

Vintage Technologies and Skill Constraints: Evidence from U.S. Exports of New and Used Machines

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When countries import production machinery, they must choose between new and used equipment. This article looks at that choice in the presence of labor-saving technical progress and complementarity between technologies and skills within the firm. It develops a theoretical model of the market for used machines. It then analyzes data on U.S. exports of metalworking machine tools by country of destination, classifying machines according to their vintage and their technological characteristics. The data show that the share of used equipment imported is higher if the importing country has a lower level of development, as measured by income per capita. Econometric estimation of the determinants of this share shows that it also is higher the greater is the technological change embodied in the machine or the greater is the change in the skills required to run the machine efficiently.

These results indicate that technological factors and skill constraints may be as important as factor prices in determining the choice of technique in developing countries. The policy recommendation emerging from this work—avoid constraints on imports of used equipment—is similar to that in the existing literature. But the reasoning is different. Instead of emphasizing inappropriate capital-labor ratios for low-wage countries, the results indicate that investment in advanced technologies is effective only if importing countries have the skills to use them.

Many developing countries design their trade policies to discriminate against importation of secondhand goods, imposing import bans, licensing requirements, or higher tariff rates. Some industrial countries even discriminate against used products: witness Australia's additional \$12,000 tariff on used cars (Wonnacott

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1994). These policies are motivated by a desire to protect domestic industries against competition from low-priced goods, to avoid becoming a dumping ground for castoffs from high-income countries, to push industries toward the technological frontier, and to avoid the use of obsolete technologies.

But trade restrictions on used capital goods appear contrary to the appropriate choice of production techniques in developing countries, where low wages and high interest rates call for the use of labor-intensive production processes. Older equipment is likely to be more labor-intensive than new equipment; technological change tends to be labor-saving, and older equipment requires greater maintenance and carries a greater risk of downtime. Moreover, the optimal scale of older machines is smaller, which may be more appropriate for the smaller markets in developing countries, and older machines may be more flexible in their use and less specialized. Thus several authors conclude that firms in low-wage developing countries would find secondhand equipment more profitable than new machines and that developing countries would suffer a welfare loss from import restrictions on used machinery (Sen 1962, Schwartz 1973, James 1974, Thoumi 1975, Mainwaring 1986, and Pack 1977).

In this literature some models focus on the impact of greater maintenance costs as machines age (Schwartz 1973 and Thoumi 1975). The literature on vintage capital emphasizes labor-saving technological change (Bardhan 1970, Smith 1976, Gabisch 1975, and Pack and Todaro 1970). And some models incorporate both phenomena (Mainwaring 1986). Recent contributions on technology transfer link the choice of technique to the skills available in a firm or country. These skills are human capital or other technological capabilities acquired through deliberate learning or learning by doing (Benhabib and Rustichini 1991, Chari and Hopenhayn 1991, Keller 1994, Jovanovic and MacDonald 1993, and Jovanovic and Nyarko 1995, 1998). The more skills that are specific to a particular technique, the more costly it is to switch to that technique. The skill factor is likely to affect the choice between new and used machines when new machines embody technical change.

In this article we model a firm's choice between new and used machines. We test the predictions emerging from the modeling exercise using data on U.S. exports of new and used metalworking machinery, disaggregated by type of machine and by country of destination. The model incorporates three factors: greater downtime as machines age, labor-saving technical progress, and the greater skill requirements of more technologically sophisticated machinery.

Most of the literature on trade in used machinery focuses on heterogeneity between countries based on the stylized fact that developing countries have lower wages and higher capital costs than industrial countries (Sen 1962, Smith 1974, and Mainwaring 1986). We adopt a slightly different model based on heterogeneity among firms (as in Bond 1983). Our model takes into account that if labor and capital markets are imperfect or distorted by sectoral labor regulations or subsidized directed credit, firms in the same country may face different wage rates and capital costs.

Firms also can differ in the technical and managerial skills available to them. Heterogeneity among firms located in different countries provides the underlying motive for international trade in new and used capital equipment. Models that do not take firm heterogeneity into account predict fairly extreme patterns of trade in used machinery. For example, several models predict that firms in developing countries would import only the oldest machinery available. The assumption that firms within developing countries may face different wage structures and interest rates is reasonable, given imperfections in capital markets, the coexistence of multinationals and purely domestic firms, and the dichotomy between the formal and informal sectors.

I. THE FIRM'S CHOICE BETWEEN NEW AND USED MACHINERY

This section develops a model that is a version of Bond (1983), modified to include international trade of machinery.

Differences between New and Used Machinery

New and used machinery can differ in three important ways: risk of breakdown, productivity of embodied technology, and required technical skills. Used machinery normally requires more maintenance and is more likely to break down than new machinery. Maintenance demands high labor input. In addition, if employees are paid for a regular work schedule, machine downtime means that workers are idle, implicitly increasing the labor intensity of the production process. We capture the impact of breakdowns and the maintenance requirements of used machines by adjusting output for downtime using the factor α , defined as the ratio of a used machine's output to that of an identical new machine, that is, one not yet operated ($0 < \alpha < 1$).

