and will show up in our regressions as a return to FMS.

[9] The most recent inspection technology, which became available in 2004, now enables the inspection to be done without any human contact; the inspection machine surrounds the valve and operates the probe to measure its features and check them against required specifications.

advances are a direct result of improvements in microprocessor, storage, and software computer technologies.

Production Efficiency Gains and Product Customization. Many of those interviewed during our plant visits underscored two key operational imperatives for remaining competitive in this industry. First, production efficiency gains are important since many plants can make a wide variety of customer orders. In describing the computer-based technology above, we have identified the three primary elements that cause production efficiencies by reducing production times in machining a valve: the *setup-time* of a machine, or the time it takes to program the machine so that it will perform the right combination of tasks to produce the specified valve; the *run-time* of the machine to complete the machining of each unit of valve; and the *inspection time* to verify the quality of the valve.[10] Second, managers also observed that their plants were increasingly relying on a strategy of customizing their production to meet customer needs. Production of commodity valves is increasingly moving abroad to low wage countries. Therefore, many U.S. valve makers are increasing the number of customized products they produce and are relying less on selling directly from their catalogs. IT advances play a critical role in the move to product customization. More sophisticated controllers will not only reduce the cost of customizing products, but technologies that reduce setup-times will also increase the speed and reduce the cost of making changeovers between product runs.

The plant visits and interviews with experienced industry practitioners help identify concrete examples of new IT-based equipment, and identify what parts of the overall machining process these IT advances would impact. To examine the impacts of IT investments on performance more broadly throughout the entire industry, we developed a customized survey for valve plants. This survey measures process improvements in each of the three production stages,

[10] When reductions in these times are achieved with the same or fewer workers, productivity also rises.

product improvements and increasing customization of valves, and investments in new IT-enhanced production machinery. The survey also asks for information on worker skills and HRM practices.

B. Survey of the Valve-Making Industry

The Sample of Valve Industry Plants. Using the insights from our field research, we designed, pre-tested, and conducted a customized industry survey in 2002.[11] To identify the population of U.S. valve-making plants for this survey, we collected contact information from Survey Sampling, Inc. for any plant in a valve-making industry class (SICs 3491, 3492, 3494, and 3593) with more than 20 employees. Of a potential universe of 416 valve making plants in the U.S., 212 plants, or 51%, provided responses to the survey questions described in this section via telephone interviews.[12] In the U.K., there was a potential universe of 120 valve-making plants of which 46% responded resulting in a sample of 55 plants. Empirical results in the study are based on the responses from the 212 valve-making plants in the U.S. and the 55 valve-making plants in the U.K.

Production Efficiency Measures. Efficiency gains in machining processes are *product-specific* measures. We asked each respondent to look up data for "the product you have produced the most over the last five years" for the following key indicators of production efficiency:

Setup-Time: About how much setup-time does (did) it take to produce one unit of this product today (and in 1997)?

[11] The Office for Survey Research at the Institute for Public Policy and Social Research at Michigan State University conducted the pre-tests and final surveys by telephone from July 31, 2002 through March 30, 2003. Interviews lasted an average of 20 minutes with an average of 7.6 phone contacts needed to complete the survey.

[12] Of 762 plants that Survey Sampling Inc. lists in the four valve-making SIC classifications, 200 were determined to have no production and another 70 were no longer in business. Assuming a similar rate of survey ineligibility for other plant names that could not be contacted yields the number of 416 valve-making plants.

Run Time: *About how much run time does (did) it take to produce one unit of this product today (and in 1997)?*

Inspection Time: *About how long does (did) it take to inspect one unit of this product today (and in 1997)?*

Product Customization Measures. Increases in customization imply changes in the number of products a plant makes, so these measures are *plant-specific* measures. To measure whether plants had increased customization of their products, the survey asks the following question:

Percent Catalog: *In 2002 (1997), what percent of your customer orders are directly from your catalog with no design change?* Although the response rate for 1997 was only 33% for this question, virtually all the plants were able to answer a companion question that indicated whether the percent catalog increased, decreased or stayed the same between 1997 and 2002

Information Technology Measures. To measure investments in new IT, the survey asks the following questions:

Number of Machines: *In order to produce one unit of this product today (and in 1997) how many machines do (did) you employ?*

New CNC Machines: *How many CNC machines does the plant have and how many are less than 5 years old (newcnc), 5 to 10 years old, and more than 10 years old?*

Flexible Manufacturing Systems (FMS): *Does the plant have FMS technology (where two or more machines are controlled by computers) and what was the year of adoption?*

Automatic Inspection Sensors (Auto Sensors): *Does the plant have automated inspection sensor equipment and what was the year of adoption?*

<u>*Three Dimensional CAD software*</u>*: Does the plant use three-dimensional CAD software for designing new products and in what year was this software first used?*

The first IT question above concerning "number of machines" is a *product-specific* question, and pertains to the plant's main valve product over the last five years. The other IT questions are *plant-specific* questions.

Human Resource Management Practices: To measure the use of various human resource management practices at the plant, the survey asks the following questions:

Basic Training: Does your plant provide formal training in basic reading and/or math skills and in what year was this introduced?

Technical Training: Does your plant provide formal training in technical skills and in what year was this introduced?

Formal Meetings: Do you have meetings with shopfloor workers to discuss the shop's performance and in what year was this introduced?

Teams: Do you have problem-solving teams for shop floor workers and when was this introduced?

