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Equipment Investment and the Relative Demand for Skilled Labor: International Evidence

By

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This paper investigates the effects of equipment investment on relative wages and employment of skilled labor, using a panel data set which includes

a wide range of countries. This work is motivated by two alternative, not mutually exclusive, hypotheses: equipment-skill complementarity and skill advantage in technology adoption.

Complementarity between equipment and skilled labor is a hypothesis about the production function: equipment and skilled labor are complements, while equipment and unskilled labor are substitutes. Under this hypothesis, equipment investment, by increasing the equipment stock, should generate a higher relative demand for skilled labor. Using U.S. data, capital-skill complementarity received empirical support in Griliches (1969), and since then by others. Recently, Krusell, Lee, and Rios-Rull (1994) analyze inequality in the U.S. using this property of the aggregate production technology. Several related studies (e.g., Bound and Johnson 1992 and Berman, Bound, and Griliches 1994) concluded that the major cause of the large relative wage increase of skilled workers during the 1980s in the U.S. was a shift in the skill structure of labor demand, brought about by skill-biased technological change. Under the presumption that skill-biased technological change is embodied in equipment, this mechanism is similar to equipment-skill complementarity from this paper's point of view.

Skill advantage in technology adoption is a related but different mechanism. Assuming again that technologies are embodied in new equipment, this hypothesis stresses a temporary productivity loss following investment, which can be alleviated by the use of skilled labor. Bartel and Lichtenberg (1987) find empirical support for this hypothesis. Grossman and Helpman (1991) stress the mechanism of adopting (‘‘imitating’’) technologies developed elsewhere. If technology adoption is a skill-intensive activity, their model implies that technology adoption should be accompanied by an increase the relative demand for skilled labor. The adoption process was recently addressed in Jovanovic (1995), who stress the relative importance of adoption costs over invention costs, and by Greenwood and Yorukoglu (1996), who analyze the impact of investment-specific technological change on the skill premium in a general equilibrium framework.

The impact of new equipment on labor market differentials is particularly important for developing economies, such as some of the Latin American countries undergoing a rapid process of privatizing and opening to international trade. This process entails a massive investment in new equipment, and hence potentially large differential effects on skilled and unskilled labor demands. For example, Feenstra and Hanson (1995) found that the relative wages of skilled workers in Mexico, particularly in industries near the border with the U.S., have increased with trade liberalization. They conclude that the large flows of direct investment had a dominant effect in determining relative wages.

The focus of this paper is on the quantitative importance and dynamics of equipment investment effects on labor market differentials, studied with data on a wide range of countries.\footnote{%
Berman, Machin, and Bound (1995) also use a cross-country data set, and find positive correlations between changes in employment of skilled workers in manufacturing across industrial countries. Their presumption is that the same technological changes must take place in many developed countries within the same decade, leading to positive correlations if there is a skill bias.} The analysis consists of panel regressions that address separately the wage ratio and the employment ratio--obtained from different sources. The wage ratio regressions include 37-39 countries and the employment ratio regressions include 35 countries.\footnote{%

Within each panel, the sample periods differ for different countries--i.e., the panel data sets are unbalanced--with wage data ranging from the middle 1980s to 1992, and the employment data from the early 1970s to 1992.} Within the present framework and available data, the two hypotheses--equipment-skill complementarity and skill advantage in technology adoption--are observationally equivalent, and hence we cannot distinguish between the two.

The results suggest that investment in equipment raises the relative demand for skilled labor, with relative wage responding after one year and relative employment after three years. The wage response lasts for one to two years only, while the employment response lasts at least six years. A one-year, one-percentage point increase in the equipment investment/output ratio raises the relative wage by six to seven percent with a lag of one year, while the impact on relative employment after three years is about 15 percent, declining gradually thereafter.

The econometric specification is based on the assumption, discussed below, that equipment investment is exogenous to relative (skilled/unskilled) changes in wages and employment. Hence, the factors determining equipment investment are not addressed here. One key factor is technological progress specific to equipment, which was found in Greenwood, Hercowitz, and Krusell (1996) to be the main source of growth in the postwar United States. Hence, we view equipment-specific technological change as the fundamental source of the effects studied here.