Machinery of a given vintage embodies the technology available when it was produced. Labor-saving technical progress is captured by distinguishing between output per worker with a machine newly produced in the current period (a_n) and output per worker with a machine embodying last period's technology, when that machine was new (a_u). Thus the ratio a_u / a_n captures the rate of labor-saving technical progress, independent of the downtime effect, α , with $(a_u / a_n) \leq 1$.

To identify the independent impacts of technical progress and the aging process in the context of metalworking machines, we distinguish between low-tech and high-tech machines. From a technological point of view machine tools (especially metal-cutting tools) can be divided into two broad categories. Numerically controlled machines have a high rate of technological upgrading, linked to the development of electronics. These are "high-tech" machines. Manual machines may improve in terms of design and safety, but they have no or a very low rate of technical progress. These are "low-tech" machines. The difference in labor productivity between new and used low-tech machines is attributable only to increases in maintenance and longer downtime. The difference in labor produc-

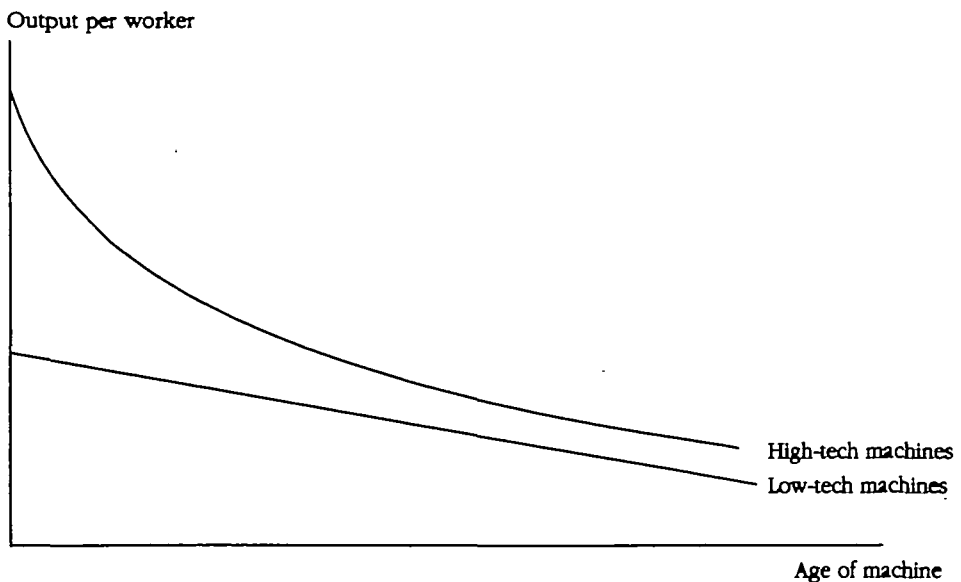
tivity between new and used high-tech machines is attributable to technical progress as well as to increases in maintenance and longer downtime.

For low-tech (manual) machines output per worker varies with age because of the downtime (α) effect (figure 1). For high-tech (numerically controlled) machines labor productivity declines with the age of the machine because of the combined effect of downtime and the lower technological sophistication embodied in older machines (figure 1). There are two key features of the relationships between labor productivity and the two types of machines. First, output per worker is always lower for low-tech than for high-tech machines. Second, at any point in time, the decline in labor productivity with age is larger for high-tech machines than for low-tech machines.

The third way in which new and used technologies may differ is in the skills required to operate the machines. The literature on vintage technology emphasizes the role of technology-specific skills (Evenson and Westphal 1994 and Keller 1994). Metalworking machine tools provide a good example. Manual machines (low-tech) require sophisticated craftsmen to operate them. Numerically controlled (high-tech) machines require electronic technicians. Accumulated learning by doing could be lost when a firm switches to a new technology (Chari and Hopenhayn 1991, Dasgupta and Stiglitz 1988, Jovanovic and MacDonald 1993, and Jovanovic and Nyarko 1995, 1996). Complementarities between workers with different skills may constrain the choice of technology (Chari and Hopenhayn 1991).

Linking the educational level of the people using the machines (craftspeople, technicians, engineers) to the technology embodied in the machines is essential,

Figure 1. *Labor Productivity and Machine Age with and without Technical Progress*



but not sufficient. Technological knowledge is often tacit and not transmittable in codified form (David 1993), and technological capabilities are related to the performance of many different technological functions (Lall 1987). Skills, then, should refer to the absorptive capacity of a firm or a country, that is, the ability to master a given technology (Evenson and Westphal 1994 and Keller 1994). Absorptive capacity is affected by the physical, social, and economic characteristics of a firm or country.

Firms therefore may be reluctant to move to high-tech machines because they do not have the skills to use them or because building up such skills would be more costly than continuing to use low-tech machines. In our simplified setting we assume that if a firm adopts a new high-tech machine that it does not have the appropriate skills to run it suffers a loss in productivity. The firm's current level of productivity is captured by γ , the proportion of full-capacity output achievable with new machines, given current skills (where $0 \leq \gamma \leq 1$). We refer to γ as the "inability coefficient," since γ is lower the less able is the firm. The skill factor may constrain the choice between new and used machines to the extent that new machines embody an increasing level of technological sophistication.