Incentive Pay: Do you have a formal incentive pay plan for your machine operators or do you give occasional special bonuses and when was this introduced?

Skill Requirements: To measure how the demand for various skills has changed over time, the survey asks whether a particular skill's importance increased between 1997 and 2002. Data on five types of skills were collected: math skills, computer skills, skills for programming machine operations, problem-solving skills, and engineering cutting tool knowledge.

III. Trends in IT Investments, Work Organization and Productivity in the Valve-Making Industry

Before turning to the trends in the adoption of new technologies and work practices, we look first at the conditions in the plants in the U.K. versus the U.S. Tables 1 and 2 show means for descriptive variables, and indicate when the mean values for the U.K. differ from those of the U.S.

There are some significant differences between the plants in the two countries. In the U.K., the plants are smaller, more likely to be unionized, and appear to have lower skill requirements. Although the mean of the plants (based on the year the plant opened) are similar across countries, the U..K. has some much older plants.

Their product mix is also different: the U.K. firms produce more for an intended final customer ('customer"=1) and less for wholesalers and distributions. As a result, the U.K. firms had fewer of their products ordered from their catalog ("percent of products ordered from catalog) – 46% versus 61% for the U.K. versus the U.S. Yet despite these differences, the same trends apply: in both countries, there was an equal move towards greater product customization ('Percent catalog down") as described below. And both countries have key customers that dominate their sales: percent of revenue from one customer is 26 to 27% in both countries, and from top four customers, it is 47 to 48% (where customers can be wholesalers or distributors).

A. The Adoption of Information Technologies

Figure 1 shows the adoption rates of the four types of IT-enabled equipment in valve-making plants in the U.S. and U.K. between 1980 and 2002. In the case of CNC machines, we see that in the U.S. the highest rates of adoption for the plant's first CNC machines occurred during the 1980's, but throughout the 1990s, plants invested heavily in new CNC machines--74 percent of plants purchased new CNC machines from 1997-2002 (see Figure 2). Plants in the U.K. adopted CNC machines somewhat later than U.S. plants; whereas in 1990, 66 percent of the U.S. plants had CNC machines, only 44% of the U.K. plants had this technology. The first half of the 1990s was a catch-up period for the U.K. plants, so that by 1995, 71% of the U.K. plants were using CNC machines compared to 78% of their U.S. counterparts. And, like the U.S. plants, the U.K. plants invested heavily in new CNC machines from 1997-2002; 63% of U.K. plants purchased new CNC machines from 1997-2002 compared to 74% of the U.S. plants (see Figure 2). In both countries, investments in other new computer-based technologies – in automated inspection sensors, flexible manufacturing systems and 3D-CAD – show the largest growth after 1995. The adoption rates for the time period 1997 through 2002 (the years for which we measure production times) are shown in Figure 2. In both countries, there was significant adoption of these new technologies during the 1997-2002 time period. There are two interesting differences in the current usage of these technologies. By 2002, U.K. plants were significantly more likely to have adopted automated inspection sensors than U.S. plants (44% compared to 28%) while U.S. plants were significantly more likely to have adopted 3D CAD than U.K. plants (73% compared to 62%).

As discussed in section II, bringing new more advanced CNC machines on line results in a reduction of the number of CNC machines it takes to produce a given product. On average, in the U.S. it took 19 percent fewer machines to produce a given valve product in 2002 compared to 1997 while in the U.K. the number of machines needed to produce a given valve product fell by 24 percent between 1997 and 2002.

B. The Adoption of New HRM Practices

Figure 3 shows that the use of teams, training programs and bonus/incentive pay plans all increased substantially in both countries since 1980 with the highest rates of adoption of these practices occurring after 1990. Figure 4 shows adoption rates for the 1997-2002 time period. Valve plants in both countries increasingly adopted new training programs and more team-based methods of job design, and more meetings with operators. Direct incentive pay plans, excluding bonus payments, are less common than the other HRM practices.[13]

C. Trends in Measures of Production Efficiency

Table 1 shows that plants in both countries realized large declines in production times at each stage of production when making their most common product. Total production time for the most common product fell by about 50 percent between 1997 and 2002 in both countries. Setup time fell by a larger percentage in the U.S. than in the U.K. while inspection time fell by a larger percentage in the U.K. than in the U.S.

D. Summary

The patterns in Figures 1-4 show that in both the U.S. and the U.K. the 1990's in the valve industry is a decade marked by rapid adoption of new machinery that incorporates many IT-based technological improvements and a growing reliance on new methods of work organization. While these trends demonstrate that production efficiency gains and product customization increases are happening at the same time that the industry is investing in new IT-enhanced machinery and new HRM practices, the empirical work to follow examines whether the improvements in various aspects of machining times or increases in customization over this

[13] Interviews suggested that direct incentive pay is difficult to adopt in an industry that makes customized products. The increase in the use of incentive pay is smaller than the increase in other HRM practices in the valve industry. By 2002, incentive pay is used by 31% of plants and special bonuses by 36% of plants, so about 50% of plants have one or the other (see Table 1), but interviews suggest that these incentives are a very small percent of total pay and are used rather erratically. As a result, we do not focus on the incentive pay plans in our HR analysis below.

period are concentrated in those plants that have made investments in these new technologies and work practices.

