Economics of Innovation and New Technology
Vol. 18, No. 7, October 2009, 675–694

Routledge
Taylor & Francis Group

Sources of learning paths and technological capabilities: an introductory roadmap of development processes†

Mario Cimoli[a,b]* and Gabriel Porcile[c,d]

[a]*ECLAC (Economic Commission for Latin America and the Caribbean);* [b]*Department of Economics, University of Venice, Italy;* [c]*Department of Economics, Federal University of Parana, Curitiba, Brazil;* [d]*CNPQ, Brazil*

(*Received 14 September 2007; final version received 4 October 2008*)

This paper aims at building bridges between evolutionary microeconomics and the structuralist theory of economic development, trying to combine both approaches in a systematic way. It is suggested that reducing the technology gap requires persistent supply side efforts for adapting and improving the use of capital equipment and the sequential development of various forms of tacit and incremental learning, associated with the transfer and acquisition of foreign technology. In addition, the expansion of employment along with labour productivity is related to the diversification of the economy, the expansion of high-tech activities and exports and the consequent dynamism of domestic and international demand. The paper argues that technological and industrial policies should take into consideration both dimensions of the development process.

Keywords: innovation; technological learning; technology gap; technological and industrial policies

Introduction

Both economic history and economic theory generally acknowledge a deep relationship between technical change and economic development. It is quite intuitive that improvements in the efficiency of production techniques or in product performances may be a determinant or at least a condition for growth in productivity and industrialization. The opening of the technological black box has often gone together with important insights on how learning and technological capabilities develop in less-developed economies. Studies on the sources, mechanisms and patterns of learning and their microeconomic impact on productivity growth have flourished over the last four decades.

This paper aims at building bridges between evolutionary microeconomics and the structuralist theory of economic development, trying to combine both approaches in a systematic way. In doing so, some key aspects of development, which usually receive less attention in the literature, come to the forefront. First, the need to analyse technical

*Corresponding author. Email: mario.cimoli@cepal.org
†The views expressed in this document are those of the author and do not necessarily reflect the views of the Economic Commission for Latin America and the Caribbean (ECLAC-UN).

ISSN 1043-8599 print/ISSN 1476-8364 online

DOI: 10.1080/10438590802564600
http://www.informaworld.com

change within a framework that describes not only the evolution of productivity, but also the evolution of aggregate income and employment levels in the economy. This helps to illuminate in which cases technical change translates into higher rates of economic growth and in which cases it basically gives rise to underemployment and heterogeneity in the labour market. With this objective, it is offered a new representation of the process of technical change (in the productivity–aggregate income space) that differs from the traditional representation, which focuses on the efficient utilization of production factors. Secondly, the need to consider at all moments the dynamics of learning and structural change, in particular why some countries *traverse* to a path where learning, production capabilities and institutions interact virtuously, while others remain in a *hysteresis* state, is highlighted. There is a lot that we can learn from the microeconomics of learning that could explain why these low-growth traps emerge and why they are so persistent and hard to overcome.

Thus, the paper builds, through several steps, a complementary view on learning and technological capabilities that incorporates the micro–macro perspective. In the early 1980s, the literature highlighted and fully described the supply-side efforts required to adapt imported technologies to local conditions and improve their efficiency and design. A more complete picture emerges when these findings are integrated within demand-led growth models. When supply efforts and demand-led growth mechanisms are integrated, the analysis produces a more comprehensive understanding of how the innovation system works and how this affects economic growth.

The first section briefly presents the background theoretical context on learning and innovation. In the second section, different approaches on learning and technological capabilities are analysed and integrated in a broad picture that describes alternative paths in the catch-up process. The third section incorporates the tools provided by the literature on innovation systems, which expands the understanding of the role of institutions and learning paths. The fourth section describes the impact and opportunities that developing countries face when new paradigms appear. The fifth section brings all of the pieces together and describes how the learning paths can lead to either a virtuous pattern or a hysteresis state. The last section is dedicated to the conclusions.

Learning and technological capabilities: supply-side efforts

The dependence theory of the 1960s and 1970s argued that technological capabilities cannot be fully developed in developing countries (Cardoso and Faletto 1969; Cardoso, 1973). According to this literature, technological dependency is associated with exporting primary goods in order to obtain the financial resources required to import capital goods and industrials products. As a result, developing countries were unable to build up their own industrial sectors, technological skills and organization, which form the basis for developing technological capabilities.

At the beginning of 1970s, Schumpeterian ideas began to increasingly permeate the empirical and theoretical analysis of technical change in developing economies. Analysts recognized that some developing countries succeeded in promoting structural change and absorbing technology. This modified the prevalent view of the 1960s regarding the impossibility of endogenously developing technological capabilities. The process of development and industrialization was strictly linked to the inter- and intra-national diffusion of 'superior' techniques (Fransman and King 1984). At any point in time, there are likely to be, at most, a very few best-practice techniques of production, which correspond to the technological frontier. The process of creating technological capabilities is thus closely linked with the borrowing, imitation, mastering and adaptation of advanced technology from countries on the technological frontier.

This view predicts persistent asymmetries among countries in terms of mastering production processes and introducing innovations. Wide differences apply to the capabilities for developing new products and the different time lags in producing them after their introduction into the world economy. Indeed, the international distribution of innovative capabilities for new products is at least as uneven as that for production processes (Posner 1961; Freeman 1963; Hirsch 1965; Hufbauer 1966; Vernon 1966). Technological asymmetries are thus associated with the different phases in the evolution of technology and a specific international distribution of innovation capacity in the production of new commodities. In the initial phase, innovative advantage is the main factor driving the production of new commodities in the advanced countries. Over time, the technology evolves into a mature phase characterized by the standardization of products and processes. International competition is then based on transfers of technology, productivity improvements and production cost advantages.

Technological change progressively incorporates visions of how to do things and how to improve them, often shared by the community of practitioners in each particular activity within firms (Lall 1982; Fransman and King 1984; Katz 1984; Teitel 1984, 1987a,b; Teubal 1984). The empirical studies on technical change in developing countries show that the diffusion of technology in these countries implied a stream of minor adaptations and innovations, thereby reviving the broader definition of innovation set forth by Schumpeter:

> By changes in the methods of supplying commodities we mean a range of events much broader than the phrase covers in its literal acceptance. We include the introduction of new commodities which may even serve as the standard case. Technological change in the production of commodities already in use, the opening up of new markets or of new sources of supply, Taylorisation of work, improved handling of material, the setting up of new business organisations such as department stores – in short, any 'doing things differently' in the realm of economic life – all these are instances of what we shall refer to by the term Innovation. (Schumpeter 1939, 84)

The path of technological learning was thus related to the capacity to acquire technologies (capital goods, know-how and so forth) and adapt them to local conditions. A number of empirical studies describe the increased technological capabilities that matured in some developing countries from the 1950s to the early 1980s; in fact, some of these countries even became technology exporters. In this respect, considerable microeconomic technological evidence now highlights the mechanisms that stimulate and limit endogenous learning in developing countries. The literature suggests that reducing the technology gap requires further forms of supply efforts in adapting and improving the use of capital equipment and the sequential development of various forms of tacit and incremental learning, related to the transfer and acquisition of foreign technology.[1] This mainly refers to microeconomic learning activities such as the use of equipment, the development of engineering skills in machine transformation and the adaptation of existing machines and final products to specific environmental conditions. Significant factors favouring this process include the literacy and skill level of the workforce, the skills and technical competence of engineers and designers in the mechanical artefacts and (increasingly) the existence of managers capable of efficiently running complex organizations.[2]

The organization of production processes progressively incorporated and diffused Taylorist and Fordist methods in most manufacturing sectors. This process required time and progressive learning in organizations. Initial efforts concentrated on product design activities (most likely as a result of past incentives provided by import substitution policies) and, increasingly, on quality improvements and product differentiation. Attention was later directed toward engineering, the organization of production and mechanized production processes. The organization sometimes developed managerial organization, such as the scientific design of production processes, the search for a higher division of labour (deskilling jobs and separating mental and manual labour), the organization of fixed product lines and the implementation of vertical integration to improve learning.