The paper is organized as follows. Section \ref{theory} addresses theoretical considerations related to equipment-skill complementarity, and Section \ref{econometric} discusses econometric considerations and the estimation procedure. The alternative interpretation to the proposed empirical equations, based on technology adoption, is addressed in Section \ref{alternative}. Section \ref{data} describes the data sources, their weaknesses, and the procedure adopted here to minimize those weaknesses. The results are presented and discussed in Section \ref{results}, and Section \ref{conclusion} concludes the paper.

\section{Theoretical considerations\label{theory}}

The basic premise in this section is complementarity between equipment and skilled labor, and substitution between equipment and unskilled labor, i.e., a production function feature. Hence, the first basic element is the aggregate production function
\begin{equation}
y_t^j=f(k_{et}^j,k_{st}^j,l_{1t}^j,l_{2t}^j;z_t^j), \label{pf}
\end{equation}
where $y_t^{j_{}}$ is output in country j at time $t,$ l_{1t}^j and $%
l_{2t}^j$ are the inputs of skilled and unskilled labor, respectively, $%
k_{et}^j$ is the stock of productive equipment, k_{st}^j is the stock of
structures, and z_t^j is an exogenous productivity shock. It is assumed
that there is no labor mobility across countries. The main assumption about $%
f(\cdot),$ stated above, is that $f_{l_1k_e}>0$ and $f_{l_2k_e}<0.$ In
contrast, structures are hypothesized to complement both skilled and
unskilled labor. Specifically, $f_{l_1k_s}>0,$ $f_{l_2k_s}>0$ and $\partial
(f_{l_1}/$ $f_{l_2})/\partial k_s=0$ is assumed. A functional form
satisfying all these conditions is the CES formulation $f(\cdot
)=z_tl_{1t}^{\alpha _1}k_{st}^{\alpha _2}[\lambda k_{et}^{}+(1-\lambda
)l_{2t}^{}]^{1-\alpha _1-\alpha _2},$ $0<\alpha _1,\alpha _2,\lambda <1,$

studied by Krusell, Ohanian, and Rios-Rull (1994).

The second basic element is the evolution of equipment

\begin{equation}
k_{et}^j=k_e^j(i_{et-1}^jq_{t-1},\text{ }i_{et-2}^jq_{t-2,}...)
\label{keacc}
\end{equation}
where i_{et}^j is gross equipment investment in consumption units--which can be interpreted as the quantity of machines--and q_t is an exogenous variable indicating the worldwide state of the equipment technology at time $%
t$, satisfying $q_t>q_{t-1}$. The product $i_{et}^jq_t$ is therefore equipment investment adjusted for technological improvement. This notion of investment in efficiency units corresponds to {\it real investment }as measured, in principle, by national income accountants. Equation (\ref{keacc}%
) incorporates the standard time-to-build assumption, i.e., there is a one-period lag between the production of investment goods and the time in which they become productive. The partial derivatives in (\ref{keacc}) are positive and declining in value for higher lags, due to physical depreciation. Hence, equations (\ref{pf}) and (\ref{keacc}) together imply that real equipment investment with a lag of at least one period--i.e., $%
i_{et-1}^jq_{t-1},$ $i_{et-2}^jq_{t-2,}...$--by increasing the current stock of productive equipment, has positive effects on:

\begin{itemize}
\item the skilled/unskilled wage ratio,

\item the skilled/unskilled employment ratio.
\end{itemize}

\noindent Lagged investment should have less of an effect as the lag increases because of depreciation.

In a general equilibrium framework, the determination of equipment investment, in consumption units, can be described by

\[
i_{et}^j=i_e(q_t,x_t^j)
\]
where x_t^j is a country-specific vector of exogenous and predetermined state variables. Accordingly, real investment is given by

\begin{equation}
I_{et}^j\equiv i_{et}^jq_t=i_e(q_t,x_t^j)q_t. \label{ie}
\end{equation}
Equation (\ref{ie}) says that real investment depends on the efficiency of new investment goods and other exogenous variables. The main content of (\ref
{ie}) in the present context is that the variable I_{et}^j represents both the state of the technology q_t and the extent to which country j
invests in this technology, $i_e(q_t,x_t^j).$ \footnote{%
See Cooley, Greenwood, and Yorukoglu (1995) for an analysis of technology adoption, in which firms decide how much of the existing capital to replace.}%
The present context does not characterize the variables entering the vector $%
x_t$, except that they are exogenous or predetermined.\footnote{%
In this setup, investment at time t involves capital goods of quality q_t
only, which, by assumption, is higher than that of previous vintages. A richer framework would incorporate the possibility of investing in

previously existing technologies. For the present purposes, however, this
generality does not seem necessary. We return to this point below in
footnote \ref{latest}.}