IV. The Impact of IT and HRM on Productivity at the Product Level

We estimate the following first difference productivity models in which time-based efficiency measures are expressed as a function of the adoption of new machining technologies and new HRM practices to see if production efficiency gains occur in those plants that adopt new technologies or work practices.

$$(1)\ \Delta \ln(\text{ProductionTime}) = a + \mathbf{b_1\Delta\ (NewTechnology)} + \mathbf{b_2\Delta(NewTechnology)^*\ UK} + \mathbf{b_3\Delta\ (NewHRM)} + \mathbf{b_4\ UK} + \mathbf{b_5 X} + e_1$$

The dependent variable in (1) is the log change in Production Time between 1997 and 2002 – where Production Time refers to setup-time, run time and inspection time *for a given product*. The vector **Δ(NewTechnology)** measures the 1997-2002 adoption of new technologies expected to reduce these machining times – the adoption of higher-quality CNC machines (as measured by the change in the number of CNC machines needed to produce the plant's main product), FMS, and automated inspection sensors. The vector **Δ(NewHRM)** measures the 1997-2002 adoption of new HRM practices, such as work teams and training programs, and **X** is a vector of controls including the age of the plant, union status, and plant size measured as number of workers to test whether the change in production efficiency is affected by these additional factors. To test for differences in the effects of new IT between the U.S. and U.K., the vector **Δ(NewTechnology)** is interacted with a dummy for U.K. plants. The U.K. dummy is also entered separately in the regression.

The results in Table 3 demonstrate that investments in new IT-machinery have improved production efficiency by reducing all components of production times. The results are remarkably straightforward and striking: the adoption of new CNC technologies reduces production times significantly. The variable "Increase CNC Quality" is defined as the reduction in the number of CNC machines used to produce the product (using the survey variable defined above, "in order to produce one unit of this product today (and in 1997) how many machines do (did) you employ."[14] The adoption of higher-quality CNC machines reduces setup-time (column 1-2) and runtime (columns 3-4). Inspection time declines with the introduction of new automated inspection sensors (column 5). The U.K. dummy, as well as the UK-interactions with CNC-quality and other technology variables (which are not shown in the table), are all insignificant.

The insignificance of the differences in the U.K. and U.S. could simply arise because the of the small sample size of the U.K. data which falls to 39 plants in the regressions using production data. However, if the production regressions are run for just the U.K. sample, the results are the same as in the entire sample for the setuptime and runtime regressions.. On just these observations, in the setuptime regression, the coefficient on "increase CNC Quality" is -.63 (t-statistic=-10.3), and in the runtime regression, the coefficient is -.35 (t-statistic=-1.60) for the median regressions. In contrast, while the dummy for the presence of automatic inspection sensors has a negative coefficient in the inspection time equation, the coefficient is not significantly different from zero.for the U.K. sample.

[14] Our measure of the increase in CNC quality (number of machines down) is significantly correlated with a dummy variable that indicates whether the plant bought a new CNC machine since 1997.

B. The Impact of HRM Practices on Product-Level Efficiency Measures

According to the results in Table 3, in both the U.S. and the U.K., plants that introduce technical training programs also realize an additional reduction in setup and run times. While these efficiency regressions find no effects of teams, it is important to remember that we are modeling the efficiency gains over time for one specific product, not the overall efficiency of the plant. Teams may be less likely to have a direct effect on product efficiency as compared to overall plant efficiency.

V. The Impact of IT on Customization in the Valve-Making Industry

In addition to reducing production times, new IT is also valuable because it allows plants to design and make new valves that are more complex. These effects of new IT are not captured in any estimated reduction in the time it currently takes to produce the plant's single most common valve product. In this section, we analyze the effect of IT-enhanced equipment on increased product customization. The extent to which a plant customizes its products is measured in our survey with questions on the percent of the plant's output that is ordered directly from their catalog. Because many respondents did not report a 1997 value of this variable, we measure the changes in customization of production in a plant between 1997 and 2002 with the related survey question that asks whether the percent of output from the catalog increased, decreased or stayed the same over this period which was answered by nearly all respondents. The dummy variable for an increase in product customization (percent catalog down) equals one if the plant reports that the percentage of output ordered from their catalog fell between 1997 and 2002. Twenty-five percent of the U.S. plants and twenty-seven percent of the U.K. plants reported that their percentage of output ordered from their catalog fell during this period.

The IT measures that are most likely to facilitate a move towards customization are 3D-CAD and new CNC machines. The former reduces the time it takes to translate a customer's specifications into an actual product design thereby making it easier for the plant to produce products that are not in its catalog. Since new CNC machines reduce setup-time, this should also make it easier for the plant to accept orders for custom products. The results in Table 4 show that in both countries the introduction of 3D-Cad and the purchase of a new CNC machine are both associated with an increase in product customization, as reflected in the decline in the percentage of orders directly from the plant's catalog. The results do not reveal any differences between the U.S. and U.K. firms in the effects of new CNC or 3D-Cad technology on customization. In particular, the U.K. dummy in line 1 of Table 4 is always insignificantly different from zero as are the U.K.-technology interaction terms (not shown in the table.) An unexpected result in Table 4 is the negative and significant coefficient on the introduction of flexible manufacturing systems which would not be expected to have an effect on product customization.[15]

When we again look only at the U.K. sub-sample of 50 plants for the customization regressions, the basic results hold, but the impacts of new technology on customization are less significant. The coefficients on the technology variables are still negative but the t-statistics are insignificant..