Trade Policy

Different trade policy instruments influence the choice between new and used machines in different ways. An equal ad valorem tariff rate, t , on all imported machines raises the domestic price of new and used machines proportionally. Restrictions discriminating against used equipment through either higher tariffs or licensing requirements increase the cost of used equipment disproportionately, discouraging its use.

Relative Prices

We assume that machines last for two periods. A firm buying a new machine can sell it at the end of the period for the going price of a used machine, but used machines will have zero scrap value at the end of the second period of use. The analysis assumes that machines are paid for at the beginning of the period and that wages are paid out at the end of the period. At the end of the period the firm's (net) cost of using a new machine embodying the current period's technology would be:

$$(1) \quad C_n = P_n(1+r)(1+t) - P_u(1+t) + \frac{w}{a_n}q.$$

The firm's (net) cost of using a machine embodying the previous period's technology (if the machine had never been used) would be:

$$(2) \quad C_u = P_u(1+r)(1+t) + \frac{w}{a_u}q$$

where C_i is the total cost of production using machinery i ($i = n$ for new machines, and $i = u$ for used machines), P_i is the price of machine i , a_i is the labor productivity of machine i ($a_i = q / L_i$) when it is (was) unused, L_i is the labor input per time period with machine i , w is the wage rate per time period, r is the interest rate, t is the ad valorem tariff rate on machinery imports, and q is the full-capacity output of a machine when it is new.¹

If the machine embodying last period's technology is used in that period, it yields only α of the output it did when new. If the productivity of the new machine is constrained because of the lack of skill in the labor force, the new machine yields only γ times the designed output.² More precisely, α is the proportion of the full-capacity output of a new machine that can be produced when the machine has been used for one period, and γ is the proportion of full-capacity output that can be produced using the new machine with current skills.

A firm will be indifferent between new and used machinery if unit costs are the same with the two types of equipment:

$$(3) \quad \frac{C_n}{\gamma q} = \frac{C_u}{\alpha q}.$$

Thus a firm will be indifferent between new and used equipment when:

$$(4) \quad \frac{P_n(1+r) - P_u(1+t) + \frac{w}{a_n}q}{\gamma} = \frac{P_u(1+r)(1+t) + \frac{w}{a_u}q}{\alpha}.$$

Solving for P_u yields U , the price of used equipment at which the firm is indifferent between using new and used equipment:

$$(5) \quad U = \frac{\alpha P_n - \gamma \beta \left(1 - \frac{\alpha a_u}{\gamma a_n}\right) \frac{w q \theta}{a_u}}{\gamma + \alpha \beta},$$

where $\beta = 1 / (1 + r)$ and $\theta = 1 / (1 + t)$.

If the market price of used machinery (P_u) is less than a firm's indifference price (U), the firm will buy used equipment; if the market price is greater ($P_u > U$), the firm will buy new equipment. Given the market price, P_u , an increase in U makes it more likely that a firm will buy used equipment, and a decrease in U raises the chance that it will buy new equipment.

1. We assume that full-capacity output of a new machine is always the same (q) independent of the type of machine, whereas the labor input necessary to achieve full-capacity output changes (thus affecting labor productivity a_i).

2. Labor input does not change if the machine is used at less than full-capacity output. Either workers are paid on a fixed schedule, or they use their idle time to maintain machines.

Equation 5 implies the following:

- The indifference price of used machines equals the price of new machines with production capacity equal to that of used machines (the first term in the numerator on the right side of equation 5), net of the higher labor costs of used compared with new machines (the second term in the numerator on the right side of equation 5).
- Other things being equal, the smaller is α (the more the use of equipment generates a loss in productivity) and the smaller is a_u/a_n (the greater is the rate of labor-saving technical progress), the lower is the indifference price (the less desirable are used machines).
- The indifference price of used machines increases as γ falls, other things being equal, so firms that do not have the technical skills required to run new machinery will be more likely to opt for used equipment.

The impact of the wage rate, interest rate, and machinery tariff rate on the indifference price of used machinery is more complicated to assess and depends crucially on the firm's skill level, γ . Unless the firm lacks most of the skills needed to use higher-technology equipment, the productivity of new machines is greater than that of used machines for the firm, that is, $\alpha a_n/\gamma a_u < 1$. In this case U declines when w and β increase, so firms facing high wages and low capital costs are more likely to prefer new machines (because it is more likely that $U < P_u$). Also, U decreases as θ increases, implying that higher tariffs raise the indifference price of used machines, making their purchase more likely. Indeed, tariff increases push the indifference price downward in the same way as do increases in the cost of capital (r). But lack of skills to make use of higher-technology equipment (a sufficiently low γ) could eliminate or reverse the influence of wages, interest rates, and tariff levels on the indifference price.

