The International Diffusion of New Technologies: A Multitechnology Analysis of Latecomer Advantage and Global Economic Integration

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The diffusion of modern, efficient technology has far-reaching consequences for the geography of economic activity, inequality, and environmental quality. This article examines two popular yet highly controversial claims about the conditions most favorable to the rapid spread of new technology. The first states that latecomer advantage allows developing countries to diffuse new technology faster than developed countries. The second claim, widely articulated by advocates of neoliberal policy reform, is that new technologies diffuse more rapidly where countries are "open" to international trade and investment. To investigate these claims we use event-history analysis to estimate the determinants of diffusion speed across a large panel of developed and developing countries for three very different technologies. These are: continuous steel casting, shuttleless textile weaving looms, and digital telephone mainlines. Our results broadly support both propositions. Countries that adopt new technology later or have a smaller existing capital stock—characteristic features of developing countries—diffuse new technology more rapidly than countries that adopt earlier or have more installed capacity—two characteristics of developed countries. Trade openness is also found to influence the rate of diffusion positively for all three technologies. Yet, consistent with recent empirical studies, we fail to find support for the idea that foreign direct investment (FDI) accelerates the diffusion of new technology in host economies. The article concludes by discussing the geographical implications of our findings. *Key Words: diffusion, globalization, industrialization, latecomer, technology.*

The role of new technology in enhancing economic growth and environmental protection is well established in the literature (Solow 1956; Porter 1990; Anderson 1996; Rigby 2000; UNDP 2001). There is, however, less certainty about the conditions under which these technologies are exploited. This article scrutinizes two popular yet controversial claims about the circumstances most favorable to the rapid diffusion of new technology.

The first is that under conditions of late industrialization new technologies diffuse more rapidly throughout the industrial structure. This, the argument goes, is because late-industrializers profit from so-called learning investments and are unencumbered by past investments in industrial capacity (Sharif 1989). Indeed, precisely because of these latecomer advantages, developing countries[1] are believed to be well placed to catch up with developed ones (Gerschenkron 1962; Abramovitz 1986). A second claim is that new technologies diffuse faster under conditions of openness to international trade and investment. Growth in trade and investment is said to increase both the demand and supply of modern technology. Hence the argument, widely articulated by advocates of neoliberal reform, that market liberalization brings with it greater technological efficiency, productivity, and competitiveness (OECD 1998).

Such claims are of particular interest to geographers. If accepted, they raise the prospect of significant shifts in the geography of economic activity, income, and environmental degradation over time as latecomer economies rapidly diffuse modern, efficient technologies as an integral part of capacity addition (Storper 1997; Rigby 2000; Lall 2002). Moreover, they point to a specific geography of technological change, influenced by the policy regime and level of integration of countries into the global economy.

In the present article we empirically investigate whether these claims are supported by recent historical experience and, in doing so, contribute to debates in economic geography about the dynamics of the world economy (N. Coe and Yeung 2001; Dicken 2003; Yeung and Lin 2003). Using quantitative estimation techniques, we analyze whether the rate at which new producer technologies diffuse is significantly influenced by (1) latecomer advantage and (2) engagement with the global economy via trade and foreign investment. We recognize and readily admit that our large-sample, quantitative approach is not without its shortcomings.

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These largely stem from the limited availability of comparable time-series data for the large number of countries that comprise the community of potential adopters at the global level. Thus, data limitations mean that we are forced to ignore several institutional and policy variables—for example, bureaucratic quality (Booth 2001), science and technology policies (Lim 1999), market structure (Porter 1990), and so on—identified in more detailed, country-level research as influential determinants of technological change. Indeed, to the extent that we are only able to investigate a handful of potential determinants, our quantitative approach runs the risk of oversimplifying the highly uneven and contingent nature of technological diffusion. Data limitations also mean that our research relies on the use of several proxies, which provide only indirect, and potentially ambiguous, measures of underlying drivers and barriers. And even where data are available, measurement errors in these data mean that our econometric estimations are potentially inaccurate. Therefore, in line with other large-sample, quantitative studies, the results of our analysis need to be approached with a degree of healthy caution.

At the same time, however, it is clear that a quantitative approach has particular strengths in the present context. By allowing us to investigate patterns of diffusion across a large number of countries and, moreover, years, we are well placed to confirm and/or reject claims about the generic determinants of technological diffusion. That is, it has the advantage of generalizability, yielding insights that are more generally applicable across a range of different geographic contexts. This does not mean, of course, that we believe our approach is superior to recent small-sample, qualitative studies in geography (e.g., Ivarsson 2002; Hayter and Edgington 2004). In the end, we would argue that both approaches are complementary, each providing valuable, mutually instructive insights into the complex process of technological diffusion at the global level.

Geographers, of course, were at the forefront of quantitative diffusion research. Hägerstrand's (1967) early work on understanding innovation diffusion in Sweden using simulation modeling is particularly noteworthy in this respect. However, already long before the "cultural turn" in economic geography (Barnes 2001), geographers' interest in formally modeling the diffusion of new innovations waned (Gregory 1985). Indeed, much of the recent quantitative research into the diffusion of new technology has been undertaken by economists, sociologists, and business scholars. The present article seeks to place geographers back at the forefront of diffusion research by investigating the spread of new technologies at the global level. Our contribution to the existing literature in this field is threefold. First, we go far further than recent studies in analyzing latecomer advantage, both in terms of learning investments and capital stock effects. Although existing work by marketing scholars has examined rates of diffusion in both early-adopting and late-adopting countries, it has failed to establish the identity of these countries (i.e., are they developed or developing countries?). Nor, with one exception (Dekimpe, Parker, and Sarvary 2000a), has the literature examined the impact of existing capital commitments. We attempt to address both of these gaps in the present article, thereby providing a more comprehensive and geographically nuanced analysis of latecomer advantage.

Our second contribution is to investigate more fully the impact of the process of global economic integration on rates of technological diffusion. While economists have analyzed the role of international trade and, to a lesser extent, investment as a channel for the transfer, adoption, and diffusion of new technology, they have tended to do so individually, often using widely varying methodological approaches (e.g., Reppelin-Hill 1999; Gong and Keller 2003). By using a single estimation model, we avoid this inconsistency and, for the first time, analyze quantitatively the comparative role of trade and investment in the geographic spread of new technology at the global level.

Our third important contribution is that, unlike previous studies, the majority of which focus on a single technology, we examine patterns of diffusion for three technologies, selected because each is widely used in a different economic sector. They are: continuous steel casting, digital mainline telephone lines, and shuttleless textile weaving looms. Given that spatial and temporal patterns of diffusion "can vary greatly across technologies and industries" (Metcalfe 1997, 123), it is naïve to assume, as some previous analysts have done, that the results from single-sector, single-technology diffusion studies also apply across other technologies and other economic sectors. A multisector, multitechnology approach helps to overcome this problem of generalizability and so better corroborate or reject claims about the generic pattern and determinants of technological diffusion.

The article is organized as follows: The next two sections elaborate recent claims about latecomer advantage and economic globalization. Next, the findings of previous studies on international technological diffusion, late industrialization, and market openness are briefly reviewed. The data, method, and estimation techniques employed in our research are then described and the results are presented. Finally, the article concludes by

summarizing key findings, discussing their geographical implications, and outlining important caveats.

Technology and Latecomer Advantage

Technologies do not spread instantaneously. Instead, diffusion is characteristically a long, drawn-out process, involving the adoption and application of new technology by a growing share of firms (Rogers 1995; Stoneman 2002). Theoretical models disagree as to why firms adopt innovations at different times. Epidemic models emphasize information (Griliches 1957). Certain firms are hypothesized to adopt earlier because they come into contact with, and learn from, adopters of the new technology before others. Economic models, on the other hand, predominantly emphasize firm heterogeneity (Ireland and Stoneman 1986). Firms adopt technologies at different times because they differ with respect to various organizational and environmental variables influencing the economic returns from adoption (Blackman 1999). Relevant factors here include the vintage of a firm's capital stock, the level of human capital, and the cost of locally available credit. The important point is that firms that expect to enjoy higher net returns to adoption are assumed to implement the new technology before their counterparts with lower expected net returns.

Applied in the context of international technological diffusion, both approaches generally predict that new technology will be adopted first in developed economies. These account for the vast majority of technological innovation and development (UNCTAD 1999). Geographical proximity with innovators and/or early adopters suggests that firms in developed countries are more likely to learn about the existence of a new technology first. A combination of skilled labor, high capital-labor ratios, and low interest rates also means that they are likely to find it more profitable to adopt more advanced, productivity-enhancing technology than their counterparts in developing countries. Firms in developed economies are additionally better able to absorb any losses arising from the adoption of new, innovative technologies owing to their superior financial resources (Lall 1992; Rogers 1995; Bell and Pavitt 1997; Todaro 2000).

Yet, while many accept that developed economies may be best placed to adopt new technology first, it has been suggested that developing countries' late-industrialization status means that they are well positioned to diffuse new technology more rapidly. Underlying this belief are two key assumptions. The first is that latecomer (i.e., developing) countries can take advantage of technological advances made by first-comer (i.e., developed) countries (Gerschenkron 1962). This can be achieved, either directly, through FDI and technology purchases (imports, licensing arrangements, etc.), or indirectly, via knowledge spillovers (Bell and Pavitt 1997; Hayter and Edgington 2004). Examples of the latter include imitation through reverse engineering and the transfer of know-how from the movement of people between firms (Saxenian 1996; Dicken 2003). Either way, the strong assumption is that developing countries can acquire modern technology innovated in developed economies, often at a fraction of the original research and development (R&D) costs, thereby leapfrogging many decades of technological progress (Teece 2000). Supporting this optimism, proponents point to Asian success stories such as Japan, South Korea, and Taiwan, whose rapid postwar growth was rooted in the successful acquisition, imitation, and copying of technologies originally developed in industrialized economies (Lim 1999).

A second assumption is that late-industrializers are able to diffuse new technology throughout their economic structure faster than early industrializers on account of their so-called latecomer advantage. Two sources of latecomer advantage are identified in the literature. One relates to the level of capital stock. Owing to their late start in industrializing, many developing countries have yet to install significant capacity. This means that they can readily select between competing technologies according to their expected returns and, moreover, adopt the new technology as an integral part of capital expansion (IBRD 1992). Many developed economies, by contrast, have often already installed significant capacity. This so-called vintage capital is known to be a source of considerable inertia in technological change (Clark and Wrigley 1997). Owing to the nonrecoverability of sunk costs and/or low capital charges, firms in developed economies may actually find it more profitable to continue using existing, less-efficient technology than to invest in new, more efficient plant and equipment (Metcalfe 1997). Especially in capital-intensive and/or network industries, characterized by large investments and long capital turnover times, past investment may considerably limit the scope for the diffusion of new technology (Soete 1985; Abramovitz 1986; Amiti 2001). It is therefore suggested that developing countries are better placed than developed ones to rapidly diffuse technological innovations throughout their industrial structure.