[15] In considering this result, it is worth noting that the results in Table 3 concerning the adoption of FMS adoption on setuptime are insignificant. In contrast, all model specifications show setup times declining after plants begin using higher-quality CNC machines. If FMS adoption does not reduce setup times as new CNC machines do, then the theoretical reason to expect that FMS adoption would lead to an increase in customization is less clear. While this can explain why FMS would not have a positive and significant effect in Table 4, it cannot explain why the coefficient is negative.

VI. The Impact of the Adoption of New HRM Practices and the Demand for Worker Skills

In this section, we examine whether the adoption of new IT is correlated with the adoption of new human resource management (HRM) practices, and whether IT raises the demand for skills. An increase in IT would increase the use of innovative HRM practices, such as team-production, if IT requires more problem solving by operators.[16] And as with any IT adoption, the demand for skills could rise or fall. The demand for skills could rise for either of two reasons. First, the use of more sophisticated machines could increase the level of skills required, as it increases the demand for computer skills or programming skills, and possibly problem-solving skills. Second, it could increase skill demand indirectly. On our plant visits, we heard that there are two types of operators—those who program and those who simply run machines but have less knowledge of the machining operations. If the new machines require fewer simple operators, overall skill demand will increase. On the other hand, we also heard stories of substitution effects – that computers on CNC machines now solve machining problems so well that the need for creative knowledge of tools and machining has decreased.

Regarding skill demand, in Table 5, we present regressions in which the dependent variable equals one if the plant reported that a particular skill's importance increased between 1997 and 2002. We collected data on five types of skill increases: math skills, computer skills, skills for programming machine operations, problem-solving skills, and engineering knowledge.

In both the U.S. and the U.K., there is a substantial increase in the demand for computer skills, programming skills, problem-solving skills, and engineering skills when the plant increases its IT use (columns 2-5). That is, the purchase of a new CNC machine is correlated with the plant's response that they increased the demand for these skills. Moreover, in the U.K,

[16] Bresnahan, Brynolfsson, and Hitt (2002); Autor, Levy, and Murnane (2003); Boning, Ichniowski, and Shaw (2001).

increased IT adoption in CNC machines had an even greater effect on the increase in demand for computer skills and programming skills than in the U.S. (row 3 columns 2 and 3). Moreover, on average, the U.K. plants did not increase their skill demand as much as the U.S. plants unless they increased their IT use: the U.K. dummy variables are negative for several skills.[17] Our finding that the introduction of IT increases the demand for certain types of worker skills provides an interesting counterpoint to Doms, Dunne and Troske (1997). In their study, the cross-sectional correlation between worker skill (as measured by the non-production worker share and the average wage) and technology adoption disappeared in a longitudinal analysis.

These results show that the effect of new CNC technology on increased importance of certain skills is more pronounced in the U.K. than in the U.S. Consistent with this pattern, when we restrict the analysis to the U.K. plants only, the CNC variable remains large and significant in the computer, programming, and engineering skill regressions.

Note that if we look back at our variable means in Table 2, the U.K. started at lower educational demand levels than the U.S. – they had few educational requirements. However, 44 percent of the U.K. firms said they increased their educational requirements from 1997 to 2002, whereas in the U.S., only 22 percent of the firms increased their educational requirements. Virtually all U.S. firms required a high school degree or more but 32 percent of U.K. firms said they had no educational requirements. Looking at the training sources in Table 2, virtually all firms offer technical training, and half of all firms send workers to local schools for updated training.

[17] The same is true for cutting-tool knowledge—U.K. plants that did not adopt IT did not increase their demand for skills.

Turning to HRM practices, in the U.S. the purchase of new CNC machines with imbedded IT is correlated with new HR practices (Table 6). The sample size for the U.K. firms falls too much for us to check for significant differences between the countries.

In sum, we find that there is an increase in the demand for skills when there is an increase in information technologies, where the skill needs are for both increased computer skills and increased mechanical machining knowledge to complement them. This would be in keeping with the rising demand for skills in the U.S. economy: even within narrowly defined occupations, wage inequality has risen, and the demand for cognitive skills has risen.[18] Moreover, there is also an increase in the demand for innovative HRM practices – including training and team-work – when there is an increase in computerization.[19]

VI. Conclusion

We pose the following three questions. Is there international micro-economic evidence that information technologies have increased productivity at the firm level? If so, what is the mechanism for increased performance? And finally, has IT increased skill demand or the demand for more innovative human resource management practices, like training or teamwork?

We find that, despite differences in the current and historical patterns of institutions in the U.K. and U.S., both countries exhibit comparable patterns of gains to IT at the plant level. Using very detailed data on the valve-making industry, we show that investments in IT that are embedded in the production process do yield increases in productivity. However, new IT investments also introduce a new strategic focus, moving to produce the products that are more

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[18] Katz and Autor (1999), Autor, Levy, and Murnane (2003).

[19] Interviews during plant visits indicated that the use of teamwork (and not IT investments themselves) made problem-solving skills more important. Consistent with this claim, an increase in the importance of problem-solving skills is correlated with the introduction of teams (correlation = 0.14, significant at 5% level), but teams were also fairly widespread prior to 1997 (35% had teams).

customized, given the greater ease of designing and producing custom-designed products. Thus, the performance of the firm is enhanced due to both new strategies and higher levels of productivity. This is true for the U.K. as well as the U.S., and our trends show that plants in both countries substantially increased their use of new IT-based technologies. Finally, those plants that purchase more IT-embedded capital also are more likely to increase their demand for technical and problem-solving skills.