The Market for Used Machines

We assume that there are two regions, North and South. Firms in the North (N) are homogeneous (all have the same γ) and face the same factor prices. Firms in the South are either large (L) or small (S). Large southern firms have more technical skills (higher γ) and face more expensive labor and cheaper capital than small southern firms.³

Given the homogeneity of northern firms, used machines are supplied at their indifference price (U_N), therefore, $P_u = U_N$. Northern firms are indifferent between purchasing used or new machines.⁴ The South is a price taker because it is

3. This assumption is consistent with widespread evidence that labor and capital markets in developing countries are fraught with imperfections and often are segmented, so that small and large firms face different wage and interest rates. These differences are a result of credit rationing, labor regulations, dichotomies between formal and informal sectors, and the coexistence of multinational and indigenous firms. In addition, small and large firms differ in terms of technical skills and therefore may have widely different values of γ .

4. The northern indifference price is the equilibrium price of used machines even if northern firms only use new machines.

small in machinery markets compared with the North. New and used machinery prices are determined in northern machinery markets, and both large and small southern firms face an infinitely elastic supply of new and used machines at those prices. In the South large firms have sufficient skills to absorb new technology (high γ). They face sufficiently high wages and low interest rates so that, at the prices of new and used machines determined in the North, large southern firms would opt for new machines, as $U_L < U_N$. Small southern firms, in contrast, have relatively low γ and face high interest rates and low wages. Thus the indifference price of small southern firms exceeds that of northern firms (from equation 5), and small firms buy only used machines. With heterogeneous firms in the South and homogeneous firms buying at the indifference price in the North, firms in both the South and the North purchase new and used machines.

In the South small firms' demand for used machines and large firms' demand for new machines depend on the demand for their output. Suppose that small and large firms' products (X_S and X_L , respectively) are imperfect substitutes, are nontradable, and have downward-sloping demand functions $P(X_i)$. The demand for used machines by small southern firms must be consistent with the zero-profit condition:

$$(6) \quad P_u = \left[\alpha P(X_S) - \frac{w_s}{a_u} \right] q \beta_s \theta,$$

where X_S is the quantity of the final product produced and sold by small southern firms, $P(X_S)$ is the price of X_S , and subscript S designates the value of the variables for small southern firms.

The production function for small southern firms is given by:

$$(7) \quad X_S = \alpha q Q_u,$$

where Q_u is the quantity of used machines employed by small southern firms.

The demand function for good X_S is given by:

$$(8) \quad P(X_S) = b - cX_S.$$

Substituting equation 7 into equation 8, and equation 8 into equation 6, yields the demand function for used machines by small southern firms:

$$(9) \quad P_u = (\alpha b - w_s/a_u) q \beta_s \theta_s - \alpha^2 q^2 \beta_s \theta_s Q_u^{DS}.$$

When $P_u > U_S$, that is, when the price of used equipment is greater than the indifference price of southern firms, they will not buy any used machines.⁵ Thus

5. Technology and the cost parameters of large and small firms are assumed to be such that large southern firms strictly prefer new machines and small southern firms strictly prefer used machines at the northern supply price, U_N . The indifference price of small firms, U_S , is the price of used machines at which small firms are indifferent between producing and not producing. We use a somewhat different notation to distinguish this concept. We thank an anonymous referee for pointing out this subtlety.

the inverse demand function (equation 9) must be consistent with the following condition: $P_u \geq U_s$ when $Q_u = 0$.

Therefore, the demand for used machines among small southern firms is given by:

$$(10) \quad P_u = U_s - c\alpha^2 q^2 \beta_s \theta Q_u^{DS}.$$

In equilibrium, because the North is large and pins down the price for used equipment, $U_N = P_u$, and the quantity of used equipment demanded by the South will be the quantity demanded at the North's indifference price (U_N). Thus the equilibrium quantity of used machines demanded by small southern firms is given by:

$$(11) \quad Q_u^{DS} = \frac{U_s - U_N}{c\alpha^2 q^2 \beta_s \theta}.$$

Equation 11 shows that the quantity of used machines demanded in the South is greater the larger is the gap between the indifference prices of small southern and northern firms.

Similarly, the demand for new machines by large southern firms must be consistent with their zero-profit condition:

$$(12) \quad P_u = P_n(1 + r_L) + \frac{w_L}{a_n} q\theta - \gamma_L P(X_L) q\theta,$$

where subscript L designates the value of the variables for large southern firms.

Their production function is given by:

$$(13) \quad X_L = \gamma_L q Q_n,$$

where Q_n is the quantity of new machines employed by large southern firms.

The demand function for good X_L is given by:

$$(14) \quad P(X_L) = e - gX_L.$$

Substituting equation 13 into equation 14, and equation 14 into equation 12, yields large southern firms' demand for new machines as a function of the price of used machines:

$$(15) \quad P_u = P_n(1 + r_L) - \left(\gamma_L e - \frac{w_L}{a_n} \right) q\theta + g\gamma_L^2 q^2 \theta Q_n^{DL}.$$

When $P_u < U_L$, that is, when the price of used equipment is less than the indifference price of large southern firms, large southern firms will not buy new machines. Thus the inverse demand function (equation 15) must be consistent with the following condition: $P_u \leq U_L$ when $Q_n^{DL} = 0$.