Another source of latecomer advantage derives from learning investments and increasing net returns to adoption over time. During the early stages of development and commercialization, new technologies are often costly, inflexible, and unreliable. For this reason, take-up is characteristically restricted to a handful of innovative,

risk-taking adopters in developed economies with the financial, technological, and managerial capabilities required to master the technology profitably. Expenditures by these firms reduce costs, improve performance, and make the new technology profitable among a much larger number of prospective adopters. Latecomers are assumed to be able to take advantage of this accumulated learning with the new technology resulting in a faster diffusion rate in developing countries (Grübler 1997; Rassekh 1998; Dekimpe, Parker, and Sarvary 2000a).

Globalization, Neoliberalism, and Technological Change

Early modernization theorists of the 1950s and 1960s were highly optimistic about the potential for developing countries to exploit their latecomer status. Through the use of Western capital and technology, it was suggested that developing countries would rapidly catch up with the industrialized nations (Rostow 1960). Not everyone, of course, shared this optimism. Advocates of dependency theory (Baran 1957; Frank 1969), and its near relation, world systems theory (Wallerstein 1979), pointed toward structural barriers inhibiting catch-up in developing countries. For example, overreliance on a handful of primary goods exports, unequal terms of trade, and high tariff barriers on manufactures in "core" economies, were all implicated in continued poverty in the "periphery." In fact, far from providing an opportunity for developing countries to escape their peripheral status, technology was seen as helping to sustain core-periphery divisions (Shrum 2001). The concentration of technological innovation, ownership, and control in the core allowed developed economies to maintain their dominant position. Transfer of technology from core to periphery was possible. Yet it took place on unfavorable terms and, moreover, involved older plant and equipment far behind the high value-added technological frontier. The implication of dependency and world systems theory was that core economies would generally retain their technological leadership position while the majority of peripheral nations would remain technological laggards. There was little scope for genuine catch-up.

Variants of dependency and world systems theory enjoy continued popularity in certain quarters. Yet the past decade has witnessed renewed interest in the possibilities for catch-up through technology transfer, adoption, and diffusion in developing countries. One reason for this optimism is the rapid and sustained pace of technological progress. The past three decades have witnessed the emergence of a range of production and consumption technologies that offer developing countries considerable promise in terms of value-added, poverty reduction, and environmental protection (UNDP 1998, 2001). Indeed, many of the same flexible ("post-Fordist") technologies that have underpinned spatial and organizational restructuring of the core economies (Dicken 2003) are often portrayed as providing new opportunities for catch-up in the periphery. Another reason for renewed technological optimism is economic globalization. According to an influential school of neoliberal thought, the growing integration of national economies has considerably increased the scope for cross-national technology transfers, opening the way for the rapid global diffusion of advanced technology (OECD 1998; IMF 2000).

The literature identifies two channels through which economic globalization accelerates the diffusion of new technology. The first is international trade. Trade allows countries to import modern technology that has been innovated or manufactured elsewhere. Indeed, it is suggested that a combination of saturated demand in home markets and the strengthening of intellectual property rights legislation has meant that firms in developed economies are increasingly willing to sell their technology to firms in developing countries. More generally, it is suggested that formal and informal interactions between trading partners promote cross-country learning about cost, technical performance, etc., of new technology. Again, these epidemic-type dynamics are said to accelerate the geographic spread of technological innovations, particularly between countries that are more open to trade (D. Coe, Helpman, and Hoffmaister 1997; Globerman, Kokko, and Sjöholm 2000).

Neoliberal theorists additionally argue that trade increases the demand for new technology through intensified market competition. Imports of cheaper and/or superior goods may stimulate domestic firms to upgrade their technology in order to remain competitive. Indeed, limited import competition, arising from high tariff and nontariff barriers, is widely blamed for the technological stagnation witnessed in developing countries such as India under import-substitution policies (Tharoor 1997). Likewise, faced with potentially high levels of competition in overseas markets, exporters may be encouraged to adopt the latest technological configurations. Thus, the existence of strong export incentives is said to have contributed to the dynamism of East Asian newly industrializing economies (NIEs), as domestic firms sought to compete in international markets by upgrading their technological base (Booth 2001).

A second channel through which globalization is thought to influence the transfer, adoption, and diffusion

of advanced technology is investments by transnational corporations (TNCs). TNCs generate, control, and manufacture the majority of the world's advanced technology (Globerman, Kokko, and Sjöholm 2000). Consequently, investments by TNCs in the form of foreign direct investment (FDI) are assumed to play a lead role in the international diffusion of new technology (UNCTAD 1999; Dicken 2003).

As well as direct investments, the involvement of TNCs in host economies is thought to accelerate the diffusion of new technology indirectly by influencing the choices of domestic firms. Market competition, in the form of cheaper and/or better-quality products, provides one mechanism through which foreign transnationals can prompt domestically owned firms to adopt more advanced process and/or product technology. Another mechanism is technological spillovers. The presence of TNCs is widely assumed to result in the transfer of information, know-how, and skills about new technologies through demonstration effects, employee mobility, and supply-chain linkages (Globerman, Kokko, and Sjöholm 2000; Campos and Kinoshita 2002; Potter, Moore, and Spires 2002; Ivarsson and Alvstam 2004).

Based on these observations, proponents of neoliberalism have argued that the diffusion of new technology will be faster in countries willing and able to interact with the global economy via international trade and investment. Conversely, countries that are comparatively closed to these channels are likely to experience slower within-country diffusion rates.

Other Determinants of Technological Diffusion

Levels of development, latecomer advantages, and trade and investment openness are not the only factors hypothesized to influence the diffusion of new technology. The recent literature identifies three other determinants.

The first involves a country's geographical location. Recent empirical work suggests that diffusion is "geographically localized" (Globerman, Kokko, and Sjöholm 2000; Keller 2002; Milner 2003) in that a technology diffuses faster in a country where it is already more widely diffused in neighboring countries. Underlying these regional effects are contagion and contact with prior users or producers of technology. Geographic proximity, it is argued, facilitates interaction, information exchange, and, hence, cross-country technological learning and imitation (Soete 1985; Ganesh, Kumar, and Subramaniam 1997).

A second determinant is the level of education. A number of cross-country analyses report a positive correlation between levels of educational attainment and diffusion success (Caselli and Coleman 2001; Kiiski and Pohjola 2002). This is commonly explained by two factors. One is that well-educated workers are more likely to be aware of the existence of new technology. A second is that educated workers are more likely to be able to profitably master new technologies.

The third determinant of adoption frequently discussed in the recent literature is social system heterogeneity. Empirical studies have found that new technologies diffuse more slowly in countries with more socially mixed populations (Takada and Jain 1991; Dekimpe, Parker, and Sarvary 1998). Again, this is commonly explained by contagion dynamics and, specifically, learning through social interaction. Actors who are similar in some way (e.g., ethnicity, age, etc.) are more likely to exchange information and imitate each other's behavior. Conversely, dissimilar actors are less likely to communicate among themselves, reducing the prospects of learning and social emulation (Rogers 1995).

The Empirical Record

So far, the article has detailed two closely related claims about the spatial and temporal pattern of cross-national technological diffusion, namely: (1) that late-industrializing (i.e., developing) countries are able to diffuse new technologies throughout their industrial structure more rapidly than early-industrializing (i.e., developed) economies; and (2) that engagement with the global economy via international trade and foreign investment accelerates the diffusion of new technology.

Clearly, both of these claims are appealing, particularly for developing countries. Yet, a key question is whether they are supported by the empirical record. Case-study evidence from small-sample, qualitative research has so far yielded somewhat mixed results. The literature documents examples of several NIEs that have rapidly exploited modern technological advances as an integral part of capacity addition (Amsden 2001). Equally, however, the literature catalogues examples of countries whose efforts to diffuse modern technology have failed, resulting in an ever-widening technology gap with leading developed economies, as well as a growing number of NIEs. For example, Lall and Pietrobelli (2002) describe how, despite a number of technology policy initiatives, institutions and intermediaries, Kenya's "technology and capabilities lag behind those of many countries in Asia and Latin America" (p. 55). Similarly, evidence that trade and investment openness have

driven technological upgrading (IBRD 1993) is contradicted by examples of countries and sectors where market opening has paradoxically resulted in technological stagnation, particularly among small-scale domestic firms (Katz 2000). Unfortunately, owing to their reliance on data drawn from single countries, single technologies, and single policy regimes, it is difficult to determine which of these variables explain the very different results achieved in previous studies.

Large-sample, quantitative evidence is less ambiguous. Yet, even here, important questions remain unanswered. Most studies agree that rates of diffusion are faster in countries that adopt the new technology later (Takada and Jain 1991; Ganesh and Kumar 1996; Dekimpe, Parker, and Sarvary 2000a). None of these studies, however, investigates the developmental status of these countries and, specifically, whether developing countries are, as widely assumed, late-adopters. Turning to a country's general level of economic development, several studies find that higher-income countries adopt and diffuse new technology more rapidly (Dekimpe, Parker, and Sarvary 2000b). Yet others find that income has only a weak or negligible impact on rates of technological diffusion (Wheeler and Martin 1991; Lücke 1993). Finally, with respect to capital stock, Dekimpe, Parker, and Sarvary (2000a) conclude that a larger installed base slows the diffusion of new technology, although it is worth noting that their study covers a single technology.

More certain is the positive influence of trade on the diffusion of new technology. Wheeler and Martin (1992), Reppelin-Hill (1999), and Caselli and Coleman (2001) all find that rates of technological diffusion are positively correlated with measures of trade openness; Blackman (1994) estimates that diffusion rates for steel technology are faster in countries that export higher volumes of steel; and Gruber (1998) finds that trade liberalizations in the wake of the World Trade Organization's Multi-Fibre Agreements are the single most important factor influencing the diffusion of textile technology within his sample of industrialized economies.

In contrast to the abundant analyses of international trade, the role played by FDI in the transfer, adoption, and diffusion of physical technology has largely been neglected in the empirical literature (van Pottelsberghe de la Potterie and Lichtenberg 2001). The only systematic evidence available is indirect and comes in the form of analyses of the relationship between FDI and economic productivity. Suffice to say, results from these studies are generally mixed. While several authors find a positive correlation between multinational corporations' involvement and rates of productivity growth (Blomstrom 1986), others find a negligible, or even negative, effect (Aitken and Harrison 1999; Mencinger 2003).