Bell and Pavitt (1993) capture the complementarities between learning in production processes and learning in organization, emphasizing the distinction (which indeed bears some Listian flavour) between the development of technological capabilities and production capacity. Technological capabilities rest on the knowledge and resources required for generating and managing technical change. Production capacity concerns the stocks of resources, the nature of capital-embodied technologies, labour skills, product and input specification and the organizational routines in use. There seem to be some patterns, albeit rather loose, in the development of national production capacity. For example, practically every country starts with clothing and textile manufacturing and perhaps with the processing of natural resource, and it then moves on – if it does – to more complex and knowledge-intensive activities.

This process of technological learning, redefining production capabilities, has as well a demand side that cannot be ignored. Both learning and demand growth should go hand in hand in the process of development to avoid unemployment. Figure 1 illustrates this point by putting together the evolution of labour productivity (π) and the evolution of aggregate demand/production (Y). In the space of π–Y, the points a and c indicate the prevailing levels of productivity and income in developing and developed countries, respectively. Naturally, these levels are higher in the developed countries.[3] In turn, N_a and N_c indicate levels of employment, which are also higher in the developed economy. The ratios $1/N_a$ and $1/N_c$ correspond to the declivity of the lines drawn from the origin to points a and c. These ratios multiplied by the productivity level give the total product and total aggregate demand. It is important to stress that these lines are hypothetical and do not represent actual paths: what counts for the argument are the different combinations of productivity and aggregate demand, and the various forms that each country traverses between two or more points.

The differences between the developed and the developing economies stem from a stronger process of industrialization in the former which stimulated demand along with

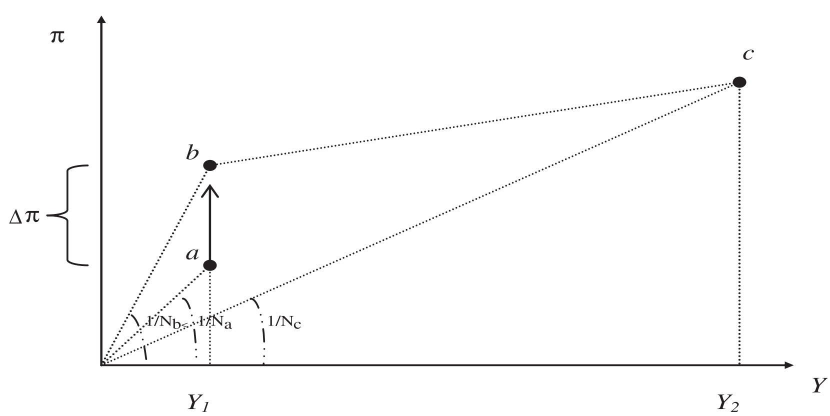

Figure 1. Supply efforts and learning.

productivity growth. On the other hand, in the developing country, this virtuous interaction between productivity and demand growth did not happen. Consider, for instance, a supply-side effort to learn and improve technological capabilities in the developing economy, from a to b in Figure 1. Although the increase in productivity $\Delta\pi$ implies a reduction of the technology gap, there is also a reduction of employment, which decreases from N_a to N_b. This illustration aims to capture the missing link between supply-side efforts and the aggregate demand mechanisms provided by the expansion of the industry.

In other words, in developed economies, the expansion of employment along with labour productivity is related to the diversification of the economy, the expansion of high-tech activities and exports and the consequent dynamism of domestic and international demand. In developing economies, on the contrary, technical change is highly localized in few export activities (both in the agricultural and industrial sectors) with feeble effects on total demand and structural change. As a result, productivity tends to grow at higher rates than demand, implying that unemployment and underemployment persist. This is what the structuralist literature denominates 'structural heterogeneity': labour productivity is remarkable different across and within sectors, with a large part of total employment allocated in subsistence sectors (Pinto 1970, 1976; Sunkel 1978).

These results pertain to specific historical and analytical circumstances, corresponding to a period of commercial protection and active industrial policies. From the 1950s to the 1970s, such protection often served to build up the minimum capabilities at the plant level for developing the skills and organization needed to industrialize. In Figure 1, the starting point a is clearly inefficient compared with b. To cover the gap in productivity, the industry (or production plant) has to pass through different stages of learning to accumulate technological capabilities (Bell 2006).

Assuming a simple mark-up equation and equal wages (w), prices can be written as follows: $p_a = mw/\pi_a$, and $p_b = m^*w/\pi_b$. Assuming constant and equal mark-ups in the two countries, the gap between the points a and b is reflected in the unit prices, $p_a > p_b$. To maintain an inefficient industry (or plant) in the market, some sort of 'learning protection' must be introduced (Lall 1982).[4] The debate on free trade and protection was approached pragmatically in the literature of the 1980s. In an initial stage, a combination of import substitution and export orientation was considered the most appropriate regime for learning and building up the minimum capabilities required in the development process (Fransman and King 1984).

Assembling supply efforts and demand-led mechanisms

Thus far, we have mainly described the learning capabilities from supply-side efforts at a microeconomic level. Demand growth increases productivity and employment through the diffusion of dynamic increasing returns in the industry, which, in turn, increases its production capacity and output. From the Smith–Young–Kaldor perspective, output growth triggers increases in the division of labour of production processes and also improves learning in each of the complementary activities and skills required in the use of equipment, the adaptation and transformation of machines tools and the management of complex organizations. These increases in productivity and per capita income then induce a recursive process that further reinforces the increase in production capacity, output and employment.[5]

The expansion of productivity, employment and output also involves the transformation of the production structure. The relationship between structural change and economic development was first explored by the development theory pioneers.[6] Development required the reallocation of production factors from low-productivity sectors to high-productivity areas in which increasing returns prevailed. Industrialization was thus seen as the way out of the 'backward' condition. The manufacturing sector would provide increasing returns and allow the development of technological learning. The increasing participation of industry in total value added would generate spillover effects, backward and forward linkages and technological externalities, which in turn would accelerate capital accumulation and growth.[7] This process would be reinforced by the continual development of new industries and new knowledge if demand and investment in new products were sustained (Metcalfe 2001).