\section{Econometric implications\label{econometric}}

\subsection{General considerations\label{general}}

The basic econometric strategy is to use panel data to estimate two
equations: one for the relative wage w_{1t}^j/w_{2t}^j and the other for
the relative employment $l_{1t}^j/l_{2t}^j,$ both including the same set of
explanatory variables. As a preliminary step to motivate the actual
estimation, consider for a moment the hypothetical case where all the x_t^j
variables are observable. One could then estimate the equations as

\begin{center}
\[
w_{1t}^j/w_{2t}^j=\alpha _{wj}^{\prime }+\beta _{w1}^{\prime }\frac{%
I_{et-1}^j}{y_{t-1}^j}+\beta _{w2}^{\prime }\frac{I_{et-2}^j}{y_{t-2}^j}%
+...+\gamma _{w0}^{\prime }x_t^j+\gamma _{w1}^{\prime
}x_{t-1}^j+...+\varepsilon _{wt}^{\prime }
\]
and
\end{center}

\[
l_{1t}^j/l_{2t}^j=\alpha _{lj}^{\prime }+\beta _{l1}^{\prime }\frac{%
I_{et-1}^j}{y_{t-1}^j}+\beta _{l2}^{\prime }\frac{I_{et-2}^j}{y_{t-2}^j}%
+...+\gamma _{l0}^{\prime }x_t^j+\gamma _{l1}^{\prime
}x_{t-1}^j+...+\varepsilon _{lt}^{\prime }
\]
where $\alpha _{wj}^{\prime }$ and $\alpha _{lj}^{\prime }$ are
country-specific constants, the real investment variables $%
I_{et}^j=i_e(q_t,x_t^j)q_t$ are expressed as ratios to output y_t to make
them comparable across countries, and the $\gamma $s represent
contemporaneous and lagged direct effects of x_t^j. The important point
here is that because of the presence of the lagged x_t^j variables, the $%
\beta $s should capture the net effects of the technological development $%
q_{t-1},$ $q_{t-2},$..$.$

However, data that reasonably capture the relevant xs in the different
countries are not available, and hence, we cannot disentangle the pure
effect of technology from the other factors determining the extent to which
it is adopted. For this reason, the actual equations estimated are of the
type

\begin{equation}
w_{1t}^j/w_{2t}^j=\alpha _{wj}+\beta _{w1}\frac{I_{et-1}^j}{y_{t-1}^j}+\beta
_{w2}\frac{I_{et-2}^j}{y_{t-2}^j}+...+\gamma _w\widetilde{x}_t^j+\varepsilon
_{wt} \label{estw}
\end{equation}

\begin{center}
and
\end{center}

\begin{equation}

l_{1t}^j/l_{2t}^j=\alpha _{lj}+\beta _{l1}\frac{I_{et-1}^j}{y_{t-1}^j}+\beta
_{l2}\frac{I_{et-2}^j}{y_{t-2}^j}+...+\gamma _l\widetilde{x}_t^j+\varepsilon
_{lt} \label{estl}
\end{equation}
where $\widetilde{x}$ is a subset of $x.$ Lagged $\widetilde{x}$s are not
included given that the attempt to isolate the partial effects of the qs
is not pursued.\footnote{\label{latest}Because the empirical emphasis is
given to equipment investment, the question whether or not the technology
embodied in it is the latest seems unimportant. The main point is that the
equipment stock increases, leading to the effects mentioned in Section \ref
{theory}.}

The main prediction, according to the discussion in Section \ref{theory}, is
that the $\beta $s are positive and that their magnitudes decline with the
lags.