Considered together, then, the existing literature neither allows us fully to confirm nor fully to refute our two central claims about cross-national patterns of technological diffusion. Although it answers certain questions, it often does so only indirectly and ignores some others altogether. Responding to these gaps and ambiguities in the existing literature, the present study attempts to provide a more conclusive analysis of technological diffusion, latecomer advantage, and global economic integration.

Building on the approach adopted by several existing studies (Lücke 1996; Gruber 1998; Dekimpe, Parker, and Sarvary 2000a, b), we use quantitative techniques to analyze the determinants of technological diffusion across a large sample of countries (between 75 and 147, depending on the technology). However, as well as examining the impact of adoption timing on rates of diffusion, we undertake two further important tests of latecomer advantage. First, to probe objectively the intuitive claim that developing countries benefit from learning investments made in developed countries, we specifically investigate the identity of early-adopters and late-adopters. Thus, we establish whether late-adopters are, as widely assumed, developing countries. Secondly, to test the claim that a smaller capital stock allows developing countries to diffuse new technology more rapidly, we analyze (1) comparative levels of capital stock between developed and developing countries and (2) the impact of capital stock on rates of diffusion. These additional tests allow us to scrutinize more thoroughly than before the empirical reality of latecomer advantage in developing countries.

Furthermore, our study focuses on three technologies, rather than one, which is the norm among much existing work (Gruber 1998; Dekimpe, Parker, and Sarvary 1998; Hargittai 1999). A particular advantage of this multi-technology approach is that it allows us to determine whether there are generic patterns and determinants of diffusion success across very different industrial sectors and technologies. Owing to the idiosyncratic nature of technological diffusion (Metcalfe 1997), single-technology studies have been unable to offer convincing generalizations.

Our technologies comprise continuous steel casting, digital telephone mainlines, and shuttleless textile weaving looms. The choice of these technologies was dictated by three considerations. First, the individual technologies are very different, both in terms of their capital requirements, technological complexity, and compatibility. For example, continuous casting equipment

is less capital intensive than shuttleless looms and can be more easily incorporated into existing plants, while digital telephony, for example, is more technologically sophisticated than either continuous casting or shuttleless looms.

Second, all three technologies are superior to older substitutes. Compared to conventional ingot casting, continuous casting is markedly more capital, energy, and labor efficient (Rosegger 1979). It delivers improved yield, that is, a higher ratio of semifinished product to liquid steep tapped from the furnace, due to the continuity of the casting process, and is particularly suitable for steel production in small and medium-sized plants (Schenk 1974). Shuttleless looms allow textile manufacturers to achieve far higher levels of productivity than traditional fly-shuttle looms (Dumas and Henneberger 1998). They benefit from greater reliability and enhanced speed compared to the conventional shuttle looms (Smith 1974). And digital telephone lines offer a number of important benefits over analog ones, such as more efficient channel usage and improved data reproduction (Barwise and Hammond 2002), potentially enhancing Internet usage (Beilock and Dimitrova 2003).

The final factor shaping our choice of technology was data availability. Reliable statistical data on the national take-up of all three technologies are not only obtainable for a large number of years, covering the period since first international adoption, but also for a large number of countries. Too many existing studies cover only "a *limited* set of industrialized countries" and the "inclusion of a larger number of countries . . . is extremely important . . . for generating empirical generalizations and normative insights for practitioners" (Dekimpe, Parker, and Sarvary 2000c, 55). Our study covers between 75 and 147 countries, depending on the technology, and is therefore much more representative than small-sample studies.

Research Design

The Dependent Variables

The dependent variables for each of our quantitative estimations are of the event-history type (Box-Steffensmeier and Jones 1997). They capture the time that elapses between initial adoption and "penetration" (see below) of the technology within each country.[2] Countries exit the sample at the time of penetration. If penetration does not take place, countries remain "at risk" of penetration until 2001, the end of our study period. Such observations are said to be right-censored. Time is measured in discrete rather than continuous units since the explanatory variables are only available annually. Initial adoption is the date when the new technology was first adopted in a country.

Our definition of penetration depends on the technology in question.[3] In the case of digital telephone lines, penetration is taken as full uptake among potential adopters, that is, all mainline telephone lines are digital. This is because there are no technical or efficiency reasons that would discourage switching all mainlines from analog to digital. To account for statistical error in the measurement of this variable, we take 99.5 percent as full uptake. France was one of the early pioneers, starting to adopt digital mainline telephone lines in 1980. By 2001, 64 out of 147 countries in our sample had achieved full adoption. Data are taken from the International Telecommunications Union's World Telecommunications Indicators Database (ITU 2003).

The corresponding definition of penetration for steel is 97 percent of steel production by continuous casting technology. Although continuous casting is superior for the vast majority of casting applications, ingot casting is still required for the production of selected specialty steels and products with certain shape requirements (Freitag 1998). These requirements, however, typically account for a small percentage of total steel output. Consequently, we take 97 percent as the benchmark for penetration of continuous casting technology, a ceiling currently achieved by most major steel-producing countries (see IISI 2002). Several developed countries started adopting continuous casting steel technology on a commercial scale in the beginning of the 1960s. By 2001, fifty-two out of seventy-eight countries in our sample had reached the benchmark of 97 percent penetration. Data are taken from various issues of the *Steel Statistical Yearbook*, published by the International Iron and Steel Institute (IISI various years) with early data complemented by Poznanski (1983).

The cut-off point we select for shuttleless looms is far lower. This choice can be explained by two factors. One is that shuttleless looms are known to have diffused far more slowly than the two other technologies. Although commercially available since the early 1960s, textile producers have proved surprisingly reluctant to adopt shuttleless looms. This was initially even true for weaving companies in developed countries (Smith 1974). Moreover, we expect traditional shuttle looms to play a significant role for some time to come. Despite suffering from lower levels of productivity, a combination of low profitability in the sector, high capital costs, long amortization periods, and the availability of second-hand equipment means that many producers will resist the imperative to upgrade to shuttleless looms in the short- to

medium-term (Smith 1974; Gruber 1998). Another potential cause for the lower speed of diffusion in the textile sector could be that the steel and telecommunications sectors are likely to have a higher degree of oligopoly, even though we have no reliable data to prove this point. A smaller number of firms might render diffusion easier to achieve. We therefore consider penetration of new technology in the textile industry as the point when shuttleless looms account for more than 50 percent of installed looms. Even at this level, only thirty of the seventy-five countries in our sample achieve penetration by 2001. Such low shares can represent a problem for event-history analysis. We therefore experimented with an even lower penetration level of 30 percent, which raised the number of countries achieving penetration to thirty-eight, and our main results were little affected. Data are taken from various issues of the International Textile Manufacturers Federation's *International Cotton Industry Statistics* (ITMF various years).

Figure 1 plots the percentage of countries in the sample achieving penetration for the three technologies against time since first adoption.

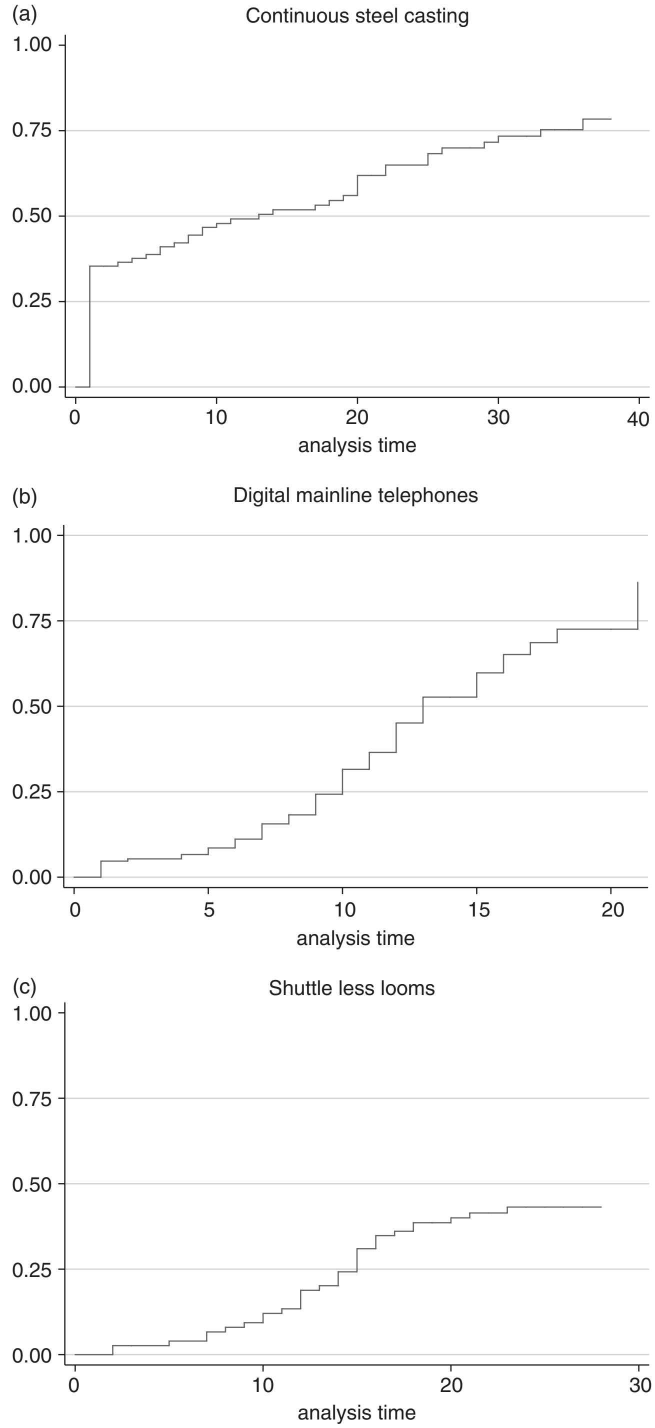

Figure 1. Percentage of sample achieving penetration since time of first adoption (Kaplan-Meier failure estimates).

Estimation Technique

To estimate our event-history models, we employ the Cox (1975) proportional hazards model. It is a popular and commonly used estimation technique in the medical and engineering sciences (Collett 1999). Within the social sciences, it is currently only widely used in economics, although it is becoming more popular in other disciplines, including geography—see, for example, Kim and Horner (2003), who estimate housing duration as a function of spatial and property-specific variables. Cox's model assumes that there is a time variant underlying baseline hazard of a certain event occurring at any point in time. In the medical sciences, the event is often death; in engineering, it is characteristically the failure of an appliance, but, in principle, any event can be modeled. In the present context, the event of interest is the penetration of a technology within a country, as defined above, and what is modeled is the duration time until penetration. Explanatory variables raise or lower the baseline hazard by a proportional amount, which is why it is called a proportional hazard model. The estimated coefficients are not directly comparable to the ones from a simple ordinary least squares (OLS) or probit model, but their intuitive meaning is similar: A coefficient with a positive sign raises the likelihood of penetration, whereas the opposite is the case for a coefficient with a negative sign.