Therefore,

$$(16) \quad P_u = U_L + g\gamma_L^2 q^2 \theta Q_n^{DL}.$$

Again, the equilibrium price of used equipment is the northern indifference price (U_N). Thus the equilibrium quantity of new machines demanded by large southern firms is given by:

$$(17) \quad Q_n^{DL} = \frac{U_N - U_L}{g\gamma_L^2 q^2 \theta}.$$

In the South large firms keep new machines for one year and then sell them to small firms. Small firms can buy used machines from large firms or import them. In the steady state, large firms' demand for new machines (Q_n^{DL}) will equal their supply of used machines (Q_m^{SL}), and the domestic market for used machines in each southern firm will be in equilibrium when:

$$(18) \quad M_u = Q_m^{DS} - Q_m^{SL},$$

where M_u is the quantity of used machines imported.

The equilibrium quantity of used machines imported by the South will be determined by the interaction between the northern indifference price, U_N , which defines foreign supply (NN in figure 2), large southern firms' supply of used machines (equation 17 and LL in figure 2), and small southern firms' demand for used machines (equation 10 and SS in figure 2). Given equation 18, the quantity of imports of used machines is the horizontal distance between LL and SS at height NN .⁶

When the gap between small southern firms' indifference price and the world price of used machines increases, the shifts in SS and NN generate an increase in the quantity of used machines demanded by small southern firms. When the gap between the world price of used machines and large southern firms' indifference price increases, the shifts in LL and NN generate an increase in the domestic supply of used machines.

The ratio Φ_U of used machines imported to total machines imported (estimated empirically in the following section) will then be

$$\Phi_U = \frac{M_u}{M_u + Q_n^{DL}} = \frac{Q_m^{DS} - Q_m^{SL}}{Q_m^{DS}} = 1 - \frac{Q_n^{DL}}{Q_m^{DS}}.$$

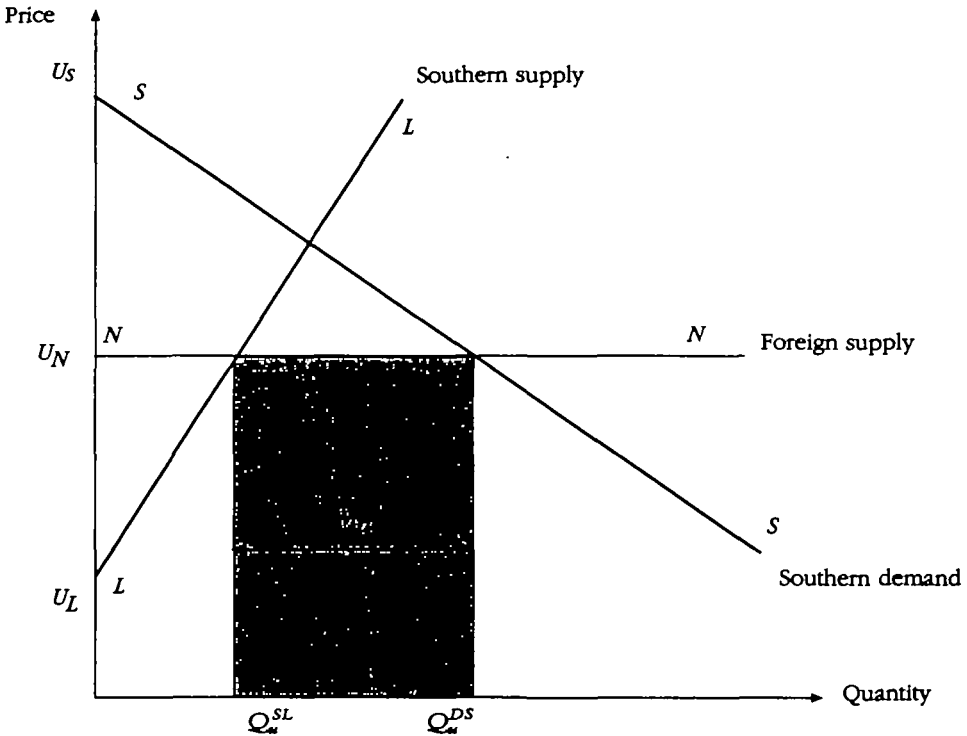
Therefore,

$$(19) \quad \Phi_U = 1 - \frac{(U_N - U_L)\alpha\alpha^2\beta_S}{(U_S - U_N)g\gamma_L^2}.$$

Equations 5 and 19 show how the share of used equipment imported depends on the technological complexity of the machine, the technical skills of the

6. Figure 2 was drawn under the assumption that the southern country is a net importer of used machines because domestic supply is lower than total domestic demand.

Figure 2. *The Market for Used Machines in the South*



importing firm, relative prices, trade policies, and consumers' demand for final output.

First, small southern firms' total demand for used machines increases with technical progress. Indeed, the greater is the technical progress differentiating new and used equipment (the lower is a_n/a_n), the larger is the $U_S - U_N$ gap for any given difference in factor prices. An increase in technical progress lowers the indifference prices of both northern and southern firms. Both NN and SS shift downward, and the equilibrium quantity of used equipment demanded in the South increases. However, because small firms in the South have lower wages, their indifference price declines less than that of the North.