Furthermore, one might still be able to identify some differences in the predominant modes of sectoral technological learning. In this respect, the taxonomy of the sectoral patterns of the acquisition of innovative knowledge suggested by Pavitt (1984) was largely adopted to describe the differences across sectors. Pavitt distinguishes four groups of industrial sectors: (i) supplier-dominated sectors, where innovations mainly enter as exogenously generated changes in capital and intermediate good and where learning is primarily associated with adoption and production skills; (ii) specialized suppliers, which provide equipment and instruments to the industrial system and rely on their innovative activities on both formal (more or less scientific) knowledge and more tacit one based also on the user–producer relationships; (iii) scale-intensive sectors, whose innovative abilities draw on the adoption of innovative equipment, the design of complex products, the exploitation of scale economies and the ability to master complex organizations and (iv) science-based sectors, whose innovative opportunities are more directly linked with advances in basic research.

In this paper, we are particularly interested in whether one may use that taxonomy to identify specific patterns in the development process. The emergence of a manufacturing sector is generally characterized by an initial stage in which supplier-dominated sectors prevail, accompanied by the emergence of specialized suppliers. The process of technical change in these sectors is characterized by a sequential development of various forms of tacit and incremental learning related to the transfer and acquisition of foreign technology (Cantwell 1991). These learning activities are mainly related to the use of equipment, the development of engineering skills in machine transformation and the adaptation of existing machines and final products to specific environmental conditions. The emergence of scale-intensive industries entails further forms of learning related to the development and use of capital equipment. Unlike supplier-dominated sectors, scale-intensive industries focus their technological efforts on (i) the development of technological synergies between production and use of innovations, often internalized via horizontal and vertical integration; (ii) the exploitation of static and dynamic economies of scale and (iii) the establishment of formal institutions undertaking research (typically, corporate R&D laboratories), which is complementary to informal learning and the diffusion of technological knowledge.

The ensemble of supply efforts and demand-led inducement to learning can be viewed as an adaptive process, which incorporates the bottom-up and the aggregate-down mechanisms for development (Setterfield and Cornwall 2002; Ocampo 2005; Metcalfe, Foster, and Ramlogan 2006). On the one hand, learning and innovation underlie the transformation of industrial structures in sectors with greater investment opportunities and higher productivity. On the other, the top-down mechanism captures the virtuous impact of demand on productivity and industrial production capacity. Moreover, some technologies have very wide domains of application, and they play a crucial role in the process of learning and industrialization. These core technologies often also imply basic infrastructures and networks common to a broad range of activities (such as the electricity grid, the road system, telecommunications and the information network). Many pieces of empirical evidence strongly convey the idea that establishing dynamic technological processes in developing countries is impossible without major structural changes and the sequential construction of a growing manufacturing sector based on indigenous skills in a set of core technologies (Rosenberg 1976; Chudnovsky, Nagao, and Jacobson 1984; Fransman 1986; Prebisch, 1981).

In Figure 2, different paths can be observed that lead from point *a* to point *c*, each of which is characterized by different combinations of supply efforts and demand-driven mechanisms for growth and learning (domestic demand and exports). There are both an income gap (Y_2 and Y_1) and a productivity gap ($\Delta\pi$) between the developed and the developing economies. Two extreme cases emerge from the figure: a purely supply-side path traced from *a* to *b*, where higher levels of productivity are reached with no increase in output and employment, and a pure demand-side path from *a* to *d*, where demand growth boosts employment with no increase in productivity. Between these two extremes, there are many paths stemming from the interaction between supply efforts and demand-led mechanisms. One of them relies initially on stronger learning efforts that elicit in the sequence a demand response. In the other case, the starter of the virtuous circle is the dynamism of demand (for instance, by exporting to worldwide markets based on cheap labour or other abundant factor), which is then used to speed up learning and structural change.

The alternative paths represent different ways of reducing the income and productivity gap. Demand growth allows for the expansion of production capacity and affects the share of the industrial sectors in total value added, which may generate spillover effects, backward and forward linkages and technological externalities. At point *c*, the industrial sector has expanded and the employment increased from N_a to N_c. This path combines simultaneous efforts of learning within plants – and firms – and the impact of demand on productive resources, improving skills and competences in the workforce and the use of capital goods. These are the sources of increasing returns, which are captured in the aggregate by growing productivity, industrialization and output.

The demand for exports is a critical component of aggregate demand, as suggested by the structuralist and Keynesian theory of the external constraint on growth. Exports therefore play a central role in explaining the accumulation of capabilities. This is mostly true in open economies, where products, production processes and sectors emerge and disappear rapidly in the international economy. The approach that integrates the Schumpeterian perspective with the Keynesian balance of payments constrained growth models, which highlight the role of demand for exports, individuate the prevalent tradeoffs in the process of structural

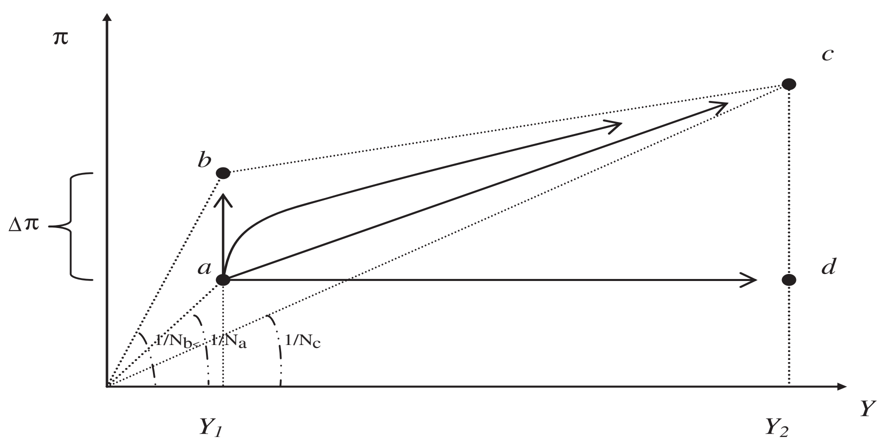

Figure 2. Assembling supply efforts and demand-led mechanisms.

transformation and specialization (Cimoli 1988; Metcalfe 1989; Dosi, Pavitt, and Soete 1990; Cimoli and Soete 1992).

The specialization pattern is embedded in the income elasticities of demand for exports and imports (Rodriguez 1977; Thirlwall 1979; McCombie and Thirlwall 1994), thus being the link between specialization patterns and demand implicitly present in these models. They permit to look at elasticities as the outcome of a process of structural change and define the relative rates of innovation and technology diffusion in the international economy. It is generally recognized that the income elasticity of demand is lower for most primary commodities than it is for manufactured products that are knowledge-intensive. The lower income elasticity of demand for primary commodities means that, for a given increment in world income, the balance of payments of the commodity-producing developing country will automatically deteriorate. And thus aggregate demand has to be reduced, affecting negatively the expansion of aggregate output and the learning process associated with this expansion. Conversely, if the economy specializes in goods that increasingly incorporate learning and produce positive externalities, then the elasticity of exports rises and the virtuous path of learning is sustained in the long term.