More formally, the hazard rate in a given year is the probability of penetration in that year, contingent on the country not having achieved penetration in the previous year. Let $\rho(t)$ be the probability of penetration at time t (given that the technology has not penetrated in the country before t); this is the hazard of penetration. Denoting $\rho_0(t)$ the exogenous baseline hazard, which reflects those time-dependent factors affecting $\rho(t)$ that

are common to all countries, the Cox proportional hazard model assumes that

$$\rho(t) = \rho_0(t)\exp(\beta^T \mathrm{x}(t)), \qquad (1)$$

where $\mathrm{x}(t)$ is a vector of covariates shifting the baseline hazard, and β^T is a vector of parameters to be estimated. Notice that covariates change over time.

A refinement of the Cox model is developed in this research, which, to our knowledge, is novel to the technology diffusion literature. Our stratified proportional hazard model allows the baseline hazards $\rho_0(t)$ to differ between strata of countries (although they are still assumed uniform within a stratum). Thus, for stratum i the stratified model can be written as

$$\rho_i(t) = \rho_{0i}(t)\exp(\beta^T \mathrm{x}(t)). \qquad (2)$$

The stratified proportional hazard model is more flexible, allowing the baseline hazard to vary across, for example, income groups. It allows us to test whether our results are simply driven by strata-specific baseline hazards. It also controls for very crude differences across strata in determinants of technology diffusion that cannot be explicitly controlled for due to lack of data, for example, differences in factor prices (see below). For stratification we follow the World Bank classification of countries into five groups comprising low income, lower middle-income, upper middle-income, Organization for Economic Co-operation and Development (OECD) countries, and, finally, other non-OECD high-income countries.[4]

For both the standard and the stratified Cox proportional hazard model, a partial Maximum Likelihood estimation is carried out, where the partial likelihood function is constructed as follows: assume that all events of failure or, in our case, penetration can be ordered along a continuous time dimension. We want to calculate the probability that, contingent on an event taking place at time t_i, it is country i that achieves penetration. The contingent probability that country i achieves penetration at time t_i equals

$$\hat{\rho}_i(t_i) = \frac{\rho_i(t_i)}{\sum\limits_{j|t_j \geq t_i} \rho_j(t_i)} = \frac{\exp(\beta^T \mathrm{x}_i(t_i))}{\sum\limits_{j|t_j \geq t_i} \exp(\beta^T \mathrm{x}_j(t_i))}. \qquad (3)$$

The numerator denotes the hazard at time t_i that country i would experience penetration divided by the sum of all the hazards for all the countries who were at risk at time t_i. Note that the baseline hazards cancel each other out as they enter both the numerator and the denominator. The partial likelihood function, one each for the three different technologies, to be maximized with respect to the vector β^T is then simply

$$\mathrm{L} = \prod_{t_i} \hat{\rho}_i(t_i), \qquad (4)$$

that is, each observed penetration contributes one term like (3) to the partial likelihood—see Collett (1999) for more details.

Event-history models are relatively novel in the mainstream technology diffusion literature but have been applied recently by marketing scholars, who similarly note their advantages over more traditional estimation techniques (Dekimpe, Parker, and Sarvary 2000a). Most existing studies have sought to estimate technology-specific diffusion functions based on the Bass, Gompertz, or logistic model (see the review in Dekimpe, Parker, and Sarvary 2000c). Compared to this literature, our use of the Cox model has two distinct advantages. First, the baseline hazard in our analysis is allowed to be very flexible, whereas logistic, Gompertz, and other functional models impose a certain diffusion shape on the technology. Although the idea of an S-shaped diffusion curve has emerged as a leading stylized fact within the diffusion literature, there is no guarantee that all technologies follow this or any other particular functional form in their global or regional diffusion (Rogers 1995; Grübler 1997). The fact that no specific functional form is required with the Cox model allows greater flexibility. Second, there is no need to estimate the underlying determinants of the baseline hazard, which depend, possibly in a complex way, on unobserved variables. The only requirement of the Cox (1975) proportional hazards model is that the explanatory variables raise or lower the baseline hazard by a constant proportional amount, an assumption that can be readily tested. As a semiparametric model, the Cox model depends on less restrictive assumptions than the fully parametric Exponential, Weibull, Gamma, or other models, which lead to more precise estimates only if the underlying probability distribution assumes a specific corresponding functional form (Collet 1999).

All estimations are based on a robust variance estimator, and observations are assumed to be clustered, that is, they are assumed to be independent only across countries but are allowed to be correlated within countries over time. Since the same set of countries appears repeatedly over time in the sample, a failure to take clustering into account would underestimate standard errors. For handling tied times of penetration, that is, where the penetration of a technology occurs in more than one country in the same year, we employ the so-called Efron method, which is an approximation of the exact marginal likelihood. We experimented with various

methods for dealing with ties, which showed that the choice of method hardly affects our estimation results, not least because, apart from the digital telephone technology, there are not many ties in the sample.

Explanatory Variables

We use two sets of explanatory variables. One set consists of variables that are generic, while the other is technology-specific. Among the generic variables are the natural log of per capita income, the stock of FDI in the economy, and general trade openness. We also include two generic control variables—secondary school gross enrollment ratio, as a proxy for the level of human capital, and ethnic fractionalization to control for the influence of social heterogeneity. Other and possibly superior proxy variables for the level of human capital, such as the tertiary enrollment ratio or educational attainment variables, have much lower data availability than the secondary enrollment ratio.

As a measure of a country's general level of development, we use per capita income (*GDP p.c.*) in real prices of 1995 (IBRD 2003). In line with previous research, we take the natural log of *GDP p.c.* due to its heavily skewed distribution. The value of the capital stock owned by foreign investors is measured by the stock of FDI relative to GDP (*fdistock*) using data taken from UNCTAD (2003b) and De Soysa and Oneal (1999). The trade (*%trade*) and school enrollment (*%secondaryenroll*) data are taken from IBRD (2003). General trade openness is measured as the sum of exports and imports divided by GDP. Ideally, we would have liked to include general export and import openness separately, but the two variables are too highly correlated with one another. We experimented with a simple dummy variable for membership in the World Trade Organization (WTO), but this is a very crude variable, which we found to be insignificant throughout and therefore have not included in the estimations.[5] We use Vanhanen's (1999) measure of ethnic fractionalization to control for social system heterogeneity. The author bases his measure of fractionalization (*ethnicfract*) on three types of ethnic groups, defined by (1) racial differences, (2) linguistic, national, or tribal differences, and (3) religious differences. Vanhanen subtracts the percentage of the largest group in each type of ethnic group from 100 as a proxy for fractionalization in each group and then sums the resulting figures across all three groups. This variable is time invariant and refers to information from the 1990s. Unfortunately, no time-series information is available for this variable, although it is worth noting that the extent of ethnic fractionalization is unlikely to vary much over time. Results reported below are very similar if we replace Vanhanen's (1999) measure of ethnic fractionalization with two competing ones created by Alesina et al. (2003) and Fearon (2003).

The technology-specific variables of greatest interest to our analysis are the year of first adoption, existing capital stock, and product-specific trade variables. The year of first adoption (*adoptionstart*) captures latecomer advantage in terms of previous learning investments. In order to capture vintage capital effects (*capitalstock*), we use the following, all measured in the year of first adoption: for digital telephone lines, the natural log of the number of mainline telephones, and for shuttleless looms, the number of installed weaving looms. For continuous casting, no capital stock variable is directly available, and so we take the natural log of steel production as a proxy for capacity. Data are taken from ITU (2003), ITMF (various years), and IISI (various years). Like Dekimpe, Parker, and Sarvary (2000a), we take the natural log of *capitalstock* to reduce the skewness of its distribution.

In the case of both steel and textiles we use product-specific exports and imports data. For steel, exports are measured relative to production and imports relative to apparent consumption (IISI various years). Unfortunately, we are unable to use the same measure for textiles, since ITMF does not provide any production data and the *Industrial Commodity Statistics Yearbook* only covers a few countries (United Nations various years). For this reason we measure exports and imports of textiles relative to the country's general exports and imports, taken from the UN Commodity Trade Statistics Database (United Nations 2003).

The context for the adoption of telecommunications equipment is very different. Unlike either steel or textiles, the vast majority of output from the telecoms sector (i.e., telephone calls, etc.) is domestic and non-traded. Competition, demonstration, and/or information effects arising from product-specific imports and exports are therefore less relevant, even though the latest trend toward locating call centers in foreign countries might change this in the future. The UN Commodity Trade Statistics Database (United Nations 2003) does not contain information on telecommunication services, and no product-specific trade variables can therefore be included. However, we might also expect general trade flows to influence the diffusion of telecommunications equipment. Trade could potentially increase the cross-country transmission of knowledge between adopters and potential adopters. For example, countries that export a large share of their output are more likely to learn about the benefits of new telecommunications equipment

Table 1. Summary Descriptive Variable Statistics (Steel, Telecommunications, and Textiles)

Variable	Obs	Mean	Std. Dev.	Min	Max
ln GDP p.c.	907	8.63	1.37	5.12	10.70
adoptionstart	907	1973.34	8.77	1962	1992
ln capitalstock	907	8.17	1.77	1.79	11.68
steelexports	907	0.36	0.30	0.00	1.76
steelimports	907	0.40	0.45	0.00	7.45
%trade	907	55.60	34.25	8.96	352.85
fdistock	907	10.32	10.53	0.00	85.87
%secondaryenroll	907	76.27	25.80	8.97	160.11
ethnicfract	907	29.11	30.07	0.00	149.00
%regionaldifusion	907	– 0.36	13.15	– 47.34	28.84
ln GDP p.c.	1430	7.68	1.62	4.44	10.74
adoptionstart	1430	1988.51	3.60	1980	1998
ln capitalstock	1430	17.55	2.32	12.70	23.07
%trade	1430	73.24	45.04	13.25	384.06
fdistock	1430	16.95	20.29	0.00	271.57
%secondaryenroll	1430	63.07	33.58	4.95	160.11
ethnicfract	1430	40.90	32.34	0.00	149.00
%regionaldiffusion	1430	– 1.81	17.59	– 45.77	33.10
ln GDP p.c.	1227	7.50	1.43	4.44	10.71
adoptionstart	1227	1977.76	3.10	1974	1999
ln capitalstock	1227	9.09	1.70	4.70	13.35
textilesexports	1227	0.03	0.05	0.00	0.46
textilesimports	1227	0.03	0.03	0.00	0.20
%trade	1227	52.21	23.87	6.32	177.08
fdistock	1227	11.75	13.65	0.00	89.16
%secondaryenroll	1227	51.43	26.48	4.28	108.49
ethnicfract	1227	42.52	32.70	0.00	149.00
%regionaldiffusion	1227	– 4.52	12.69	– 26.37	46.08

through a variety of formal and informal linkages. In order to enhance national competitiveness, countries more open to trade might also have an incentive to switch faster to digital telecommunications.