An implication of this result is that faster technical progress (smaller a_n/a_n) will increase the technological gap between northern and southern capital stocks. The increase in total demand for used machines does not necessarily result in an equal increase in imports of used machines because the increase in demand can be counterbalanced partly by the downward shift of LL . If wages in large southern firms are higher and interest rates are lower than those in the North, the downward shift in LL will be greater than the downward shift in NN , and the domestic supply of machines will rise. However, if the lower indifference price for large southern firms is due to greater technical skills (higher γ), LL will shift less than NN , and the domestic supply of used machines will decline.

Second, the net effect of an increase in the downtime of used machines (a decline in α) on the indifference prices is the same as the one caused by technical progress: SS , LL , and NN shift downward, and the net demand for used machines is expected to increase. Moreover, SS becomes flatter because of the effect of the decline in output per machine on the equilibrium price of output.⁷

Third, a lower γ (a less-skilled labor force) in small southern firms implies a higher southern indifference price and therefore a larger demand for used machines. Indeed, the increase in productivity of new machines will be offset by the lack of appropriate skills to use them. Equally, a lower γ in large southern firms implies an upward shift in LL and a reduced supply of used machines. Thus when technical skills in the South are lower, the share of used machines imported is greater.

Fourth, factor prices and tariffs affect the equilibrium quantity of used machines in the expected directions. A relative increase in northern wages lowers the northern indifference price, increases the quantity of used machines demanded by small southern firms, and reduces the domestic supply of used machines.⁸ The share of used machines imported increases. Indeed, the price of used machines would decline more than southern returns from used machines. The opposite occurs when there is a relative increase in southern wages. If wages in small southern firms increase, the domestic demand for used machines declines. If wages in large southern firms increase, the domestic supply of used machines increases. For the same reason, a decline in northern interest rates raises the equilibrium quantity of used machines bought by the South.

Fifth, the choice of machines also is affected by demand for the two products X_L and X_S . If consumers' preferences shift toward one of the two products, the demand for machines will change accordingly. This effect is captured by parameters c and g in the two demand functions.

II. DETERMINANTS OF TRADE IN USED EQUIPMENT

In this section we apply the model to data on U.S. exports. U.S. export data on some types of vehicles, equipment, and machinery are sufficiently disaggregated to distinguish between new and used goods. We concentrate on U.S. exports of metalworking machine tools in 1990–94, disaggregated by commodity classification, whether they are new or used, and country of destination. The sample covers 38 types of metalworking machines, aggregated to the six-digit level in the Harmonized System, that are exported to 23 countries.

Different types of metalworking machine tools require different types of skills. Manual machines are operated by skilled workers or craftspeople. Numerically controlled machines are operated by both technicians and unskilled workers. Machining centers are even more complex, demanding higher-level technicians

7. In equations 11 and 18, α is multiplied by c , which is the slope of the demand function of X_S .

8. This holds if $(\alpha_a / \gamma \alpha_a) < 1$, from equation 5.

Table 1. *The Skill Requirement Index*

<i>Value of index</i>	<i>Minimum level of worker required</i>
1	Unskilled labor
2	Skilled craftspeople
3	Technicians
4	Higher-level technicians, engineers

Source: Authors' calculations.

and engineers. Furthermore, machines with higher skill requirements tend to have a faster rate of technological change. Thus firms upgrading from manual to numerically controlled machines must change their endowment of skills. This requirement probably explains why only 25 percent of new investments in machine tools made in the United States between 1985 and 1989 were in numerically controlled machines, although U.S. manufacturers started investing in these types of machines in the early 1970s (Oliner 1993).

With the guidance of an engineer intimately familiar with the complexities and skill requirements of each type of machine, we developed a skill index for each 10-digit export category, reflecting the degree of skill required to operate that type of machine. The value of the index ranges from 1 to 4, increasing with the level of skill required (table 1). Looking at the shares (by quantity) of used machinery in total imports of machinery from the United States, we see, as expected, that low-income countries import a higher ratio of used to new machinery (table 2). But the variation in the shares of machines imported secondhand is not huge (between roughly 10 percent for high-income countries and about 24 percent for low-income countries). The average skill index of imported machinery is higher for high-income countries than for low-income countries, but again the difference is not large. If we divide machines into high-tech (skill indexes 3 and 4) and low-tech (skill indexes 1 and 2) categories, the same pattern emerges. The ratio of used machines to new machines imported is greater for low-income countries than for high-income countries. In addition, the share of equipment imported secondhand is larger for high-tech than for low-tech machines.

These figures provide some empirical support for our hypotheses on trade in used equipment. However, they do not tell us which of the factors cited as determining the choice between new and used machines are significant. To cast some light on this issue, we use econometric analysis.