In sum, countries far from the technological frontier may exhibit patterns of factor allocation, which are 'efficient' in terms of relative prices, for a given distribution of technological capabilities. Yet this allocation efficiency may well entail negative long-run implications for growth as it would be associated with a lower-income elasticity of the demand for the goods that the country can competitively produce (compromising the 'growth efficiency') and with a lesser innovative potential (compromising the 'innovative efficiency'). Whenever tradeoffs between different notions of efficiency arise, 'sub-optimal' or 'perverse' macroeconomic outcomes may emerge. Since the *future* pattern of technological advantages/disadvantages is also related to the *present* allocative patterns, we can see at work here dynamic processes which Kaldor called 'circular causation': economic signal related to intersectoral profitabilities – which lead in a straightforward manner to 'comparative advantages' and relative specializations – certainly control and check the allocative efficiency of the various productive employments, but may also play a more ambiguous or even perverse role in relation to long-term macroeconomic trends.

Spaces and complementarities between market and non-market institutions

Learning activities hold a special status in the construction of the institutional system. Sound theoretical arguments and growing empirical evidence indicate that the observed patterns of industrial structures are the outcome of the interaction of specific modes of learning and institutions supporting technical change. Nations are characterized by particular modes of institutional governance, which to a certain extent make them diverse auto-reproducing entities. There is also an element of nationality stemming from the shared language and culture, as well as from the national focus of other policies, laws and regulations that constrain or stimulate the innovative environment. These factors contribute to the organizational and technological context within which each economic activity takes place. In a sense, they set the opportunities and constraints facing each individual process of production and innovation, including the availability of complementary skills, information on intermediate inputs and capital goods and demand stimuli to improve particular products.

A significant body of literature outlines the importance of institutions and their role in learning and technological capabilities (Freeman and Perez 1988; De Bresson and Amesse 1991; Cimoli et al. 2006). This literature provides examples of the functioning of national innovation systems (NIS).[8] A variety of overlapping definitions of national innovation systems have been introduced, with differing emphasis on firms and on the meso- and macroeconomic levels (Freeman 1987; Nelson 1993). Metcalfe (1995, 462–3) provides a policy-oriented definition of an NIS as a 'set of institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process'. He argues that the nature of each NIS is fundamentally shaped by both the division of labour and the peculiarities of information, which cause a predominance of coordination by non-market means. The institutions that compose these systems (including private firms, universities and other educational institutions, public research labs, private consultancies, professional societies and industrial research associations) 'make complementary contributions, but they differ significantly with respect to motivation and to a commitment to dissemination of the knowledge they create' (465).

The empirical findings on NIS reveal other elements and linkages that affect the learning process and the generation of technological capabilities. In particular, firms themselves are nested in networks of linkages with other firms and also with other non-profit organizations (such as public agencies). These networks, or lack thereof, enhance or limit the opportunities for each firm to improve its problem-solving capabilities. The general point here is that competition and efficiency are not made by single firms, but by networks of dissimilar organizations, both public and private. Firms must adapt to rapidly changing market conditions or take the lead by innovating their products and production processes in a world where technological developments are occurring at an ever-increasing speed and where the rate of specialization (through division of labour) is also rising. It is becoming increasingly difficult for individual firms to produce all the relevant knowledge themselves and to translate this knowledge into innovative products or production process (Teece 1998; Teece, Pisano, and Shuen 1990).

Learning patterns are clearly nested into the broader ('macro') conditions of the institutional system (Teitel 2004; Kanatsu 2006). For example, the literacy and skill level of the workforce, the skills and technical competence of engineers and designers in the mechanical and (increasingly) electronics fields, the existence of managers capable of efficiently running complex organizations and the quality of higher education and research capabilities are all clearly relevant. Moreover, sectoral learning patterns and overall national capabilities are dynamically coupled via input-output flows, knowledge spillovers, complementarities and context-specific externalities.

Can we measure the 'goodness' or 'badness' of a specific NIS? Recall that the path from a to c involves the interaction between the supply efforts, demand-led mechanisms and the virtuous impacts of institutions that promote technical progress. In Figure 3, the triangle where productivity and employment increase ($+\Delta\pi$ and $+\Delta N$, represented by the set of points to the left of the au line segment) indicates the area in which the virtuous paths of productivity, output and employment take place under the stimulus of non-market institutions. This area defines the industrializing path of those countries that reached the technological frontier in the last 30 years. Evidence from the industrialized countries (such as USA, Germany, the Scandinavian countries, Japan, etc.) shows that they not only learned and accumulated technological capabilities but also expanded industry and employment. These paths characterize also the economies that are industrializing (Korea and China), which have successfully assembled both the supply efforts, demand-led mechanism and non-market institutions.

Given the microfoundations of learning introduced above, it may be possible to explain why technological gaps rise or fall across different nations over time. Such gaps may open up because individual responses produce different (sometimes sub-optimal) collective

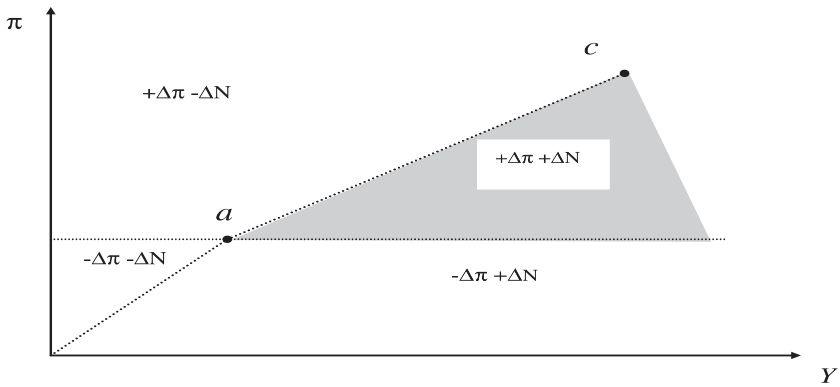

Figure 3. Institutional spaces for learning and industrialization.

outcomes. The existence of diverse institutions and organizations, with specific modes of interaction, determines unique national innovation systems which, over time, exhibit certain invariant characteristics. These invariances account for phases of relative technological success and failure. Well-organized innovation systems thus serve as a powerful motor of progress, whereas poorly organized systems can seriously inhibit the whole process (Nelson 1993; Cimoli and Dosi 1995; Katz 1997; Kim 1997; Lall 1997; Cimoli 2000).

Far from reviewing the immense evidence on these issues, we draw on selected examples from developed countries and, in particular, a somewhat archetypical comparison between the experiences of East Asia and Latin America. In the case of the newly industrialized economies of the Pacific Rim, the process underscores the message that learning does not proceed in isolation. Firms were integrated into and interacted within a network with others firms and institutions (public and private). The resulting system was capable of expanding the education system to provide a high degree of engineering studies, increasing scientific activities within firms and the public sector, developing technological infrastructure, diffusing linkages between public and private institutions, generating financial incentives in innovative activities and improving and diversifying learning activities. Moreover, the success of institutions in some newly industrialized economies (namely, South Korea and Taiwan) has to be understood in terms of the capacity of establishing and applying performance criteria, so that, for example, credit allocation by the state was tightly bound with export performance; in this way, international competition was used to foster internal learning (Amsden 1989; Wade 1990).