A relevant question at this point is whether an empirical relationship
between the relative labor market variables and lagged investment can be
generated by reverse causality, {\it in the absence }of equipment-skill
complementarity. To check for such reverse causality, let us consider the
econometric results that would obtain if movements in w_{1t}^j/w_{2t}^j
and l_{1t}^j/l_{2t}^j, due to exogenous relative demand (or relative
supply) shifts, are expected in advance. Given that the labor market
variables are ratios, an absolute {\it increase} in the demand for skilled
labor, for example, would be reflected in the same way as an absolute {\it %
decline} in the demand for unskilled labor. Hence, both absolute movements
are consistent with both higher and lower levels of expected economic
activity. Correspondingly, there should not be any systematic correlation
between wages and employmen {\it ratios }and I_{et-1}^j, I_{et-2}^j,...%
\footnote{%
There is an additional possibility of reverse causality {\it with }%
equipment-skill complementarity, where equipment investment reacts primarily
to the expected relative wage of skilled labor. Consider first a relative
supply shock of skilled workers. Given that this is expected in advance, $%
I_{et-1}^j$and $I_{et-2}^j,...$increase. Hence, shocks of this type would
lead to positive $\widehat{\beta }_l$s, but to {\it negative} $\widehat{%
\beta }_w$s, since higher lagged investments are accompanied by {\it lower }%
relative wages. Consider now an independent shock to the relative demand for
skilled workers. In this case the $\widehat{\beta }$s in {\it both}
equations would be {\it negative}, because investment would be reduced
(given the higher future cost of skilled labor) while relative wages and
employment increase. If both shocks coexist, one would accordingly expect
{\it negative }$\widehat{\beta }_l$s, while $\widehat{\beta }_w$s could be
of either sign. Hence, negative coefficients in the relative employment
equation would still be consistent with equipment-skill complementarity,
although obviously, that would invite a different formulation of the
equations.}

The following variables are selected for $\widehat{x}_t$:

\begin{itemize}
\item a time trend and per capita output, $y_t/pop_t,$ both representing
secular effects on both supply and demand for labor. They are intended to
capture the education level of the labor force, which, as a relative supply
shift, should have a positive effect on l_{1t}/l_{2t} and a negative
effect on $w_{1t}/w_{2t}.$ They may also represent shifts in the skill
composition of output demand, which is likely to be towards skilled labor.

In this case the effects on both l_{1t}/l_{2t} and w_{1t}/w_{2t} should be positive. Overall, we expect positive effects of time and y_t/pop_t on $%
l_{1t}/l_{2t}$ but uncertain effects on $w_{1t}/w_{2t}.$

\item output growth, $\ln (y_t/y_{t-1}),$ representing current aggregate shocks. No particular sign is predicted for the coefficient of this variable, but given the likelihood of a positive correlation with equipment investment, it seems appropriate to hold it constant, in order to isolate the partial effects of equipment investment.
\end{itemize}

\subsection{Estimation procedure}

A panel data estimation routine with fixed country-specific constants is used. In other words, all the slope coefficients are constrained to be the same across countries, but specific factors not included in the $\widehat{x}$%
s are allowed in the country-specific constants.

\section{An alternative interpretation: skilled labor advantage in technology adoption\label{alternative}}

Grossman and Helpman (1991, chapter 11) stress the mechanism of adopting (‘‘imitating’’) technologies developed elsewhere.\footnote{%
In this model, the technology is developed in the ‘‘North’’ and imitated in the ‘‘South’’.} If technology adoption is a skill-intensive activity, their model predicts that technology adoption should be accompanied by an increase in the relative demand for skilled labor. The empirical results in Bartel and Lichtenberg (1987) are consistent with this hypothesis. They focus on the labor market implications of technology adoption, estimating labor demand equations which incorporate the average age of the equipment stock--proxying for the average time since the introduction of new technologies. They find a negative effect of this variable on the relative demand for highly educated workers, supporting the hypothesis that adopting equipment-embodied technologies increases the demand for skilled labor.