For each category of machinery we estimate the share of used machinery in total U.S. exports to each importing country as a function of variables specific to the importing country (trade barriers and levels of education and development), variables specific to the machines (skill level required and a proxy for the rate of technical progress), and a variable combining both country and machine factors (wage-rental ratio). The basic estimating equation is:

$$(20) \quad Q_{ij}^u = \alpha_0 + \alpha_1 W_{ij} + \alpha_2 T_{ij} + \alpha_3 S_{ij} + \alpha_4 E_j + \alpha_5 t_{ij} + \alpha_6 Y_j + v_{ij}.$$

Table 2. Imports of Metalworking Machine Tools from the United States

Importing countries ^a	Ratio of used to new machinery imported	Average index ^b	Ratio of used to new machinery imported	
			Low skill (skill indexes 1 and 2)	High skill (skill indexes 3 and 4)
High-income	0.096	2.93	0.082	0.296
Middle-income	0.112	2.71	0.095	0.339
Low-income	0.235	2.63	0.159	0.526

a. High-income countries have GDP per capita greater than \$12,000, middle-income countries have GDP per capita between \$1,300 and \$12,000, and low-income countries have GDP per capita less than \$1,300.

b. Weighted average by value of shipments.

Source: Authors' calculations.

where Q_{ij}^u is the quantity of used machinery of type i exported to country j as a proportion of total machinery of type i imported by country j between 1990 and 1994; W_{ij} is the wage-rental ratio, which is $\log \{w_j / [P_i (i_j + d)]\}$, where w_j is the average annual wage in dollars (1990–94), P_i is the unit value of new machinery of type i , i_j is the average real interest rate in country j , and d is the depreciation rate (assumed to equal 10 percent);⁹ Y_j is gross domestic product (GDP) per capita in dollars in country j (1990–96 average); T_{ij} is the percentage difference between the unit values of new and used machinery of type i imported by country j , which we use as a proxy for the rate of technological change; S_{ij} is the average skill requirement index for machines of type i exported to country j ; E_j is the education level in country j , measured by average years of schooling (over 1990–96); t_{ij} is the tariff rate on imports of machinery of type i in country j ; and v_{ij} is the disturbance term. See the appendix for data sources.

Consistent trade data for new and used machinery are available only as far back as 1990.¹⁰ Many country-specific variables are not available for all of these years, so we aggregate the five years. We use total U.S. exports of each commodity classification to each country in 1990–94 for trade flows and average observations on the other variables across the five years or over the largest number of years for which we have observations.

We estimate two versions of the model, including and excluding per capita GDP as a general indicator of development (table 3). Initial estimates using the ordinary least squares (OLS) estimation method (which are not reported) posed heteroskedasticity problems because the variance of the error term is decreasing with the share of imports of machines of type i in total imports of country j . Indeed, when the share is lower, imports of a given machine are less stable. We

9. The results were not sensitive to experiments using depreciation rates of 7.5 and 12.5 percent. In earlier versions of this article we attempted to use wages or ratios of wage to interest rates rather than the more appropriate ratio of wage to rental rates. The estimated coefficients of these variables were uniformly insignificant at standard confidence levels.

10. A reclassification of the export data in 1990 created a break in the series, so although data on used machinery exports are available for previous years, they are not based on exactly the same commodity classifications.

Table 3. *Determinants of Imports of Used Machinery*

Variable	1a	1b	2a	2b
	Weighted OLS	White corrected	Weighted OLS	White corrected
Constant	0.602*** (5.047)	0.467*** (3.507)	0.504343*** (3.048)	0.491*** (2.810)
Wage-rental ratio	-0.024* (-1.928)	-0.026** (-2.078)	-0.02782** (-2.103)	-0.025* (-1.947)
Technical change	0.066*** (5.803)	0.057*** (4.985)	0.064734*** (5.638)	0.058*** (4.938)
Skill requirement	0.051** (2.206)	0.047* (1.795)	0.046061* (1.796)	0.048* (1.813)
Education	-0.043*** (-3.314)	-0.013 (-0.975)	-0.047299*** (-3.379)	-0.011 (-0.723)
GDP per capita			0.021825 (0.857)	-0.005 (-0.212)
Tariff	-0.003* (-1.736)	-0.0001 (-0.632)	-0.003028* (-1.751)	-0.001 (-0.627)
Adjusted R ²	0.3974	0.3464	0.3967	0.3436
F-value	30.941	25.066	25.876	20.804
Number of observations	228	228	228	228

*Significant at the 10 percent level.

**Significant at the 5 percent level.

***Significant at the 1 percent level.

Note: The dependent variable is the share of machinery imported secondhand. *t*-statistics are in parentheses. Data are for imports of U.S. metalworking machines for 1990-94.

Source: Authors' calculations.

correct for heteroskedasticity using two methods. The first is a weighted least squares method, using as weights the share of imports of machines of type *i* in total imports of country *j*. Because this method may generate endogeneity problems that risk introducing spurious correlation, we also use White's method of correcting standard errors in the presence of heteroskedasticity.

As expected, the results for all of the equations indicate that factor costs affect the choice between new and used capital equipment. An increase in the wage-rental ratio shifts imports toward new and away from used machines.

The results also indicate the importance of technological and skill factors in the choice between new and used equipment. The positive and significant estimated coefficient of the machine-specific skill index indicates that the more high-tech are the machines, the greater is the proportion of equipment imported secondhand. The performance of the machine-specific skill variable is strong and robust across all versions of the estimated equations. The results also indicate that the faster is the rate of technical progress (as measured by our proxy, the percentage drop between new and used equipment prices), the larger is the share of capital equipment imported secondhand.