All this contrasts sharply with the experience of Latin America, where the arrangement between the state and the private sector has often been more indulgent as regards inefficiencies and rent accumulation and less attentive to the accumulation of socially diffused technological capabilities and skills (Fajnzylber 1990). Furthermore, the changes in technology policies and in the corresponding institutional infrastructure engendered a radical shift in science and technology priorities from learning dynamics to the accessibility of information. Innovation-related institutions came to be regarded as ‘markets’ for trading or exchanging information rather than as part of an articulated and flexible system for transferring know-how and codified and non-codified knowledge embodied in routines, production processes or research results. Latin American integration with global trade is thus occurring asymmetrically. Domestic agents participate in international production processes, but they are marginal actors in the globalization of scientific, technological and economic activities.

Paradigms and their radical impacts on learning

Paradigms generally define basic models of artefacts and systems, which are progressively modified and improved over time.[9] These basic artefacts can also be described in terms of some fundamental technological and economic characteristics. For example, the basic attributes of an airplane can be described not only in terms of inputs and production costs, but also on the basis of some salient technological features such as wing load, take-off weight, speed, the distance it can cover and so forth. Technical progress seems to display patterns and invariances in terms of these product characteristics. Similar examples of technological invariances can be found in automobiles, agricultural equipment and a few other microeconomic technological studies. Paradigms also evolve with specific forms of production organization. In the mechanical and electrical paradigms, learning and technological capabilities were developed under the Taylor and Ford methods of production. In the case of information and communications technologies (ICT) and biotechnologies, the pattern of learning evolves with different forms of organization in production process.

Even if microeconomic paradigms present considerable invariances across countries, the ways that various paradigms interact with each national innovation system – shaped by country-specific institutions and policies – highlight a considerable variety of outcomes. The diffusion of ICT and biotechnologies paradigms is not the exception. It has radical effects on learning patterns and technological capabilities, increasing the role of science-based activities and non-market institutions (Perez 1985; Freeman 2001; Miozzo and Walsh 2006; Rothaermel and Thursby 2007).

Countries that have experienced successful structural change showed, simultaneously and not surprisingly, an adaptive pattern of learning that favoured science-based activities in the public sector and firms, networking and complementarities between firms and the public sector, a Taylorist organization of R&D activities (basic and applied), human capital incorporating tacit knowledge and expertise in specialized areas of science, intellectual property governing the market for knowledge and the intangibility of results, potential products and production processes. This is the typical case of Southeast Asian countries. In the last 30 years, these countries have experienced changes in the composition of the production structure, while the rise in their R&D expenditure generally stemmed from the application of a set of long-term coordinated policies directed at the accumulation of technological capabilities. Industrial and trade polices in Korea promoted a gradual upgrading of domestic technological capabilities and subsidies to public science- and technology-intensive activities.

This is also the case of ICT, where the asymmetries in the absorption and diffusion of these technologies are now clear. Southeast Asian countries developed learning and technological capabilities in the production and use of ICT, whereas Latin America countries have not transformed their production structures and learning patterns toward sectors that produce tangible and intangible components (such as semiconductors, hardware and software). The main impact has been on activities that use and diffuse these technologies.

The pervasiveness of ICT has affected production processes by increasing the share of capital and the incorporated technologies, particularly in sectors with high export shares and services. Their impacts are also displayed in other essential activities, such as design, production, marketing and transport. Table 1 summarizes the impact of ICT in Latin America.

The natural resource sector increasingly uses ICT. Natural-resource-processing industries producing commodities for highly competitive world markets are now highly capital-intensive, with incorporated technologies that are mainly imported. These industries have

Table 1. The impact of ICT in Latin America.

	ICT impact	
Learning	Production and adoption	Use and diffusion
Opportunities	Modernization (incorporated in capital goods and production processes) and reduction of transaction costs	Employed by natural-resource-processing and low-skill industries and services
	Enhanced linkages and efficiency with world centres of technology and multinational corporations	Increased efficiency and reduction in transaction costs in approaching input market for developed and industrializing economies
Constraints	Structural inertia and sticky diversification pattern	Reduced capabilities in R&D and engineering-intensive industries
	Polarized production systems and scant density of domestic linkages	Persistence of informal activities and income distribution

largely managed to improve their relative labour productivity. They are highly automated, with a large ICT component incorporated in their capital goods and production processes. It is in this sector, as well as in non-tradables sectors such as telecommunications or energy and transport services, that Latin American countries have partially closed the relative productivity gap with more mature industrial economies. In contrast, activities intensive in R&D and engineering (such as the production of pharmaceutical raw materials and capital goods) and unskilled-labour-intensive industries (such as the manufacture of shoes, garments or furniture for the domestic markets) have done worse, rapidly losing ground vis-à-vis the evolving international efficiency frontier. ICT also has important consequences for these industries.[10]

The effects of ICT reflect the fact that most of the knowledge-production centres are localized in advanced economies, including research on new material, basic science research and product design. Under this scenario, ICT clearly facilitates and speeds the exchange of information, which does not necessarily support the relocation of the above activities to Latin American economies. On the contrary, this technology promotes communication and the exchange of information, but not the local creation and diffusion of knowledge. For example, the automobile industry evaluates quality control and certification online, based on the exchange of information from one part of the world to the other.

Subsidiaries of multinational corporations and large domestic firms tend to operate in real time, planning their production activities online with their external licensors and technological services. Controlling companies, which are mainly located in advanced economies, benefit from comparative advantages in technology and innovation and the exchange of information in real time to operate production and R&D activities. Multinational companies concentrate the bulk of their research and development activities in their countries of origin or, as recent trends suggest, in strongly dynamic economies that specialize in highly technology-intensive industries and that represent huge potential markets for technological products, such as China, Korea and Malaysia.

Since the 1970s, the emergence of the biotechnology paradigm has also affected the sources and paths of learning. The technologies of genetic, protein and cell and tissue engineering have an impact on human and veterinarian health and on a range of industrial and agricultural activities.[11] Opportunities to develop new products and processes can still effectively emerge almost anywhere (Ebers and Powell 2007). In fact, science activities, production and business opportunities are in a continuous process of transformation.

However, some stylized learning patterns and their implication for development can be identified. The public science sector plays an important role and has the potential to revolutionize the pharmaceutical, chemical and agricultural industries. At the same time, the ability of firms to evaluate and absorb external knowledge explains a large part of the learning and innovation process (McMillan, Narin, and Deeds 1999). The networks between public institutions, large companies and small and specialized firms are at the centre of the organization of production patterns.

Thus, as occurred with ICT, learning patterns can change radically with the diffusion of biotechnologies. Science and R&D are increasingly the main activities in learning and the creation of technological capabilities (Chataway, Tait, and Wield 2004). Networks and alliances among firms and between public and private institutions seem to offer opportunities to complement the specialization in research activities and exploration of new frontiers. Again, Southeast Asian countries are increasing their resources in those activities and transforming the institutional setting to integrate public and private actors. The ability of these countries to catch up in mechanical-electronics technologies and diffuse ICT in their production systems gives them the learning and technological capabilities to experiment with and absorb the biotech paradigm. In contrast, Latin American countries have remained anchored to their learning pattern in adopting and mastering technologies in more mature sectors. In the case of the agribusiness and food sectors, the diffusion of science activities among public and private agents seems too incipient to foster the adoption and diffusion biotechnologies.