Note that the regression equations (\ref{estw}) and (\ref{estl}) above may also be interpreted along the technology adoption lines. Under this interpretation, the mechanism at work is not related to the production function itself, but to the process of technology adoption--which requires a high proportion of skilled labor. Correspondingly, the equipment investment variables should have positive coefficients in both equations. Therefore, the implications here are similar to those of the skill complementarity in production, described in Section \ref{theory}. In a recent paper, Jovanovic (1995) stresses the relative importance of technology adoption over that of R\&D. The invention/adoption distinction highlights the similarity between the implications of the technology adoption and the production function considerations. In both cases, given the nature of the capital evolution equation it should be the lagged investment variables which have important effects on the labor variables. Current investment represents contemporaneous production, while adoption starts only after the equipment goods are incorporated into the capital stock. Both the adoption hypothesis and the equipment-skill complementarity hypothesis imply that the impact of equipment investment on labor market differentials, in terms of both wages and employment, is a temporary one - the first because it refers to the adoption period only, and the second because of depreciation, as discussed in Section \ref{theory}. We discuss this point further in the concluding section.

\section{The data\label{data}}

Three data sets are used: one for wages, another for employment, and a third for investment and other macro data. Given the different forms in which the wage and the employment data were constructed, the skilled/unskilled classification is not the same for the two variables. We report below (at the end of Section \ref{results}) some tests which suggest that the mismatch may not be important for the results. The list of countries in the data set appears in appendix, Table A1. The only criterion for including of a country in each regression is that data for all the variables in that regression are available.

\smallskip\

Wages:

\smallskip

The data are from the International Labor Organization (ILO) October Inquiry, which is a worldwide annual survey. The October Inquiry, started in its current form in 1983, is the only available detailed survey of wages by occupation and industry for a large number of countries.\footnote{%
This data set was used previously by Freeman (1994).} The wage data cover 65 countries from all continents and all income levels. For most countries the data cover the period from the mid 1980s through the early 1990s (about a third of the countries have 5 years of data or less).

To minimize problems with the original data, we limited our coverage to eight industries (mostly nonservices; see list in the Data Appendix). From the different occupations reported for each industry we selected ‘‘laborers’’ as unskilled labor, and the rest of the occupations as skilled labor. Given that only a few industries report professional occupations, we defined skilled production workers as skilled labor. In the absence of employment data by the same occupational classification, the averages across industries are unweighted. First, average wages by skill levels within each industry were used to compute the industry wage ratio, and then the ratios across industries were averaged.

Whenever monthly wages were not reported, the hourly, daily, or weekly figures were converted into monthly wages, using average hours worked--and if not available, 40 hours per week were assumed. In some cases, only contractual wage rates were available. Whenever both actual average earnings and contractual wages were reported, actual earnings were used. In a few countries and for some occupations, the wage provided was only for men or only for women. For the rest it was the average for men and women. A detailed description of the characteristics of the wage data by countries is given in the appendix, Table A1. The specific countries entering the wage ratio regressions and the corresponding sample periods are shown in Section \ref{results} following the regression results.

\smallskip\

Employment:

\smallskip\

The employment data are from the ILO Statistical Database. They cover 52 countries over the period 1970 through 1993 (about 20 countries have data only from the mid 1980s through the early 1990s). This database includes economy-wide employment and unemployment by a broad occupational classification. Skilled workers include professional, technical, and related workers, and administrative and managerial workers. The unskilled category is comprised of production and related workers, transport equipment operators, and laborers, which are reported together. For this reason the skilled/unskilled definition in the employment data differs from that used in the wage data: the unskilled in our employment data include all production workers, while in our wage data skilled production workers are categorized as skilled.

We did not include a number of occupations - clerical and related workers, sales workers, service workers and agriculture, animal husbandry, and forestry workers - where the classification between skilled and unskilled seems less meaningful in the present context. Given that these occupations comprise most of the service and agriculture sectors, our definition of the skilled/unskilled ratio is roughly parallel to that of nonproduction/production workers used by Berman, Bound, and Griliches (1994) for manufacturing only.

The list of countries entering the employment ratio regressions and the corresponding sample periods are shown in Section \ref{results} following the regression results.

\smallskip\

Macro data:

GDP and investment are from the Penn World Tables developed by Summers and Heston (1991).

\section{Results\label{results}}

Basic results are addressed in subsection \ref{basic}, then the dynamics of equipment investment effects are further analyzed in subsection \ref{lagged}%
, and subsection \ref{additional} reports an additional test, addressing indirectly the mismatch in the definitions of skilled labor in wages and employment.

\subsection{Basic Results\label{basic}}

We first address estimates of the wage-ratio equation and then estimates of the employment-ratio equation, discussing the links between them.