The remaining technology-specific variable seeks to control for the influence of neighborhood contagion effects. For each technology, we measure the average share of the new technology within the region relative to the global average share (*%regionaldiffusion*). The variable is measured relative to the global average in order to correct for the increasing global adoption of the technology over time. This ensures that the variables do not spuriously pick up a time effect. The classification of regions follows World Bank conventions: Northern America, Latin America and the Caribbean, Western Europe, Eastern Europe and Central Asia, Northern Africa and the Middle East, Sub-Saharan Africa, South Asia, as well as, lastly, East Asia and the Pacific.

A basic lack of data means that we are unable to control for technology-specific factor prices of capital, labor, and resource inputs. Even general factor price data are not available for a large sample of countries. Yet it is worth noting that previous small-sample studies have generally failed to find a significant effect of factor prices on rates of technological diffusion (Gruber 1998; Reppelin-Hill 1999). Also, stratification along income groups should partially control for some crude differences in these omitted variables. Table 1 provides summary descriptive statistical information for our explanatory variables for each of the three samples.

Results

Our first step is to determine whether developing countries (1) adopt new technologies later than developed countries and (2) are characterized by a smaller capital stock. Results for our preliminary analysis are provided in Table 2. It shows the 25, 50 (median), and 75 percentile, as well as mean year of first adoption and logged level of installed capital for the group of developed OECD countries and developing countries. Half of the developed countries had first adopted continuing casting technology by 1969. It was not until 1984, however, that the equivalent share of developing countries had done so. By then, the technology had been adopted by all developed economies (not shown in table). The difference in the average year of first adoption is 12.4 years, which is highly statistically significant. What this suggests, then, is that steel producers in developing countries first made use of continuous casting much later than their counterparts in developed economies.

The difference between the developed and developing country median and mean adoption is about four years in the case of digital telephony. Again, this suggests that developing countries at the time of first adoption of the new superior technology generally adopt new telecommunications technology later than developed ones, although the disparity is smaller than in the case of steel casting technology. The difference is least for the textile technology, amounting to one year in median and 2.3 years in mean comparison, which is still statistically significant, albeit only at the 10 percent level. Two factors possibly explain the comparatively small difference between developed and developing countries in adoption timing for shuttleless looms. One is investment cost. The high capital requirements of shuttleless looms means that producers in developed economies with installed capacity have been reluctant to upgrade to the new technology. Indeed, a number of firms have continued to use older, shuttle looms, despite their lower efficiency. A second factor is product mix. Shuttleless looms are particularly suitable for manufacturing the

Table 2. Summary Statistics on First Year of Adoption and Installed Capital Stock by Country Group

Country group (# of countries):	Technology:	*Year of first adoption* 25%	50%	75%	Mean	*t*-test stats. difference of means (*p*-value)
OECD (20)	Steel	1964	1969	1974	1970.2	
Developing (58)		1980	1984	1987	1982.6	
						6.53 (0.0000)
OECD (23)	Telecommunications	1983	1986	1990	1986.3	
Developing (124)		1989	1990	1992	1990.1	
						5.37 (0.0000)
OECD (16)	Textiles	1975	1977	1978	1976.9	
Developing (59)		1976	1978	1981	1979.2	
						1.78 (0.0796)

Logged installed capital stock

Country group (# of countries):	Technology:	25%	50%	75%	Mean	t-test stats. difference of means (p-value)
OECD (20)	Steel	6.86	8.64	9.80	8.35	
Developing (58)		4.52	6.13	7.84	6.14	
						– 3.83 (0.0003)
OECD (23)	Telecommunications	19.04	19.80	21.19	19.95	
Developing (124)		15.14	16.82	18.06	16.66	
						– 7.55 (0.0000)
OECD (16)	Textiles	8.90	9.93	10.69	10.02	
Developing (59)		7.40	8.30	9.81	8.56	
						– 3.11 (0.0027)

Notes: OECD = Organization for Economic Co-operation and Development.

high-volume, standardized fabrics in which developing countries characteristically specialize (Smith 1974; Dicken 2003). Hence, despite high capital costs, producers in these countries have responded to market incentives by investing in shuttleless looms at an early stage.

Taken together, therefore, the above suggests that developing countries, on average, have lagged in the adoption of new technology relative to OECD countries, although the degree of lag varies between the individual sectors. We stress, however, that there will invariably be variations in adoption within countries as well as among countries. A similar difference between OECD and developing countries emerges in the case of capital stock. The mean and percentile value for the logged level of installed capacity is lower for the developing country grouping than the developed country one. This difference holds across all three technologies and is statistically significant throughout. In other words, developed economies generally have more installed textile, steel, and telephone capacity than developing countries. Again, the difference between the two groups of countries varies among the three sectors. The largest difference is found in telecommunications and the least in textiles.

That developing countries should lag developed countries little in terms of installed weaving capacity is hardly surprising. As a labor-intensive activity and, moreover, one in which many low-income countries possess a cost advantage, developing countries have characteristically added substantial textile capacity from an early stage of industrialization. Conversely, growing competition from developing countries has led to a contraction of textile capacity in a large number of developed economies, particularly in low value-added segments (Dicken 2003). The result is that the difference between developing and developed countries in installed textile capacity is comparatively small. The much larger difference in telecommunications capacity is equally plausible. Demand for telecommunications services is typically smaller in low-income countries. Ability to pay for the large investments required to build landline capacity is equally limited. It makes sense, therefore, that installed telecommunications capacity should be lower in developing countries than developed ones.

The above characteristics with respect to (1) adoption timing and (2) capital stock are consistent with expectations. However, in order to determine whether they allow developing countries to diffuse new technologies

Table 3. Within-Country Diffusion of Continuous Casting Steel Technology

	Common baseline hazard	Stratified by income groups
Ln GDP p.c.	0.262	0.778
	(1.92)*	(2.03)**
adoptionstart	0.134	0.133
	(3.69)***	(3.30)***
ln capitalstock	– 0.574	– 0.648
	(6.46)***	(7.58)***
steelexports	1.003	0.315
	(1.99)**	(0.55)
steelimports	0.501	0.937
	(4.83)***	(2.41)**
%trade	0.005	0.005
	(1.33)	(1.10)
fdistock	0.007	0.014
	(0.72)	(2.15)**
%secondaryenroll	– 0.005	0.003
	(0.49)	(0.34)
ethnicfract	0.006	0.003
	(1.47)	(0.73)
%regionaldiffusion	0.025	0.026
	(1.85)*	(2.04)**
Observations	907	907
# countries	78	78
# penetrations	52	52
Log likelihood	– 131.0	– 69.8
Global chi^2–test of Proportional hazard (p-value)	6.52 (0.7700)	5.55 (0.6971)

$^*0.05 < \alpha < 0.10$, $^{**}0.01 < \alpha < 0.05$, $^{***}\alpha < 0.01$

Table 4. Within-Country Diffusion of Digital Mainline Telecommunications Technology

	Common baseline hazard	Stratified by income groups
ln GDP p.c.	0.438	0.606
	(2.32)**	(2.03)**
adoptionstart	0.324	0.335
	(4.61)***	(4.86)***
ln capitalstock	– 0.340	– 0.343
	(2.85)***	(3.10)***
%trade	0.004	0.003
	(1.97)**	(1.01)
fdistock	0.001	0.001
	(0.17)	(0.20)
%secondaryenroll	0.005	0.009
	(0.65)	(1.15)
ethnicfract	0.002	0.003
	(0.47)	(0.55)
%regionaldiffusion	0.054	0.062
	(5.45)***	(5.71)***
Observations	1430	1430
# countries	147	147
# penetrations	64	64
Log likelihood	– 231.0	– 144.9
Global chi^2–test of proportional hazard (p-value)	2.85 (0.9435)	4.31 (0.8283)

$^{**}0.01 < \alpha < 0.05$, $^{***}\alpha < 0.01$

faster, we must now turn to our event-history estimations. Tables 3, 4, and 5 report the estimation results for steel, telecommunications, and textile technology, respectively. The first column of each table presents results under the assumption of a common baseline hazard, while the second column allows this hazard to be stratified according to income groups. We first report the results for the common baseline hazard. Wealthier countries diffuse new steel and telecommunications technology throughout their economic structure more rapidly than poorer ones. Penetration of textile technology, however, is unaffected by a country's level of development. We find evidence of latecomer advantage for all three technologies. The later the technology becomes adopted in a country, the faster it reaches penetration. We also find that the new technologies, that is, shuttleless looms, continuous casting, and digital telephone mainlines, each diffuse more rapidly throughout the economic structure in countries with a smaller installed capacity. Combined with our findings above (Table 2), these estimations provide compelling support for the idea that developing countries' late industrialization start allows them to diffuse new technologies more quickly than developed countries.

Global economic integration also clearly drives diffusion. Countries that are more open in terms of steel imports and exports diffuse continuous casting technology faster than more closed countries. A country's general trade openness, however, does not appear to matter. Shuttleless looms diffuse faster in countries that are major textile exporters. Yet, being a major textile importer does not have such an effect and, if anything, might negatively affect rates of diffusion. We have no product-specific trade variables for telecoms. We nevertheless find that countries that are generally more open toward trade switch faster from analog to digital mainline telephones than more closed ones.