Dynamics of learning paths: traverse and hysteresis

The achievement of learning and technological capabilities implies that developing countries have to move to a virtuous path characterized by increasing productivity, the generation of new products and an institutional system that supports and diffuses these capabilities. This transition from one path to another, which is termed traverse, may or may not be possible, depending on the sequence of change and adjustment at a microeconomic level, as describe above, and on structural changes in production capacity and innovation systems (Setterfield and Cornwall 2002; Setterfield 2002). Examples from developed countries and, in particular, East Asia illustrate the successful transition to a virtuous path in learning and technological capabilities. In Figure 4, the path that moves from *a* to the area characterized by $+\Delta\pi$ and $+\Delta N$ captures this process.

The ability to promote structural change in order to profit from new technological paradigms and demand growth is a critical determinant of a country's relative economic performance in the international arena. This is especially true in open economies, where products, production processes and sectors quickly emerge and disappear at the international level. This idea is directly related to theories of production that allow for dynamic increasing returns, from Young and Kaldor to the recent and more rigorous formalizations of path-dependent models of innovation diffusion, whereby the interaction between microeconomic decisions and some form of learning or externalities produces irreversible technological paths and lock-in effects with respect to technologies that may well be inferior, on any welfare measure, to other notional ones, but still happen to be dominant (loosely speaking) because of the weight of their history (David 1985; Arthur 1989). However, paradigms are generally embodied in larger technological systems and in even bigger economy-wide systems of production and innovation.

The path of learning and technological capabilities can be affected by macroeconomic shocks and new paradigms. After a negative shock, for example, an economy cannot return

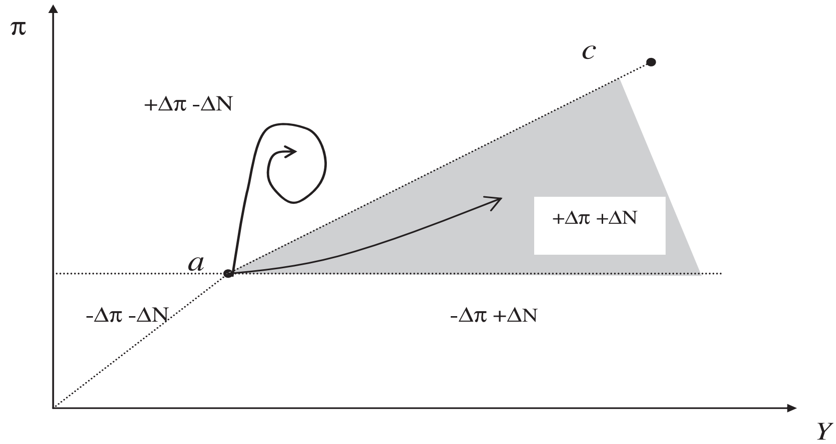

Figure 4. Traverse in development process and hysteresis.

to its previous path and, at the same time, does not invoke a virtuous path in the accumulation of learning and technological capabilities. The impact of an exogenous shock persists in the system even after the shock ceases; this is the case of a hysteresis state.[12] This case is sketched in Figure 4, which summarizes the development stage of Latin American countries and their difficulties in reaching the area defined by $+\Delta\pi$ and $+\Delta N$. Learning and technological capabilities do not traverse to a path where the supply efforts, the demand-driven mechanisms and NIS interact virtuously (Cimoli and Correa 2005). Moreover, the lack of all these factors does not favour the ability to absorb established new paradigms. The learning path does not develop the potential to achieve point c, and the country remains in a hysteresis state in an area with a lower combination π–Y relative to the industrializing countries and the technological frontier.

In the long term, the learning paths should be developed through different stages that incorporate supply efforts in production, demand-driven mechanisms and innovation systems that increasingly incorporate science and R&D activities. Each of these components interacts with the others and further increases learning opportunities and capabilities.

Latin American countries have undergone economic reforms that affected the sources of learning and technological capabilities. These reforms include the new set of rules established under a different trade regime (determined by the elimination of many of the trade barriers adopted in the previous decades), the privatization of large domestic firms (particularly in the service sector) and the deregulation of labour and financial markets. This 'shock' provides an effective way to retool economic activities, by combining a new environment in terms of relative prices with new incentives that affect learning and technological capabilities. Since the beginning of this liberalization period, most countries have experienced an increasing internationalization process. The specialization pattern in Latin America can be mapped out on the basis of comparative advantages and access to abundant factors of production, namely, natural resource endowments or cheap labour. Geographically, two separate patterns have emerged: the South American countries have intensified their specialization in natural resources and standardized commodities, while Mexico and the Central American countries have globalized their manufacturing and assembly activities on the back of relatively abundant cheap labour (Mortimore and Peres 2001).

Trade liberalization and the massive inflow of imports have modified the pattern of learning in many production activities. Technology-intensive fields, in particular, have rapidly proceeded toward vertical production organization technologies, substituting domestically produced intermediate inputs with cheaper (and sometimes better) imported inputs and reorganizing themselves as assembly-type operations based on a much higher unit-import content. The share of large firms (either local subsidiaries of transnational corporations or domestically owned conglomerates) in gross domestic product has significantly increased during the adjustment process. Most of the empirical evidence further indicates that the sources of learning have changed dramatically.

The learning path remains anchored in activities that modernize production processes and reduce costs in export sectors. Imported capital goods and learning in process improve productivity in selected sectors, while plants and production units absorb technology according to their segment in the international production networks. Learning activities are enforced in the Taylorist and Fordist organization of production, with only a few cases in which new products are created and adapted. Supply efforts and demand-led mechanisms are circumscribed in some sectors. The national innovation system and public policies have not been capable of diffusing networking activities and enforcing science-based activities in the public sector and firms with Taylorist methods of R&D activities (basic and applied).

Conclusions

This paper discussed the need to combine evolutionary microeconomics with the structuralist and Keynesian focus on structural change and demand growth. In the 1950s to the 1970s, the structuralist tradition lacked the microeconomic foundations that could sustain its approach to growth and trade. Such bases would only be developed by evolutionary theory since the beginning in the 1980s. Patterns of learning and the accumulation of technological capabilities change over time. From the 1940s to the 1970s, the dominant learning path was based on the ability to acquire technologies (including capital goods, know-how and so forth), absorb these technologies and adapt them to local conditions. The sequential stages include product design activities, quality improvement, process engineering and economies of scale. Production processes also evolve with the improvement of managerial capabilities. To fully develop these supply efforts, demand-led mechanisms should operate, increasing production capacity and diffusing the industrial sector in the economy. Countries that combine supply efforts and demand mechanisms have industrialized and increased employment in manufacturing activities.