Table 1 reports the results for the wage ratio equation under different specifications. The regressions also include country-specific dummies, and the t-statistics, in parenthesis, are computed using heteroskedasticity-robust standard errors. These regressions include 37 to 39 countries, and, as shown in the countries list in Table 1a, the samples vary across countries within the period from the middle 1980s to 1992.

Investment in machinery with a lag of one year, $IMACHY(-1)$, enters in all the specifications positively and significantly at the one percent level. Column 2 reports a basic formulation with three additional variables: income per capita--$YCAP$-- and a time trend--$YEAR$-- to capture long-run developments, and GDP growth--DY-- to capture current aggregate shocks. $% YCAP$ does not have a significant effect on the wage ratio. As discussed above in subsection \ref{general}, this may reflect the offsetting effects of a larger supply of skilled labor in more developed countries, and a higher demand for skilled-labor intensive goods. The time trend represents similar factors as $YCAP$, but stresses the time series aspect within each country. The negative and significant coefficient suggests a high skill premium at the beginning of the sample--the mid 1980s--and a decline over time since then, probably reflecting a steady increase in the supply of more educated workers. The coefficient of DY is significant and negative. This effect is consistent with the notion that unskilled labor demand, which is likely to require little investment in specific human capital, is more sensitive to short-run cyclical fluctuations. In contrast, hiring skilled labor is likely to require specific training, and hence it would occur gradually over time, as the economy permanently expands. This implies a countercyclical behavior of both wage and employment ratios. The cyclical behavior of the employment ratio is tested below in the context of the coefficient of DY in the employment-ratio equation.

The other columns check the robustness of the results in column 2, as well as testing additional variables. The theoretical considerations in Section \ref{theory} imply that only lagged equipment investments are relevant. Column 3 tests this by also including current $IMACHY$. The coefficient is insignificant, as the theory predicts. Equipment investment with a two-year lag is introduced in column 4, but it also turns out to be statistically insignificant. The coefficient and the t-statistic, though, are higher than those of the current variable. Capturing effects of investment at different lags is econometrically problematic given the strong autocorrelation of the $IMACHY$ variable: 0.96 in the current sample. In subsection \ref{lagged} below, we address the dynamics further.

Other investments relative to GDP, $OIY(-1)$, are included in column 5 to test whether it is indeed machinery investment which has the positive effect, or whether it is proxying for investment in general. The considerations reviewed in Section \ref{theory} imply that OIY, which includes other private as well as public investment, should have no effect. Surprisingly, the coefficient turned out to be negative and significant, suggesting complementarity between capital other than machinery and unskilled labor.

Column 6 also includes an interaction term between machinery investment and GDP per capita, to test whether the relative wage effects of equipment-skill complementarity depend on the country's level of development. The negative and significant coefficient of the interaction term indicates that the relative wage response is weaker in richer countries. This result is consistent with a higher supply elasticity of skilled labor in more developed countries, which generates a smaller wage response to higher skilled labor demand. The overall coefficient of equipment investment is computed from column 6 as $14.6-0.59YCAP,$ which remains highly positive for all countries in the sample.

Table 2 reports the same set of regressions as Table 1, but with the employment ratio as the dependent variable. The number of countries here is 35. As Table 2a shows, the set of countries covered in these regressions overlaps only partially with the set included in Table 1, and the sample periods here are longer: they range from the early 1970s to 1992. The coefficient of machinery investment is positive in all the specifications except in column 4, which also includes $IMACHY(-2),$ and the significance level is sensitive to the specification. These results, and particularly the positive and significant coefficient of $IMACHY(-2),$ led us to check longer lags. Running the basic specification (column 2 in Table 2) with an increasing number of $IMACHY$ lags indicates that the strongest effect is after three years: when $IMACHY(-3)$ is included, the other lags, including the fourth, are insignificant. Hence, the employment ratio equations are reestimated with $IMACHY(-3)$ replacing $IMACHY(-1),$ and reported in Table 3, on which we focus in what follows.