The influence of trade is most likely rooted in competitive effects. Evidence suggests that exporters face strong market pressures to reduce product costs and/or improve quality. One way to achieve this is through investments in more advanced process technology, which may explain the positive relationship between exports and rates of diffusion for continuous steel casting and shuttleless looms. Indeed, this interpretation is supported by empirical studies, which have found that export-oriented firms in both the steel and textile sectors

Table 5. Within-Country Diffusion of Shuttleless Loom Textile-Weaving Technology

	Common baseline hazard	Stratified by income groups
ln GDP p.c.	0.067	− 0.032
	(0.25)	(0.06)
adoptionstart	0.176	0.153
	(3.11)***	(2.42)**
ln capitalstock	− 0.344	− 0.315
	(2.03)**	(2.07)**
textilesexports	13.341	12.115
	(5.99)***	(4.74)***
textilesimports	− 11.774	− 9.642
	(1.83)*	(1.03)
%trade	0.012	0.018
	(1.40)	(1.89)*
fdistock	− 0.011	− 0.027
	(0.61)	(1.20)
%secondaryenroll	0.052	0.052
	(3.70)***	(3.14)***
ethnicfract	− 0.007	− 0.004
	(0.54)	(0.31)
%regionaldiffusion	0.033	0.027
	(2.31)**	(1.64)*
Observations	1227	1227
# countries	73	73
# penetrations	30	30
log likelihood	− 81.0	− 46.3
Global chi^2–test of proportional hazard (p-value)	12.86 (0.2316)	8.28 (0.6019)

*0.05< α<0.10, **0.01< α<0.05, ***α< 0.01

have invested in modern technology in order to compete more effectively in international markets (Kher 1997; Amann and Nixson 1999). Competition from cheaper and/or better quality imports might have a similar impact to exports although, as evidenced by the case of textiles, potentially can have the opposite effect. This negative influence has previously been documented in several developing and transition economies following trade liberalization. Here, high levels of import penetration have reduced the economic viability of domestic enterprises, particularly in the small-scale sector, and hence their ability to invest in productivity-enhancing technology (Katz 2000).

With respect to the other generic variables, we do not find that a country's FDI stock influences diffusion. This is perhaps surprising given the strong theoretical arguments about the economic benefits of inward investment in terms of, for example, positive spillover effects. The result, however, is broadly consistent with recent studies, which have similarly failed to find an unambiguously positive correlation between FDI and productivity growth (Hanson 2001). A higher secondary school enrollment ratio is associated with a faster rate of diffusion for shuttleless looms. Yet the level of human capital does not influence the diffusion of the other two technologies. That secondary school enrollment only appears to impact take-up of one of the three technologies is intriguing. It is widely assumed that human capital is an important enabling factor in technological change (Abramovitz 1986; Bell and Pavitt 1997). However, our result may simply reflect the supply-dominated nature of steel and telecommunications, whereby the capabilities needed to successfully operate the new technology are embodied in the technology. This reduces the learning requirements and hence the importance of a well-educated workforce in adoption. Ethnic fractionalization is statistically insignificant throughout. This contradicts several recent studies, which have found that new technologies diffuse more slowly in more ethnically heterogeneous economies (Takada and Jain 1991; Dekimpe, Parker, and Sarvary 1998). Yet it is not entirely unexpected. While it is conceivable that ethnic diversity might inhibit the geographic transfer of tacit knowledge (Gertler 2003), the idea that it should also shape the spread of embodied technologies is less compelling.

We find evidence for all three technologies that the rate of regional technology adoption influences within-country diffusion. A higher share of technology adoption within the region positively influences the within-country diffusion rates of the technology. Similar regional contagion effects have been documented in the recent literature (Milner 2003) and are most likely the product of learning through interaction. Geographic proximity might be expected to increase the probability of coming into contact with, and learning from, regional neighbors who have already adopted a particular technology.

Our results are little different if we allow the baseline hazard to be stratified according to income groups. The only differences are that the steel export variable becomes insignificant, whereas the FDI stock variable becomes statistically significant with the expected positive coefficient sign. General trade openness becomes very marginally insignificant for telecommunications (p-value of 0.113), but is now statistically significantly positive for textiles. Textile imports are no longer statistically significantly negatively associated with the technology diffusion rate. Overall, therefore, the fact that the reported results change very little after stratification of the baseline hazard lends further support to the robustness of our statistical estimations. Tests of the proportional hazard assumption fail to reject the hypothesis in all cases. This suggests that the Cox model is valid for the available data.

Conclusions

The purpose of the present article was to scrutinize empirically two questions about the international diffusion of new technology. First, are late-industrializing (i.e., developing) economies able to diffuse new technology throughout their economic structure faster than early industrializers (i.e., developed economies) on account of latecomer advantage? And second, does engagement with the global economy through international trade and investment accelerate the diffusion process?

Our motivations for this project were both academic and pragmatic. Neither of the above questions has been adequately addressed in the empirical literature (Saggi 2002). Despite a long-standing tradition of diffusion research (Hägerstrand 1967; Smallman-Raynor and Cliff 2001), geographers have paid scant attention to the dynamics of technological diffusion at the global level. This is perhaps surprising. Future shifts in the geography of economic activity, inequality, and environmental pressure all significantly hinge on the extent to which different countries are able rapidly to exploit new technology. Precisely for this reason, advancing current understanding of the geographic pattern and determinants of international technological diffusion is an important research task, especially for geographers interested in the evolving and uneven dynamics of the global economy.

Moreover, given the neoliberal suggestion that market liberalization is the most effective policy for accelerating the diffusion process, it seems apt to investigate the role of open markets for trade and investment in the geographical spread of a range of new technologies. Our large-sample, quantitative approach is especially well suited to this purpose. Thus, not only is it capable of producing generalizable results, but, significantly, it commands methodological legitimacy among mainstream neoliberal policy analysts.

On the first question, our findings appear to offer considerable promise to developing countries. A higher level of development, proxied here by per capita income, may indeed provide developed economies with an advantage in the diffusion of new technology. Yet, developing countries possess two advantages of their own. They generally adopt new technologies later. And developing countries are more likely to have a smaller capital stock. Both characteristics are widely believed to allow countries to diffuse new technologies more rapidly. Confirming these advantages, this study finds that countries that exhibit these attributes, that is, late adoption and small capital stock, diffuse new technologies faster. Most striking is the fact that, despite their very different characteristics, these patterns are consistent across all three technologies.

The degree of latecomer advantage enjoyed by developing countries varies among our three technologies. It is most pronounced in the case of continuous steel casting and least in the case of shuttleless textile looms. While latecomer advantage may be generalizable, therefore, our results suggest that the prospects for rapidly diffusing new technology may be better in some sectors than others. In the case of textiles, producers in developing countries adopted shuttleless looms at a comparatively early stage, despite their high capital costs. This largely reflected the existence of a well-established textile industry in developing countries and, moreover, its specialization in mass-produced fabrics. This is a product sector where productivity-enhancing technologies such as shuttleless looms are of particular commercial advantage. Continuous casting is similarly a capital-intensive technology well suited to high-volume applications. However, during its early stages of commercialization, few developing countries were significant steel producers, and even fewer manufactured steel on a large scale. Hence, the economic incentive to adopt continuous casting in developing countries was comparatively low. Instead, it was only later when developing countries began to substantially expand steel capacity and, crucially, began high-volume steel production, that the economic benefits of the technology became apparent. An important consequence of this is that firms in the steel sector could take advantage of greater learning investments than their counterparts in the textile sector. What this suggests is that latecomer advantage is more likely to manifest itself in sectors where developing countries do not have significant existing capacity and, moreover, where the new technology is not involved in the production of goods in which developing country producers are already specialized.

Our empirical estimations are more ambiguous with respect to neoliberal claims regarding the benefits of market liberalization and engagement with the global economy. Consistent with previous cross-country studies, we find evidence that higher levels of product-specific imports, exports, and/or general trade openness are associated with more rapid technology diffusion. Of particular note, trade emerges as a statistically significant determinant across all three technologies, underlying its importance as a generic channel for the rapid diffusion of new technology. That the textile industry has historically been, and indeed continues to be, one of the most protected economic sectors might partly explain why the general rate of diffusion of shuttleless looms is relatively low (Dicken 2003).

Conversely, and confounding neoliberal orthodoxy, our results fail to support the oft-made claim that TNC investments result in the more rapid diffusion of new technologies. The stock of host-country FDI is statistically insignificant for all three technologies in the common baseline-hazard model and significant only in the case of continuous casting steel technology in the model with baseline hazards stratified by income groups. This, of course, is not entirely surprising. Recent research that has examined the impact of foreign investment on rates of productivity growth has reached similar conclusions (see review by Hanson 2001).

Equally, however, our result for FDI may simply reflect two factors. First, all three sectors (steel, telecommunications, textiles) have historically been subject to limited inward investment and/or ownership by foreign transnationals. Instead, they have been predominantly domestically owned and operated. In fact, it is only very recently that our sectors have been the subject of FDI and, even then, levels have been comparatively low. Second, owing to lack of data, our FDI measure is not technology-specific, meaning that it may be poorly suited to identifying sector-specific effects. Thus, while our study suggests that overall levels of foreign investment are unimportant, it does not allow us to discount the role of FDI in accelerating the diffusion of new technology altogether.

Overall, therefore, our results are a source of optimism. They suggest that developing countries are well positioned for the rapid exploitation of modern, efficient technologies as an integral part of capacity addition. Indeed, the fact that levels of secondary school enrollment emerge as statistically significant factors in diffusion success for only one of our three case-study technologies indicates that the limited human capital of developing countries may be less of a disadvantage than is often assumed. Our results also underscore the importance of open markets for international trade. Moreover, they suggest that trade liberalization, a policy embraced by the majority of countries in recent decades, is likely to have enhanced the prospects for the geographic spread of productivity-enhancing technologies.

Inevitably, a cautionary note is in order. The existence of latecomer advantage does not mean that developing countries will necessarily catch up economically with today's developed economies. Three factors count against developing countries in this respect. The first is that developing countries generally adopt later than developed economies. Ironically, while this means that developing countries generally diffuse new technologies faster, it is possible that by the time developing countries have fully adopted an innovation, developed ones will have already advanced to the next generation of technology. Developing countries may, in other words, be permanently caught in a cycle of catch-up by way of the fact that developed ones are better placed to adopt new technologies earlier. Furthermore, owing to their enhanced ability to adopt new technologies early on, developed country firms are potentially able to exploit monopoly rents for a period of time. Late adoption can therefore be a double-edged sword. It allows faster diffusion, but there are also advantages of being among the first adopters.

Second, acquiring technology is only one, and possibly the most straightforward, stage of technological diffusion (Bell and Pavitt 1997; Gertler 2003). The other is operating the technology efficiently. Case-study evidence suggests that this is far more difficult, not least because it requires a sufficient pool of locally available technological capabilities (Lall 1992). Indeed, the absence of well-developed technological capabilities is said to explain the failure of imported technology to achieve its design potential, or even fall into obsolescence, in many developing countries (Kher 1997). The important point is that differences in technological capabilities may hinder catch-up in resource efficiency, productivity levels, and income, regardless of the ability of late-industrializing countries to readily acquire physical technology (Soete 1985; Chen 1999; Felipe 2000).