With the new paradigms, the learning pattern develops in a new institutional setting and NIS configuration. Learning and capabilities are now based mainly on the interaction between science-based activities in the public sector and firms, Taylorist organization of R&D activities and human capital in scientific areas. This does not mean that the previous pattern disappears. Rather, they interact and co-evolve. The new technologies define the opportunities to produce new goods and processes, however, and they thus introduce novelty in the economy. Countries that have developed these patterns and transformed their production structures to incorporate R&D activities have captured the opportunities of new paradigms. They have traversed from the previous path to this new one, which characterizes the predominant pattern on the technological frontier. In contrast, countries that remain anchored only to their supply efforts have not benefited from the demand-led mechanisms, and their industrial sector remains truncated. The impact of trade liberalization, the inertia in industrial structures and the lack of a national innovation system capable of creating incentives for science and R&D activities put these countries in a state of hysteresis in their learning pattern, technological capabilities and, hence, development process. There is no endogenous mechanism that could spontaneously move the economy away from the state of hysteresis. To devise new institutions capable of placing the economy in a new growth trajectory (in which productivity growth advances *pari passu* with aggregate demand growth) is the key challenge that policy-makers will have to address in the following years.

From the combination of both approaches can be derived a research agenda that differs form the mainstream growth theory and seems particularly adequate for analysing the process of economic development. Some aspects are worthwhile stressing in this respect. As mentioned, patterns of learning vary across sectors and not all sectors display the same technological opportunities nor generate the same externalities. The traverse from a structure in which technology-intensive sectors are poorly represented toward a structure in which they respond for a higher share of total output is a critical research field, particularly in a period in which technological paradigms are rapidly changing. More research on the links between productivity growth and patterns of structural change in developing countries are required.

Secondly, it is necessary to look more closely at how learning, demand and productivity growth interact so as to avoid the emergence of unemployment and underemployment (and, as a consequence, of heterogeneity in production and labour market). Very high rates of productivity growth do not imply higher welfare levels if unemployment is rising. Moreover, to the extent that demand growth feeds productivity growth in a virtuous spiral, the latter would be compromised if there is no parallel increase in the aggregate demand. Researchers should look at the evolution of aggregated demand (particularly exports) as carefully as they look at the process of technological innovation and diffusion.

Last but not least, the research agenda should give a role to the interactions between macroeconomic policies, relative prices and economic growth. In the past, policies of rapid trade liberalization combined with real currency appreciation led to severe debt crises, as in 1982 and 1999–2000. These crises in turn elicited a sharp contraction in aggregate demand and investment. Both deeply affected learning and productivity growth, producing a vicious circle of loss of competitiveness and capabilities. More recently, higher prices for commodity exports have reinforced the prevailing pattern of specialization in natural resources in several developing countries. As mentioned, to the extent that this pattern is less dynamic from the point of view of aggregate demand growth and technological learning, the impact of recent changes in relative prices may have negative long run implications. Capabilities embodied in people and firms engaged in production are destroyed when they run out of business because of sharp fluctuations in the real exchange rate. Such capabilities would be difficult to rebuild thereafter, as new paradigms are emerging and increasingly more sophisticated capabilities required.

Acknowledgements

The first draft has benefited from the suggestions and comments of N. Correa, J.C. Ferraz and S. Rovira We thank C. Antonelli, K. Dopfer, G. Dosi, J. Foster, A. Kirman, D. Lane, L. Marengo, S. Metcalfe and the colleagues at the Brisbane Club workshop in Pollenza, June 2007, for the stimulating and constructive comments. A second draft has benefited the stimulating discussion with G. Dosi and L. Marengo at the LEM Seminar, October 2007. This final version has benefited from the constructive comments of two anonymous referees. The usual disclaimer applies.

Notes

1. The same view is prevalent in the literature on technology and industrialization in developed economies, which explicitly emphasizes that the means, methods and know-how through which

agents 'do things' define the concept of technology. It concerns problem-solving activities involving – to varying degrees – tacit forms of knowledge embodied in individuals and organizational procedures, as well as the means and interfaces through which knowledge is produced, codified or transformed in transferable artefacts (Rosenberg 1976, 1982; Dosi 1982, 1988; Pavitt 1987; Freeman, 1982, 1994).

2. This explicitly corroborates the view that technologies are, to a fair extent, incorporated in particular organizations (namely, the firms) whose learning capabilities are fundamental in shaping the rates and directions of technological advance (Atkinson and Stiglitz 1969; Antonelli 1995; Metcalfe 1995). This learning, in turn, is local, in that the exploration and development of new techniques is likely to occur in the neighbourhood of the techniques already in use, and cumulative, in that the current technological development – at least at the level of individual business units – often builds on past experiences of production and innovation, and it proceeds via sequences of specific problem-solving junctures.
3. After all, not much proof of this is needed: informed tourists recognize that most countries can be unequivocally ranked in terms of average productivity and income gaps.
4. Alternatively, wages have to be reduced in developing countries or the exchange rate devaluated.
5. This literature suggests that optimizing choice among technical alternatives commonly shared by all agents has little to do with all this and that one should rather look for an explanation of the accumulation of technological learning and capabilities. The contrast between (imperfect) learning and optimal resource allocation as the fundamental engine of development is emphasized by Kaldor, Pasinetti and Schumpeter, among others.
6. Hirschman, Prebisch, Rosenstein-Rodan, Gerschenkron, Chenery and Sirkin are some of the classical authors in the development theory.
7. Diversification of production structures and increasing returns in R&D-intensive sectors explain sustained per capita income growth in the long term, and structural change depends on the creation of new capital assets, increasing labour division and improvements in the quality of industrial products. At the same time, the innovation pace of the R&D-intensive sectors sustains production structure diversification and increasing returns.
8. Most of these approaches point out that learning is not automatic. Learning needs a 'social capability' which can be viewed as a 'rubric that covers countries' levels of general education and technical competence, the commercial, industrial and financial institutions that bear on their ability to finance and operate modern, large-scale business and the political and social characteristics that influence the risks, the incentives and the personal rewards of economic activity, including those rewards in social esteem that go beyond money and wealth' (Abramovitz 1989).
9. A variety of concepts have recently been put forward to define the nature of radical changes in technology: paradigms, technological regimes, trajectories, salients, guideposts, dominant designs and so on. These concepts overlap in that they try to capture a few common features of the procedures and direction of technical change and how change occurs when a new paradigm appears (Dosi 1988).
10. In the extreme case of *maquila* industries, which are intensive users of low-skilled labour, ICTs are abundantly incorporated in capitals goods and production processes (Capdevielle 2005). On the one hand, firms and plants reach the efficiency of those on the technological frontier. On the other, these industries have neither increased their productivity nor displayed strong linkages with the rest of the economy; in fact, increasing integration with international markets does not imply increasing dynamism in all domestic technological activities. In particular, regional technological capabilities in hardware and artefacts that can be associated with ICT are mainly explained by policies that promote foreign direct investment, as in the case of *maquila* industries, Mexico's Temporary Import Program for Exporters (PITEX) and free trade zones. Most of the 'locally installed' regional production capacity is accounted for by subsidiaries of multinational corporations, which are leaders in electronics, semiconductors, printed circuit, microprocessors, mobile phones, televisions (LCD and plasma) and personal computers. It is not surprising that these corporations are from regions and countries – such as Europe, Japan, Korea, Singapore and the United States – that have radically transformed their industrial structures to promote the expansion of firms and sectors associated with the ICT paradigms.
11. Nevertheless, the biotechnology industries have not met performance expectations. After four decades, the industry has not achieved expected profits, and it has suffered from the tension between the requirements of science and those of business (Pisano 2006; Silverthorne 2006).