Column 2 reports the basic specification, with $IMACHY(-3)$ having a positive and significant effect. The long lag until machinery investment affects the employment ratio, along with the short lag for the effect on the wage ratio, suggesting that the supply of skilled labor is inelastic in the short run. Hence, when the equipment stock is enlarged--with a lag of one year after machinery production--the increase in the relative demand for skilled labor induces a higher skill premium immediately. Only with a lag of two more years does the supply of skilled labor increase, either by formal learning or by on-the-job training, leading to the delayed effect of machinery investment on the employment ratio.\footnote{%
Note, however, that an increase in the relative input of skilled labor may occur earlier by extending the number of hours per worker.} We return to the dynamic effects of investment below in subsection \ref{lagged}.

The effect of other investment $OIY(-1)$ is negative and significant (see column 3 in Table 3), as in the wage ratio equation. This strengthens the impression of complementarity between other capital and unskilled labor, suggested by the wage ratio regressions.

The positive and significant coefficient of $YCAP$ is consistent with both a higher stock of human capital in higher-income countries (a supply effect), and a higher demand for skilled labor-intensive goods (a demand effect), as discussed earlier in the parallel context of the wage ratio. There, these two effects offset each other, while here both increase the employment ratio. DY has a negative and significant effect, as it has on the wage ratio, supporting the notion discussed earlier that unskilled labor demand is more sensitive to the cycle than skilled labor demand. The time trend, representing the within-country long-run demand and supply effects has, as expected, a positive and significant coefficient. The interaction term between investment in machinery and per capita income turns out to be insignificant, while it should have been positive to be consistent with the supply elasticity interpretation given to the negative coefficient in the wage ratio equation. The insignificant effect of this term here, though, may be related to its multicolinearity with $YCAP,$ which is very highly significant in the employment regressions.\footnote{%
Deleting $YCAP$, the effect of the interaction term becomes positive and highly significant, but the coefficient of the investment in machinery itself becomes negative and insignificant. The total effect of investment in machinery based on this regression ranges from -0.4 to 5.2, with 8 out of the 35 countries included in the regression exhibiting a negative effect.}

\subsection{Lagged investment effects\label{lagged}}

As mentioned above, the $IMACHY$ autocorrelation is 0.96 in the relative wage sample (in the relative employment sample the autocorrelation is 0.94). Hence, capturing separate effects of subsequent lags is econometrically difficult. Given that the dynamics are a key component in the mechanism under study, the equations were reestimated with $IMACHY(-1),$ $IMACHY(-3),$ $IMACHY(-5)$, etc$.$ In this way, the problem of a strong correlation between two subsequent investment variables is weakened and at the same time longer dynamics are tested.

Table 4 reports the results. Columns 1 and 2 report the results for the wage ratio without and with $OIY(-1),$ $OIY(-3),$ and $OIY(-5),$ and columns 3 and 4 correspond to the employment ratio. The results here are consistent with basic ones above. The relevant machinery investment lags are short for the wage ratio - only $IMACHY(-1)$ is significant, although $IMACHY(-3)$ also has a positive and quantitatively important coefficient. In contrast, in the employment equation, columns 3 and 4, the first lag is insignificant, while $IMACHY(-3)$ and $IMACHY(-5)$ are significant. Additional lags of up to nine years were included and reported in column 5. $IMACHY(-7)$ turned out to be significant but $IMACHY(-9)$ did not.

As mentioned above, the results suggest a very small elasticity of skilled labor supply in the short run, but a larger elasticity in the longer run (after at least two years). The dynamics following an $IMACHY$ shift can then be described as follows. Investment has, once it is incorporated in the equipment stock, a strong immediate impact on skilled relative wages, but little effect on relative employment. Given higher wages, the relative supply of skilled labor increases through learning, thereby lowering the wage ratio and raising the employment ratio. This brings the relative wage to the original level, but relative employment remains high for several more years.

Quantitatively, a one-year, one-percentage point increase in the machinery investment/output ratio raises the wage differential after a year by about 0.09, or 6.5 percent (the average wage ratio is 1.4). As mentioned above, the effect thereafter is small and statistically insignificant. The corresponding impact on relative employment can be judged by the sum of the $% IMACHY$ coefficients, which equals 2.9 in column 5. Given that not all the lags are included, one needs an additional assumption to identify the year-by-year path of the coefficients. Assuming that starting from the third lag (the first that is significant) the effect declines linearly, reaching zero at the ninth lag, the resulting coefficients are 0.83, 0.69, 0,55, 0.41, 0.28, 0.14, and 0. This implies that a one-year, one-percentage point increase in the machinery investment/output ratio raises the employment ratio by 0.08, or by about 15 percent (the average employment ratio is 0.57) after three years, with the effect declining gradually over six more years.