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Figure 1
Proportion of Plants with Computer-Aided Production Technologies (UK v. US)

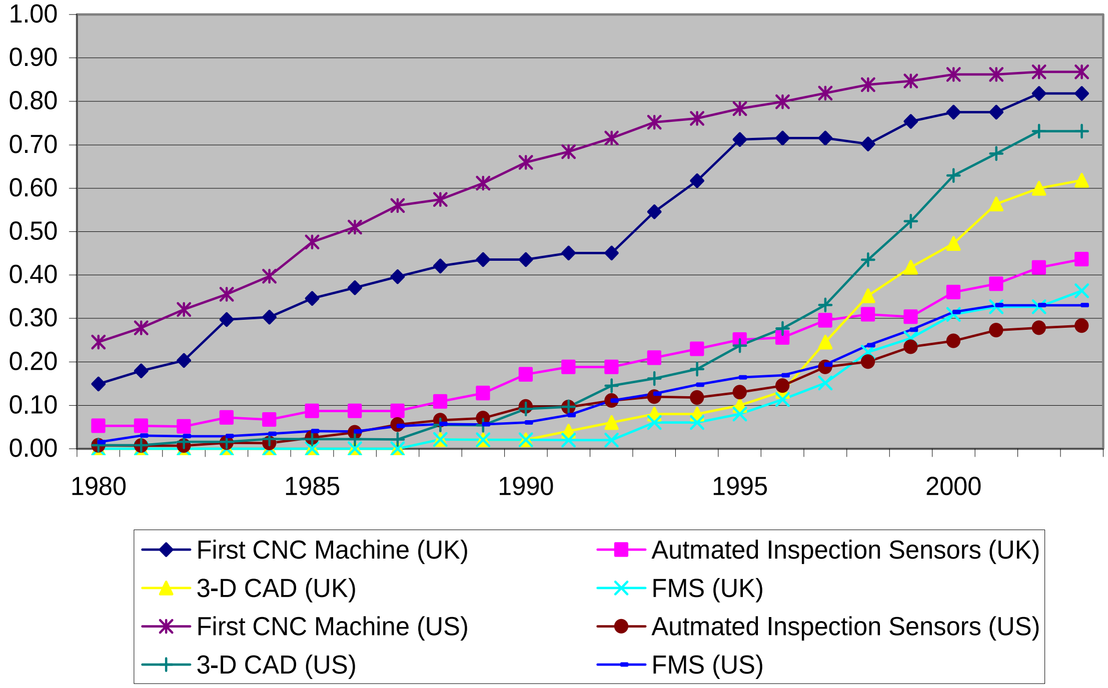
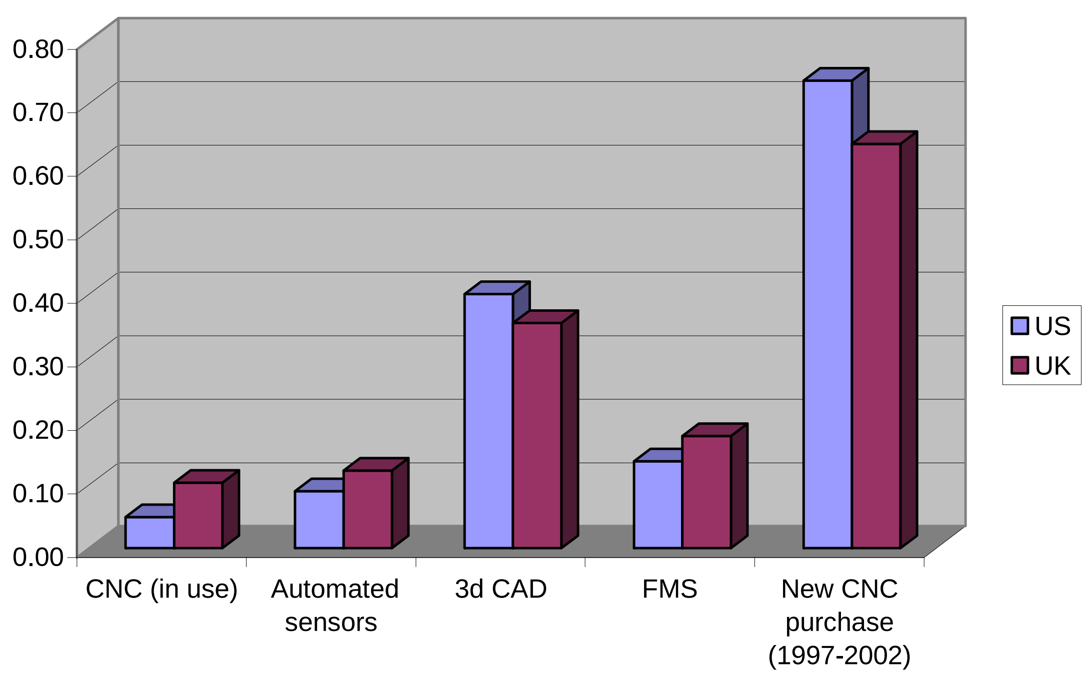