The rationale behind using the price differential between new and used machines as a proxy for the rate of technical progress is that greater improvement in a new machine results in a greater drop in the market price of the previous model. We recognize, however, that this measure is an imperfect proxy because the gap

between the prices of new and used machines could be influenced by other factors, such as asymmetric information (the "lemon" phenomenon). In addition, the measured technology variable could include variation in the average price of a given type of machinery across countries as well as variation across types of machines. Machines in the used category could range from barely used to barely usable. For countries that choose very old (and therefore much cheaper) machines, the relative price of new machines will be high. Thus the estimated coefficient may be biased because the measured technology variable could be correlated with the factors that make the country more prone to select used machines.¹¹ Bearing in mind these caveats, the evidence that technological factors are important in the choice of new or used machinery should be interpreted with some caution.

The estimated coefficient of the country-specific, skill-related education variable has the expected sign and is significant in the weighted OLS estimations, but not in the equations estimated using White's corrected standard errors. The education variable was measured as average years of schooling, which may be too general to capture the extent of technical training. We include GDP per capita as another potential measure of a country's technological development, but the results are insignificant.¹² The results for the tariff variable are somewhat disappointing. The model predicts that tariffs on machinery, by increasing the cost of capital to the firm, would encourage firms to opt for more labor-intensive used machinery. Yet the estimated coefficient of the tariff variable is negative and at times significant.¹³

III. CONCLUSIONS

Developing and transition economies frequently discriminate against imports of secondhand goods, including production machinery. The literature on this issue points out that these restrictions are costly because they deny firms access to older equipment, which is usually more labor intensive than new equipment and thus more appropriate for low-wage countries. In this article we developed a model that extended the established approach to take into account technological

11. We thank an anonymous referee for this point. This bias could possibly be corrected by using U.S. domestic data on the new-to-used price differential across different types of machines to construct the proxy for the technical change variable. Unfortunately, even if these data were readily available, difficulties and uncertainties in constructing a cross-classification between domestic and export product categories would render the results questionable.

12. In principle, problems of multicollinearity may emerge between the education and GDP per capita variables. All the same, given the broader meaning of the GDP variable, we keep both variables in the equation.

13. We also included a dummy variable for the existence of nontariff import barriers on used machinery, but we dropped it from the equation because the sign of the estimated coefficient was inconsistent and the coefficient was never significant. The lack of significance may have been due to incomplete data. The variable was generated using reports of the existence of nontariff barriers on used machinery in various surveys of trade policy in the countries in the sample, but some barriers may not have been reported.

progress embodied in new machinery and skill constraints faced by firms in developing countries. We tested hypotheses based on the model using data on U.S. exports of new and used metalworking machinery, differentiated by country of destination.

The results tend to corroborate the view that demand for used equipment is relatively high in lower-income developing countries. The proportion of each type of machinery bought secondhand is especially high for high-tech equipment requiring more sophisticated operating skills. Econometric tests of the determinants of the trade in used machinery indicate a significant role for relative prices, but also for technological and skill factors. Our results provide some support for the hypothesis that the absorptive capacity of a country (the ability to master a new technology) affects the choice of type and vintage of machines.

The finding that developing countries buy a larger share of old vintage machines when machines have a high rate of technological progress may be of some concern because it implies that the technological gap between the North and the South is likely to increase with faster technological progress. What policies can reduce the risk of a growing technology gap? The traditional criticism of restrictions on imports of used equipment is that such restrictions deny firms access to more appropriate labor-intensive techniques embodied in older vintage machinery. Our model and results indicate that, in addition, such restrictions force firms to buy more expensive new equipment that they may not be able to operate at full efficiency because of skill constraints in the labor force. Instead of imposing restrictions on used machinery imports, countries should concentrate on fostering education (particularly technical education) in an effort to improve the overall investment environment and firms' capacity to absorb new technologies.

APPENDIX: DATA DESCRIPTIONS AND SOURCES

<i>Variable</i>	<i>Description</i>	<i>Source</i>
Q_{ij}	Quantity of used machinery of type i exported to country j as a proportion of total machinery of type i imported by country j , 1990–94	U.S. Department of Commerce, Bureau of the Census, Exports of Merchandise CD-ROM
w_j	Average annual wage in country j in dollars, 1990–94	United Nations Industrial Development Organization, <i>Industrial Statistics</i>
r_j	Average real interest rate in country j	International Monetary Fund, <i>International Financial Statistics</i>
T_{ij}	Depreciation of machinery of type i imported by country j , measured as the difference between the logs of unit values of new and used machinery	Calculated from export data from U.S. Department of Commerce, Bureau of the Census, Exports of Merchandise CD-ROM
S_{ij}	Skill requirement index for machines of type i exported to country j	Based on classification by Anthony Bratkovich, engineering director of the U.S. Association for Manufacturing Technology
Y_j	GDP per capita in dollars in country j (1990–96 average)	World Bank data
E_j	Education level in country j , measured by average years of school (over 1990–96)	World Bank database (STARS)
t_{ij}	Tariff rate on imports of machinery of type i imposed by country j	World Bank data

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