\subsection{An additional test\label{additional}}

As discussed in Section \ref{data}, the definitions of skilled and unskilled labor in the wage and employment data are different. The mismatch is due to the inclusion of skilled production workers in the skilled category for wages, and in the unskilled category for employment. For two industries, however, chemicals and electric light and power, wages of professional occupations are available. Hence, the wage ratio of professionals to laborers can be computed and used to test the change in wage ratio equation results. The regressions using this wage ratio are reported in Table 5. The results are qualitatively similar to those in Table 1. One difference is the larger magnitude of the $IMACHY$ coefficients, which is consistent with a monotonically increasing effect of machinery investment on labor demand by skill levels. In other words, the demand effect is strongest on professionals, weaker on skilled production workers, and weakest on laborers.

\section{Concluding remarks\label{conclusion}}

The evidence reported in this paper supports the hypotheses of equipment-skill complementarity or skill advantage in technology adoption, as manifested by a positive effect of machinery investment on the relative demand for skilled labor. The results indicate an immediate response of the relative wage of skilled labor and a delayed increase in relative employment. This suggests that the supply of skilled labor is inelastic in the short run, but reacts positively after a period of training. The present results should be put in perspective by recalling that the wage and employment data come from different sources, and differ in the respects discussed earlier.

The present empirical formulation and data set do not make it possible to distinguish between equipment-skill complementarity in production, and skill advantage in technology adoption. The lack of a significant effect of the current increase in the equipment stock (machinery investment with a lag of one year) on the current relative employment of skilled labor does not seem to support the need of skilled labor for technology adoption. However, it is possible that the relative input of skilled labor does respond immediately by an increase in hours per worker rather than in employment, given the time involved in training new workers. (Our data set does not include hours per worker.)

Investment other than in machinery has, surprisingly, a negative effect on both relative wages and relative employment of skilled workers. This suggests complementarity between other capital (private and public structures) and unskilled labor. Studying the effects of more disaggregated investment seems an interesting direction to pursue.

Time works in the direction of reducing wage differentials during the period from the mid 1980s to the early 1990s, which is covered by the wage data. This is a partial effect of time, which probably reflects high wage differentials at the beginning of this period and an increase in the skill level of the labor force during the period. Income per capita, which varies dramatically across the countries in the sample, is very positively correlated with relative employment of skilled labor, as one may expect, but uncorrelated with the relative wage. The explanation we offer for these results is that in higher income economies in both the relative supply and the relative demand for skilled labor are higher, effects which cancel out on the relative wage but work on relative employment in the same direction.

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DATA APPENDIX
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Wages:

Source: ILO October Inquiry, years 1983-1994.

Simple averages of wage rates by occupation (disaggregation of 159 occupations) from the following industries:

1. spinning, weaving, and finishing textiles

2. printing, publishing, and allied industries

3. manufacturing of industrial chemicals

4. manufacturing of other chemicals

5. manufacturing of machinery

6. manufacturing of electronic equipment

7. electric light and power

8. construction

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Definitions of variables:

$WRATIO:$ average across industries of ratios of average wages of skilled labor to average wages of unskilled labor. Skilled are professionals (a few industries) and all production workers except laborers, and unskilled are laborers.

$WRATIO1:$ average professional/laborers wage ratio of two industries: industrial chemicals and electric light and power.

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Employment:

Source: ILO Labor Statistics Database.

Economy-wide data by broad occupational classification, excluding clerical and related workers, sales workers, service workers, and agriculture, animal husbandry, and forestry workers.

$ERATIO:$ ratio of employment of professional, technical, and related workers + administrative and managerial workers to employment of production and related workers, transport equipment operators, and laborers.

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Macro data:

Source: Penn World Tables. Data are expressed in a common currency by using purchasing power parities from the International Comparison Program of the World Bank. See Summers and Heston (1991).

$YCAP:$ GDP divided by population.

$DY:$ annual growth rate of GDP.

$IMACHY:$ investment in machinery as a fraction of GDP.

$OIY:$ other investment (total investment less machinery investment) as a fraction of GDP.

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