Figure 2
Fraction of observations adopting equipment between 1997 & 2002



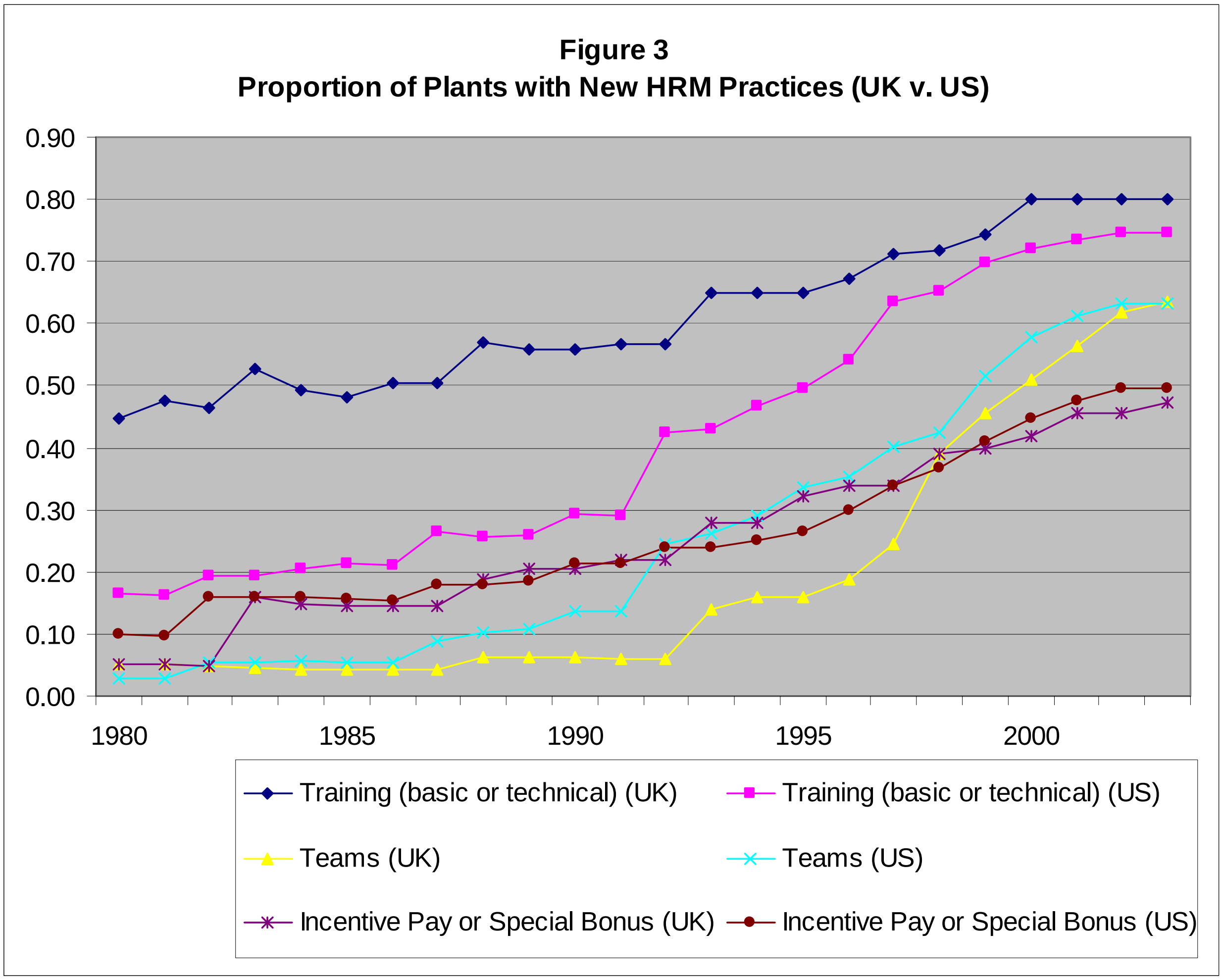


Figure 3
Proportion of Plants with New HRM Practices (UK v. US)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1980
1985
1990
1995
2000
Training (basic or technical) (UK)
Training (basic or technical) (US)
Teams (UK)
Teams (US)
Incentive Pay or Special Bonus (UK)
Incentive Pay or Special Bonus (US)