Third, while our study suggests that trade may be a fillip to technological diffusion, it needs to be remembered that many of the world's poorest countries have found themselves largely excluded from international trade flows. Nowhere is this more starkly illustrated than in Africa, which accounts for a mere 2 percent share of world imports and exports (UNCTAD 2003a). In fact, to the extent that trade reinforces the advantages enjoyed by more successful trading states, it may actually lead to further marginalization of the least economically dynamic developing countries.

Although the primary contribution of this article is empirical, we wish to end by reflecting on two methodological contributions. First, our study confirms the importance of multitechnology analyses of the diffusion process. Not only do such analyses reveal potentially instructive idiosyncrasies, they help us to identify more generalizable patterns and determinants of international technological diffusion. There can be no doubt that our conclusions regarding latecomer advantage, for example, would be far more tentative if we were to have focused on the textile sector alone. Second, our study highlights the value of using event-history models, and the stratified Cox model in particular, for estimating the determinants of within-country diffusion. The Cox model has

advantages since it allows the baseline diffusion to be extremely flexible without a need to explicitly model its determinants, and the stratified Cox model allows the baseline diffusion to differ across groups of countries. Event-history models offer an easy way to include the year of first adoption in the modeling and estimation of within-country diffusion. More ambitious simultaneous estimation of both first adoption and within-country diffusion would involve some very complex modeling and is left to future research.

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Appendix

List of countries included in samples.

Steel

Algeria, Argentina, Australia, Austria, Azerbaijan, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Finland, France, Georgia, Germany, Ghana, Greece, Guatemala, Honduras, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Jordan, Kazakhstan, Kenya, Korea (Rep.), Latvia, Malaysia, Mexico, Moldova, Netherlands, Nigeria, Norway, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Saudi Arabia, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Syria, Thailand, Trinidad and Tobago, Tunisia, Turkey, Uganda, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Uzbekistan, Venezuela, Vietnam, Zimbabwe.

Telecommunications

Albania, Algeria, Angola, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Belarus, Belgium, Benin, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Dem. Rep., Congo, Rep., Costa Rica, Côte d'Ivoire, Croatia, Cyprus, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Eritrea, Estonia, Ethiopia, Fiji, Finland, France, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, Iceland, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Korea, Rep., Kuwait, Kyrgyz Republic, Lao PDR, Latvia, Lebanon, Lesotho, Lithuania, Luxembourg, Macedonia FYR, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Rwanda, Saudi Arabia, Senegal, Sierra Leone, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Swaziland, Sweden, Switzerland, Syria, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen, Zambia, Zimbabwe.

Textiles

Algeria, Argentina, Australia, Austria, Belgium, Benin, Bolivia, Botswana, Brazil, Bulgaria, Cameroon, Canada, Chile, China, Colombia, Costa Rica, Côte d'Ivoire, Croatia, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Finland, France, Germany, Ghana, Greece, Guatemala, Hungary, India, Indonesia, Iran, Israel, Italy, Japan, Kenya, Korea (Rep.), Kyrgyz Republic, Macedonia FYR, Madagascar, Malawi, Malaysia, Mexico, Morocco, Netherlands, Nicaragua, Nigeria, Pakistan, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Senegal, South Africa, Spain, Sri Lanka, Swaziland, Switzerland, Syria, Tanzania, Thailand, Tunisia, Turkey, Uganda, United Kingdom, United States, Uruguay, Venezuela, Zambia, Zimbabwe.

Notes

1. The terms "developing country," "late industrializer," and "latecomer" are used interchangeably throughout the present article. While we recognize the potential problems of dividing states into "developed" and "developing" categories—not least, because it conceals a great deal of diversity within and between these two groupings over space and time—it nevertheless serves a useful analytic purpose in the present context.
2. The use of country-specific initial adoption times is important since "many prior studies comparing within-country

diffusion curves have failed to adjust for a comparable time of origin across countries" (Dekimpe, Parker, and Sarvary 2000c, 65).

3. Note that the idea of variable, technology-specific adoption "ceilings" is consistent with the empirical record, which reveals that individual technologies have very different penetration levels (see Grübler 1997).
4. The OECD countries included in the sample encompass the United States, Canada, Western Europe, Japan, Australia, and New Zealand, but not Mexico, Turkey, and South Korea, as these were admitted to the club of developed countries for mainly political reasons in the 1990s.
5. Note that events that affect all countries, such as the conclusion of trade rounds in a certain year at the WTO, are absorbed by the baseline hazard of the Cox estimator.

References

Abramovitz, M. 1986. Catching-up, forging ahead and falling behind. *Journal of Economic History* 46 (2): 385–406.

Aitken, B. J., and A. E. Harrison. 1999. Do domestic firms benefit from direct foreign investment? Evidence from Venezuela. *American Economic Review* 89:605–18.

Alesina, A., A. Devleeschauwer, W. Easterly, S. Kurlat, and R. Wacziarg. 2003. Fractionalization. *Journal of Economic Growth* 8 (2): 155–94.

Amann, E., and F. I. Nixson. 1999. Globalisation and the Brazilian steel industry: 1988–97. *Journal of Development Studies* 35 (6): 59–88.

Amiti, M. 2001. Regional specialization and technological leapfrogging. *Journal of Regional Science* 41 (1): 149–72.

Amsden, A. H. 2001. *The rise of the rest: Challenges to the West from late-industrializing economies*. New York: Oxford University Press.

Anderson, D. 1996. Energy and the environment: Technical and economic possibilities. *Finance and Development* 33 (2): 10–13.

Baran, P. 1957. *The political economy of growth*. New York: Monthly Review Press.

Barnes, T. J. 2001. Retheorizing economic geography: From the quantitative revolution to the "cultural turn." *Annals of the Association of American Geographers* 91:546–65.

Barwise, P., and K. Hammond. 2002. *Predictions: Media*. London: London Business School.

Beilock, R., and D. V. Dimitrova. 2003. An exploratory model of inter-country Internet diffusion. *Telecommunications Policy* 27:237–52.

Bell, M., and K. Pavitt. 1997. Technological accumulation and industrial growth: Contrasts between developed and developing countries. In *Technology, globalisation and economic performance*, ed. D. Archibugi and J. Michie, 83–137. Cambridge, U.K.: Cambridge University Press.

Blackman, A. 1994. *The usefulness of macroeconomic statistics in explaining international differences in the diffusion of process innovations: A note*. Washington, DC: Resources for the Future.

———. 1999. *The economics of technology diffusion: Implications for sustainable development*. Discussion Paper 99–42. Washington, DC: Resources for the Future.

Blomstrom, M. 1986. Foreign investment and productive efficiency: The case of Mexico. *Journal of Industrial Economics* 35:97–110.

Booth, A. 2001. Initial conditions and miraculous growth: Why is Southeast Asia different from Taiwan and South Korea. In *Southeast Asia's industrialization: Industrial policy, capabilities and sustainability*, ed. K. S. Jomo, 30–58. London: Basingstoke.

Box-Steffensmeier, J. M., and B. Jones. 1997. Time is of the essence: Event history models in political science. *American Journal of Political Science* 41:1414–61.

Campos, N. F., and Y. Kinoshita. 2002. Foreign direct investment as technology transferred: Some panel evidence from the transition economies. *The Manchester School* 70 (3): 398–419.

Caselli, F., and W. J. Coleman. 2001. Cross-country technology diffusion: The case of computers. *American Economic Review* 91 (2): 328–35.

Chen, Z. 1999. Adoption of new technology by a lagging country: Leapfrogging or no leapfrogging? *Pacific Economic Review* 4 (1): 43–57.

Clark, G. L., and N. Wrigley. 1997. The spatial configuration of the firm and the management of sunk costs. *Economic Geography* 73:285–304.

Coe, D. T., E. Helpman, and A. W. Hoffmaister. 1997. North-South R&D spillovers. *The Economic Journal* 107:134–49.

Coe, N. M., and H. W.-C. Yeung. 2001. Geographical perspectives: An introduction to the JEG special issue—Mapping globalisation: Geographical perspectives on international trade and investment. *Journal of Economic Geography* 1:367–80.

Collett, D. 1999. *Modelling survival data in medical research*. London: Chapman & Hall.

Cox, D. R. 1975. Partial likelihood. *Biometrika* 62 (2): 269–76.

Dekimpe, M. G., P. M. Parker, and M. Sarvary. 1998. Staged estimation of international diffusion models: An application to global cellular telephone adoption. *Technological Forecasting and Social Change* 57:105–32.

———. 2000a. Global diffusion of technological innovations: A coupled-hazard approach. *Journal of Marketing Research* 37:47–59.

———. 2000b. "Globalization": Modeling technology adoption timing across countries. *Technological Forecasting and Social Change* 63:25–42.

———. 2000c. Multimarket and global diffusion. In *New product diffusion models*, ed. V. Mahajan, E. Muller, and Y. Wind, 49–73. London: Kluwer Academic Publishers.

De Soysa, I., and J. R. Oneal. 1999. Boon or bane? Reassessing the productivity of foreign direct investment. *American Sociological Review* 64:766–82.

Dicken, P. 2003. *Global shift: Reshaping the global economic map in the 21st century, 4th ed*. London: Sage Publications.

Dumas, M. W., and J. E. Henneberger. 1998. Productivity trends in the cotton and synthetic broad woven fabrics industry. *Monthly Labor Review* 111 (4): 34–38.

Fearon, J. D. 2003. Ethnic and cultural diversity by country. *Journal of Economic Growth* 8 (2): 195–222.

Felipe, J. 2000. Convergence, catch-up and growth sustainability in Asia: Some pitfalls. *Oxford Development Studies* 28 (1): 5169.

Frank, A. G. 1969. *Capitalism and underdevelopment in Latin America: Historical studies of Chile and Brazil*. New York: Monthly Review Press.

Freitag, D. W. 1998. Steel industry. In *Opportunities for advanced ceramics to meet the needs of the industries of the future*, ed. D. W. Freitag and D. W. Richerson, 5-1–5-16. Prepared by U.S.

Advanced Ceramics Association and Oak Ridge National Laboratory for the Office of Industrial Technologies Energy Efficiency and Renewable Energy, U.S. Department of Energy.

Ganesh, J., and V. Kumar. 1996. Capturing the cross-national learning effect: An analysis of an industrial technology diffusion. *Journal of the Academy of Marketing Science* 24 (4): 328–37.

Ganesh, J., V. Kumar, and V. Subramaniam. 1997. Learning effect in multinational diffusion of consumer durables: An exploratory investigation. *Journal of the Academy of Marketing Science* 25 (3): 214–28.