Figure 4
Fraction of observations adopting HRM practices between 1997 & 2002

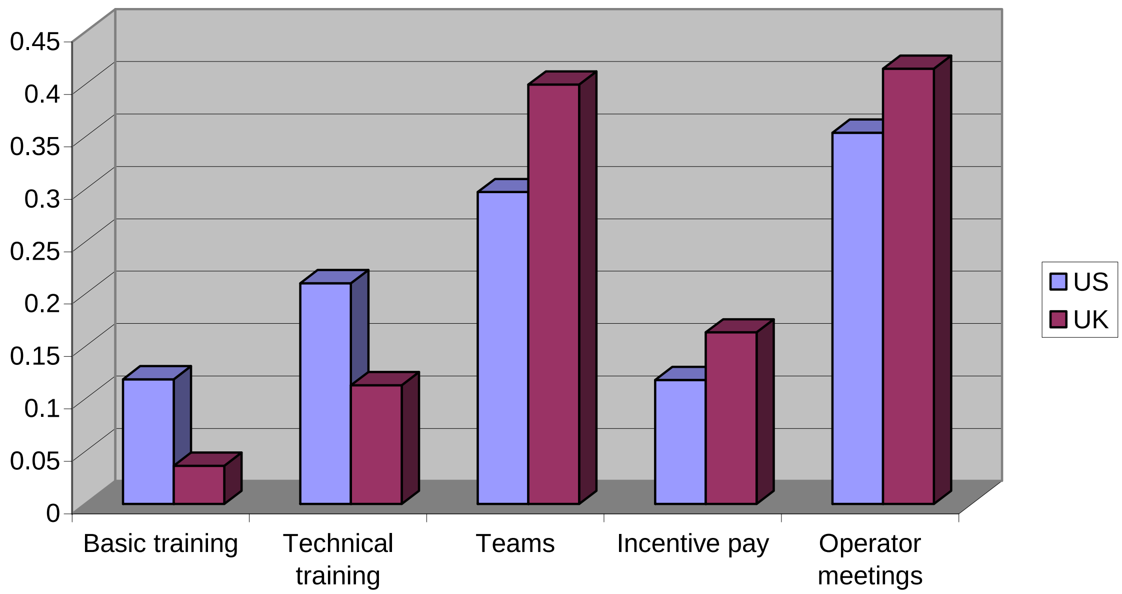


Table 1: Variable Means

	UK	US
Number Shop employees, 2002 (Standard Deviation) [min, max]	74** (111) [20, 300]	96 (94) [8 ,490]
Number Shop employees, 1997 (Standard Deviation) [min, max]	100 (171) [2, 1000}	106 (103) [7, 550]
Year Plant was Opened (Standard Deviation) [min, max]	1959 (40) [1798, 1999]	1968 (22) [1900, 2000]
Number CNC operators, 2002 (Standard Deviation) [min, max]	14** (16) [1, 80]	25 (36) [0, 300]
Number CNC operators, 1997 (Standard Deviation) [min, max]	10 (9) [1, 40]	19 (24) [0, 100]
Number CNC machines (Standard Deviation) [min, max]	10** (13) [0, 70]	15 (17) [0, 100]
Number conventional machines (Standard Deviation) [min, max]	22 (23) [0, 100]	25 (23) [0, 100]
Percent Unionized	33**	21
New CNC	0.63**	0.74
New Flexible Manuf. System	0.25**	0.15
New automated sensors	0.18	0.14
New 3-D CAD	0.49**	0.39
Setup time (hours), 2002	2.0+	1.50+
Setup time (hours), 1997	3.0+	3.00+
Runtime (hours), 2002	0.42+	0.17+
Runtime (hours), 1997	0.50+	0.25+
Inspect time (hours), 2002	0.08+	0.14+
Inspect time (hours), 1997	0.1+	0.17+
Percent of products ordered from catalog (PCT CAT)	46**	61
Percent catalog up	16	13
Percent catalog down	27	24

+ Median values ** UK different from US at 5 percent or higher . The sample size for most variables is 212 for the U.S. and 55 for the U.K.

Table 2
Variable Means: Skills and Products

	UK	US
Educational Requirements Up since 1997	0.44***	0.22
Minimum education required for CNC operators (dummy response)		
High school	0.07***	0.71
Technical school	0.07	0.04
Apprenticeship	0.09	0.05
None	0.32***	0.09
Training sources (dummy variable responses yes=1)		
Government-sponsored training	0.35***	0.24
Vendor	0.78	0.80
Firm-basic	0.18***	0.33
Firm-technical	0.80	0.75
Firm-local schools	0.50	0.50
Type of customer for key product		2
(dummy variables) Customer	0.35***	0.22
Wholesaler	0.04***	0.18
Distributor	0.11***	0.18
Mixture	0.50	0.42
Percent of revenue		
From primary customer	27%	26%
From top 4 customers	47%	48%
Competition		
Number of competitors (s.d.)	21 (43)	21 (60)
Number of competitors-up	0.22	0.33
Number of competitors-down	0.44***	0.29

*** UK different from US at 5 percent or higher
The sample size for most variables is 212 for the U.S. and 55 for the U.K.

Table 3
The Effects of IT and HRM on Production Efficiency, 1997-2002[a]
Dependent Variables: Product –Specific Production Times

Dependent Variable:	Percentage Change in Setup-Time	Percentage Change in Setup-Time	Percentage Change in Runtime	Percentage Change in Runtime	Percentage Change in Inspection Time
	(OLS)	(Median Regression)	(OLS)	(Median Regression)	(OLS)
UK Dummy	0.095 (0.155)	-0.029 (0.113)	0.039 (0.161)	0.009 (0.094)	0.097 (0.191)
Log (Change in "CNC Quality")[b]	-0.651*** (0.249)	-0.659*** (0.099)	-0.406* (0.153)	-0.404*** (0.078)	-0.180 (0.178)
Adopted Flexible Manuf. System	-0.018 (0.177)	-0.148 (0.113)	-0.037 (0.206)	-0.080 (0.092)	0.165 (0.205)
Adopted Automated Inspection Sensors	-0.172 (0.208)	-0.132 (0.136)	0.062 (0.214)	0.025 (0.111)	-0.610** (0.332)
Adopted Technical Training	-0.387*** (0.177)	-0.385*** (0.122)	-0.391*** (0.166)	-0.345*** (0.097)	-0.191 (0.280)
Adopted Teams	0.204 (0.162)	-0.014 (0.099)	0.050 (0.168)	0.058 (0.085)	-0.243 (0.255)
Observations	185	185	177	177	192
R^2/Pseudo R^2	0.13	0.12	0.14	0.14	0.07

Huber-White robust standard errors in parentheses.

* significant at 10%; ** significant at 5%; ***significant at 1%

[a] All regressions include controls for age of plants (five age dummies), number of shopfloor workers, a dummy for unionization, and two dummy variables indicating whether the number of competitors that produce a product that competes with the firm's main product went up or down.

[b] Log (Change in "CNC quality") is measured by the percentage decrease in the number of CNC machines used to produce the plant's main product; or, log(# of CNCs used to produce the main product in 2002) – log (# of CNC's used to produce the main product in 1997). A decrease in the number of CNC machines used to produce a given product indicates an increase in the quality of the CNC machines being used. See Section IV of text for explanation.

Table 4

The Effects of IT on Change in Product Customization, 1997-2002[a]

	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Dependent Variable:	Percent Catalog Up[b]	Percent Catalog Down[b]	Percent Catalog Up[b]	Percent Catalog Down[b]	Percent Catalog Up[b]	Percent Catalog Down[b]	Percent Catalog Up[b]	Percent Catalog Down[b]
UK Dummy	0.427 (0.489)	0.334 (0.404)	0.414 (0.487)	0.158 (0.402)	0.372 (0.493)	0.453 (0.412)	0.525 (0.504)	0.614 (0.433)
Bought New CNC Machine	0.558 (0.469)	0.795** (0.409)					0.617 (0.477)	0.989*** (0.441)
Adopted 3D-CAD			-0.332 (0.435)	0.660** (0.334)			-0.251 (0.442)	0.738*** (0.353)
Adopted Flexible Manufacturing System					0.046 (0.511)	-1.630*** (0.596)	0.031 (0.525)	-1.610*** (0.598)
Adopted Automated Inspection Sensors							-0.888 (0.720)	-0.525 (0.504)
Observations	233		233		233		233	
Pseudo R-squared	0.075		0.077		0.088		0.119	

Huber-White robust standard errors in parentheses. *Significant at 10%; ** Significant at 5%; *** Significant at 1%

[a] Each pair of columns reports estimated coefficients from one multinomial logit model. Regressions include interactions between the technology variables and the U.K. dummy, controls for age of plants (five age dummies), number of shopfloor workers, and dummy for unionization

[b] The dependent variable has 3 categories: the *percent catalog down* category includes plants that report that the percentage of customer orders that were valves in the product catalog with no modifications went down between 1997 and 2002; the percent catalog up category includes plants that report that this percentage went up between 1997 and 2002; and the (omitted) category includes plants that reported that this percentage was unchanged between 1997 and 2002. The percent catalog up (down) category identifies plants with decreases (increases) in customized production over this five-year period.

Table 5
The Effects of IT Adoption on Increased Importance of Different Types of Skills[a]
Dependent Variable: Equals One if Skill's Importance Increased Between 1997 and 2002

	(1) Math	(2) Computer	(3) Programming	(4) Problem-Solving	(5) Engineering Knowledge
UK Dummy	-0.022 (0.139)	-0.432*** (0.126)	-0.308** (0.143)	0.032 (0.129)	-0.391*** (0.123)
Bought New CNC Machine	0.107 (0.084)	0.139** (0.082)	0.270*** (0.086)	0.144** (0.083)	0.195*** (0.081)
UK * New CNC	-0.0203 (0.166)	0.310*** (0.067)	0.331** (0.145)	0.057 (0.148)	0.216 (0.185)
Adopted 3D-CAD	-0.038 (0.069)	0.103 (0.064)	0.081 (0.071)	-0.114 (0.096)	-0.018 (0.070)
Adopted Flexible Manufacturing System	0.236*** (0.075)	0.177 (0.070)	-0.053 (0.090)	0.084 (0.075)	0.133 (0.089)
Adopted Automated Inspection Sensors	0.068 (0.100)	-0.015 (0.095)	-0.082 (0.104)	-0.101 (0.097)	0.071 (0.100)
Pseudo-R^2	0.072	0.132	0.142	0.055	0.088
Sample Size	255	254	249	253	252
Mean UK	0.45	0.60	0.44	0.63	0.30
Mean US	0.57	0.71	0.53	0.68	0.52

Huber-White robust standard errors in parentheses.
*Significant at 10%; ** Significant at 5%; *** Significant at 1%

[a] Probit coefficients evaluated at the mean are shown . Regressions include controls for age of plants (five age dummies), number of shopfloor workers, and dummy for unionization

Table 6
The Effects of IT Adoption on the Adoption of New HRM Practices, 1997-2002[a]
Dependent Variable: Equals One if Plant Adopted the HRM Practice Between 1997 and 2002

	(1)	(2)	(3)
Dependent Variable[b]:	Teams	Shopfloor Meetings	Technical Training
UK Dummy	0.151 (0.097)	0.125 (0.098)	0.013 (0.133)
Bought New CNC Machine	0.279*** (0.081)	0.191** (0.105)	0.212*** (0.091)
Adopted 3D-CAD	0.068 (0.083)	0.076 (0.084)	0.236*** (0.098)
Adopted Flexible Manufacturing System	-0.005 (0.110)	-0.029 (0.110)	0.161 (0.114)
Adopted Automated Inspection Sensors	-0.070 (0.121)	0.110 (0.105)	0.375*** (0.149)
Observations	173	119	128
Log Likelihood	-102.8	-66.9	-64.06
Pseudo R2	0.136	0.059	0.233
Mean UK	0.52	0.81	0.32
Mean US	0.42	0.69	0.36

Huber-White robust standard errors in parentheses.
*Significant at 10%; ** Significant at 5%; *** Significant at 1%

[a] Probit coefficients evaluated at the mean are shown . Regressions include controls for age of plants (five age dummies), number of shopfloor workers, and dummy for unionization

The samples for these probit models include those plants that did not have the given practices as of 1997, and the dependent variable equals one for those plants that adopt the given practice by 2002.