Gerschenkron, A. 1962. *Economic backwardness in historical perspective: A book of essays*. Cambridge, MA: Belknap Press of Harvard University Press.

Gertler, M. S. 2003. Tacit knowledge and the economic geography of context, or the indefinable tacitness of being (there). *Journal of Economic Geography* 3:75–99.

Globerman, S., A. Kokko, and F. Sjöholm. 2000. International technology diffusion: Evidence from Swedish patent data. *Kyklos* 53:17–38.

Gong, G., and W. Keller. 2003. Convergence and polarization in global income levels: A review of recent results of international technology diffusion. *Research Policy* 32: 1055–79.

Gregory, D. 1985. Suspended animation: The stasis of diffusion theory. In *Social relations and spatial structures*, ed. D. Greogry and J. Urry, 296–336. London: Macmillan.

Griliches, Z. 1957. Hybrid corn: An exploration in the economics of technological change. *Econometrica* 25:501–22.

Gruber, H. 1998. The diffusion of innovations in protected industries: The textile industry. *Applied Economics* 30:77–83.

Grübler, A. 1997. Time for a change: On the pattern of diffusion of innovation. In *Technological trajectories and the human environment*, ed. J. H. Ausubel and D. H. Langford, 14–32. Washington, DC: National Academy Press.

Hägerstrand, T. 1967. *Innovation diffusion as a spatial process*. Chicago: University of Chicago Press.

Hanson, G. H. 2001. *Should countries promote foreign direct investment?* G-24 Discussion Paper Series. Geneva: United Nations Conference on Environment and Development.

Hargittai, E. 1999. Weaving the Western Web: Explaining differences in Internet connectivity among OECD countries. *Telecommunications Policy* 23:701–18.

Hayter, R., and D. W. Edgington. 2004. Flying geese in Asia: The impacts of Japanese MNCs as a source of industrial learning. *Tijdschrift voor Economische en Sociale Geografie* 95 (1): 3–26.

IBRD. 1992. *World development report 1992: Development and environment*. Washington, DC: World Bank.

———. 1993. *The East Asian miracle: Economic growth and public policy*. Washington, DC: World Bank.

———. 2003. *World development indicators on CD-ROM*. Washington, DC: World Bank.

IISI. various years. *Steel statistical yearbook*. Brussels: International Iron and Steel Institute.

IMF. 2000. Globalization: Threat or opportunity? *IMF Issue Briefs* 00/01.

Ireland, N., and P. Stoneman. 1986. Technological diffusion, expectations and welfare. *Oxford Economic Papers*. 38, 283–304.

ITMF. various years. *International cotton industry statistics*. Zurich: International Textile Manufacturers Federation.

ITU. 2003. *World telecommunications indicators database*. Geneva: International Telecommunications Union.

Ivarsson, I. 2002. Transnational corporations and the geographical transfer of localised technology: A multi-technology study of foreign affiliates. *Journal of Economic Geography* 2:221–47.

Ivarsson, I., and C. G. Alvstam. 2004. International technology transfer to local suppliers by Volvo trucks in India. *Tijdschrift voor Economische en Sociale Geografie* 95 (1): 27–43.

Katz, J. 2000. The dynamics of technological learning during the import-substitution period and recent structural changes in the industrial sector of Argentina, Brazil, and Mexico. In *Technology, learning and innovation: Experiences of newly industrializing economies*, ed. L. Kim and R. R. Nelson, 307–34. Cambridge, U.K.: Cambridge University Press.

Keller, W. 2002. Geographic localization of international technology diffusion. *The American Economic Review* 92: 120–42.

Kher, M. 1997. *Coping with technological change*. New Delhi: Response Books.

Kiiski, S., and M. Pohjola. 2002. Cross-country diffusion of the Internet. *Information Economics and Policy* 14:297–310.

Kim, T.-K., and M. W. Horner. 2003. Exploring spatial effects on urban housing duration. *Environment and Planning* A 35:1415–29.

Lall, S. 1992. Technological capabilities and industrialization. *World Development* 20 (2): 165–86.

———. 2002. Transnational corporations and technology flows. In *Governing globalization: Issues and institutions*, ed. D. Nayyar, 78–107. Oxford, U.K.: Oxford University Press.

Lall, S., and C. Pietrobelli. 2002. *Failing to compete: Technology development and technology systems in Africa*. Cheltenham, U.K.: Edward Elgar.

Lim, Y. 1999. *Technology and productivity: The Korean way of learning and catching-up*. Cambridge, MA: The MIT Press.

Lücke, M. 1993. The diffusion of process innovations in industrialized and developing countries: A case study of the world textile and steel industries. *World Development* 21 (7): 1225–38.

———. 1996. Diffusion of innovations in the world textile industry. *Journal of Economic Development* 21 (2): 121–43.

Mencinger, J. 2003. Does foreign direct investment always enhance economic growth? *Kyklos* 56:491–508.

Metcalfe, J. S. 1997. On diffusion and the process of technological change. In *Economics of structural and technological change*, ed. G. Antonelli and N. De Liso, 123–44. London: Routledge.

Milner, H. V. 2003. *The global spread of the Internet: The role of international diffusion pressures in technology adoption*. New York: Columbia University.

OECD. 1998. *Open markets matter: The benefits of trade and investment liberalisation*. Paris: Organization for Economic Co-operation and Development.

Porter, M. E. 1990. *The competitive advantage of nations*. London: Macmillan.

Potter, J., B. Moore, and R. Spires. 2002. The wider effects of inward foreign direct investment in manufacturing on UK industry. *Journal of Economic Geography* 2:279–310.

Poznanski, K. Z. 1983. International diffusion of steel technologies: Time-lag and speed of diffusion. *Technological Forecasting and Social Change* 23:305–23.

Rassekh, F. 1998. The convergence hypothesis: History, theory, and evidence. *Open Economies Review* 9:85–105.

Reppelin-Hill, V. 1999. Trade and environment: An empirical analysis of the technology effect in the steel industry. *Journal of Environmental Economics and Management* 38: 283–301.

Rigby, D. L. 2000. Geography and technological change. In *A companion to economic geography*, ed. E. Sheppard and T. J. Barnes, 202–23. Oxford, U.K.: Blackwell.

Rogers, E. M. 1995. *Diffusion of innovations*, *4th ed*. New York: Free Press.

Rosegger, G. 1979. Diffusion and technological specificity: The case of continuous casting. *The Journal of Industrial Economics* 28 (1): 39–53.

Rostow, W. W. 1960. *The stages of growth: A non-communist manifesto*. London: Cambridge University Press.

Saggi, K. 2002. Trade, foreign direct investment, and international technology transfer: A survey. *The World Bank Research Observer* 17 (2): 191–235.

Saxenian, A. 1996. *Regional advantage: Culture and competition in Silicon Valley and Route 128*. Cambridge, MA: Harvard University Press.

Schenk, W. 1974. Continuous casting of steel. In *The diffusion of new industrial processes – an international study*, ed. L. Nabseth and G. F. Ray, 232–50. Cambridge, U.K.: Cambridge University Press.

Sharif, M. N. 1989. Technological leapfrogging: Implications for developing countries. *Technological Forecasting and Social Change* 36:201–8.

Shrum, W. 2001. Science, technology, and development. In *International encyclopedia of the social and behavioral sciences*, ed. N. J. Smelser and P. B. Baltes, 13607–10. Oxford, U.K.: Elsevier Science.

Soete, L. 1985. International diffusion of technology, industrial development and technological leapfrogging. *World Development* 13 (3): 409–22.

Smallman-Raynor, M., and A. D. Cliff. 2001. Epidemic diffusion processes in a system of U.S. military camps: Transfer diffusion and the spread of typhoid fever in the Spanish-American War, 1898. *Annals of the Association of American Geographers* 91:71–91.

Smith, R. J. 1974. Shuttleless looms. In *The diffusion of new industrial processes — an international study*, ed. L. Nabseth and G. F. Ray, 251–93. Cambridge, U.K.: Cambridge University Press.

Solow, R. M. 1956. A contribution to the theory of economic growth. *Quarterly Journal of Economics* 70 (1): 65–94.

Stoneman, P. 2002. *The economics of technological diffusion*. Oxford, U.K.: Blackwell.

Storper, M. 1997. *The regional world: Territorial development in a global economy*. New York: Guilford Press.

Takada, H., and D. Jain. 1991. Cross-national analysis of diffusion of consumer durable goods in Pacific Rim countries. *Journal of Marketing* 55:48–54.

Teece, D. J. 2000. Firm capabilities and economic development: Implications for the newly industrializing economies. In *Technology, learning and innovation: Experiences of newly industrializing economies*, ed. L. Kim and R. R. Nelson, 105–28. Cambridge, U.K.: Cambridge University Press.

Tharoor, S. 1997. *India: From midnight to the millennium*. New York: Arcade Publishing.

Todaro, M. P. 2000. *Economic development*, *7th ed*. Reading, MA: Addison Wesley Longman.

UNCTAD. 1999. *World investment report 1999: Foreign direct investment and the challenge of development*. Geneva: United Nations.

———. 2003a. *Economic development in Africa: Trade performance and commodity dependence*. Geneva: United Nations.

———. 2003b. *World Investment Directory*. Geneva: United Nations.

UNDP. 1998. *Human development report 1998: Consumption for human development*. Oxford, U.K.: Oxford University Press.

———. 2001. *Human development report 2001: Making new technologies work for human development*. Oxford, U.K.: Oxford University Press.

United Nations. 2003. *UN Commodity Trade Statistics Database (UN Comtrade)*. Department of Economic and Social Affairs, Statistics Division. http://unstats.un.org/unsd/comtrade/ (last accessed 13 February 2005).

———. Various years. *Industrial Commodity Statistics Yearbook*. New York: United Nations.

Vanhanen, T. 1999. Domestic ethnic conflict and ethnic nepotism: A comparative analysis. *Journal of Peace Research* 36 (1): 55–73.

van Pottelsberghe de la Potterie, B., and F. Lichtenberg. 2001. Does foreign direct investment transfer technology across borders? *The Review of Economics and Statistics* 83 (3): 490–97.

Wallerstein, I. 1979. *The capitalist world-economy*. Cambridge, U.K.: Cambridge University Press.

Wheeler, D., and P. Martin. 1992. Prices, policies, and the international diffusion of clean technology: The case of wood pulp production. Unpublished manuscript presented at the World Bank Symposium on International Trade and the Environment, Washington, DC.

Yeung, H. W.-C., and G. C. S. Lin. 2003. Theorizing economic geographies of Asia. *Economic Geography* 79 (2): 107–28.

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