12. Derived from the Greek *hysterein*, meaning to be late or to fall short, hysteresis is one of many economic concepts drawn from physics, where it was originally used to refer to the process by which a magnetised ferric metal does not immediately return to its unmagnetized state after the magnetic force is removed from it. In economics, it has come to mean that the impact of an exogenous shock persists in the system in some way, even after the shock ceases.

References

Abramovitz, M. 1989. *Thinking about growth*. Cambridge: Cambridge University Press.

Amsden, A. 1989. *Asia's next giant: South Korea and late industrialization*. New York: Oxford University Press.

Antonelli, C. 1995. *The economics of localized technological change and industrial dynamics*. London: Kluwer Academic Publishers.

Arthur, W.B. 1989. Competing technologies, increasing returns and lock-in by historical events. *Economic Journal* 99, no. 1: 116–31.

Atkinson, A., and J. Stiglitz. 1969. A new view of technological change. *Economic Journal* 79, no. 315: 573–57.

Bell, M. 2006. Time and technological learning in industrialising countries: How long does it take? How fast is it moving (if at all)? *International Journal of Technology Management* 36, no. 1–3: 25–39.

Bell, M., and K. Pavitt. 1993. Technological accumulation and industrial growth: Contrasts between developed and developing countries. *Industrial and Corporate Change* 2, no. 1: 157–210.

Cantwell, A.J. 1991. The theory of technological competence and its application to international production. In *Foreign investment, technology and growth*, ed. D.G. Mc Fetridge, 33–76. Calgary: University of Calgary Press.

Capdevielle, M. 2005. Globalización, especialización y Cambio Estructural en América Latina. In *Heterogeneidad Estructural, asimetrías Tecnológicas y Crecimiento en América Latina*, ed. M. Cimoli, 101–26. Santiago: BID-CEPAL.

Cardoso, F. 1973. *Problemas del subdesarrollo latinoamericano*. Mexico City: Nuestro Tiempo.

Cardoso, F., and E. Faletto. 1969. *Dependencia y desarrollo en América Latina*. Mexico City: Siglo XXI.

Chataway, J., J. Tait, and D. Wield. 2004. Understanding company R&D strategies in agro-biotechnology: Trajectories and blind spots. *Research Policy* 33, no. 6–7: 1041–57.

Chudnovsky, D., M. Nagao, and S. Jacobson. 1984. *Capital goods production in the third world: An economic study of technical acquisition*. London: Francis Pinter.

Cimoli, M. 1988. Technological gaps and institutional asymmetries in a North-South model with a continuum of goods. *Metroeconomica* 39, no. 3: 245–74.

Cimoli, M., ed. 2000. *Developing innovation systems: Mexico in the global context*. Pinter series: Science, technology and international political economy. London and New York: Pinter.

Cimoli, M., and N. Correa. 2005. Trade openness and technological gaps in Latin America: A low growth trap. In *Beyond reforms: Structural dynamics and macroeconomic vulnerability*, ed. J.A. Ocampo, 45–69. Stanford: Stanford University Press.

Cimoli, M., and G. Dosi. 1995. Technological paradigms, pattern of learning and development: An introductory roadmap. *Journal of Evolutionary Economics* 5, no. 3: 243–68.

Cimoli, M., G. Dosi, R.R. Nelson, and J. Stiglitz. 2006. Institutions and policies shaping industrial development: An introductory note. LEM Working Paper, No. 2006/02, Laboratory of Economics and Management, Pisa, Italy.

Cimoli, M., and L. Soete. 1992. A generalized technology gap trade model. *Economie Appliquée* 45, no. 3: 33–54.

David, P.A. 1985. Clio and the economics of QWERTY. *American Economic Review* 75, no. 2: 332–7.

De Bresson, C., and F. Amesse. 1991. Networks of innovation: A review and introduction to the issues. *Research Policy* 20, no. 5: 363–81.

Dosi, G. 1982. Technological paradigms and technological trajectories: A suggested interpretation of the determinant and direction of technological change. *Research Policy* 11, no. 3: 147–62.

Dosi, G. 1988. Sources, procedures and microeconomic effects of innovation. *Journal of Economic Literature* 26, no. 3: 1120–71.

Dosi, G., K. Pavitt, and L. Soete. 1990. *The economics of technical change and international trade*. London and New York: Harvester Wheatsheaf Press/New York University Press.

Ebers, M., and W.W. Powell. 2007. Biotechnology: Its origins, organization, and outputs. *Research Policy* 36, no. 4: 433–37.
Fajnzylber, F. 1990. *De la Caja Negra al Casillero Vacío.* Santiago de Chile: CEPAL.
Fransman, M. 1986. *Technology and economic development*. Brighton: Wheatsheaf.
Fransman, M., and K. King. 1984. *Technological capability in the third world*. London: Macmillan.
Freeman, C. 1963. The plastic industry: A comparative study of research and innovation. *National Institute Economic Review* 26: 22–62.
Freeman, C. 1982. *The economics of industrial inovation*. London: Francis Pinter.
Freeman, C. 1987. *Technology policy and economic performance: Lessons from Japan*. London: Francis Pinter.
Freeman, C. 1994. Technological revolutions and catching-up: ICT and the NICs. In *The dynamics of technology, trade and growth*, ed. J. Fagerberg, N. von Tunzelman and B. Verspagen, 198–221. London: Edgar Elgar.
Freeman, C. 2001. A hard landing for the 'new economy'? Information technology and the United States national system of innovation. *Structural Change and Economic Dynamics* 12, no. 2: 115–39.
Freeman, C., and C. Pérez. 1988. Structural crises of adjustment, business cycles and investment behaviour. In *Technical change and economic theory*, ed. G. Dosi et al., London: Pinter Publishers.
Hirsch, S. 1965. The US electronics industry in international trade. *National Institute Economic Review* 34: 92–107.
Hufbauer, G. 1966. *Synthetic materials and the theory of international trade*. London: Buckworth.
Kanatsu, T. 2006. Why Toyota does not fly while Bandeirante does: Comparative study of the Japanese and the Brazilian aircraft industry. Department of Political Science, Hofstra University.
Katz, J. 1984. Domestic technological innovations and dynamic comparative advantage. *Journal of Development Economics* 16: 13–38.
Katz, J. 1997. Structural reforms, the sources and nature of technical change and the functioning of the national systems of innovation: The case of Latin America. Paper presented at the STEPI International Symposium on Innovation and Competitiveness in NIEs, May in Seoul, Korea.
Kim, L. 1997. Korea's national innovation system in transition. Paper presented at the STEPI International Symposium on Innovation and Competitiveness in NIEs, May in Seoul, Korea.
Lall, S. 1982. *Developing countries as exporters of technology: A first look at the Indian experience*. London: Macmillan.
Lall, S. 1997. Technological change and industrialisation in the Asian NIEs: Achievements and challenges. Paper presented at the STEPI International Symposium on Innovation and Competitiveness in NIEs, May in Seoul, Korea.
McCombie, J.S., and A. Thirlwall. 1994. *Economic growth and the balance of payments constraint*. New York: St. Martin Press.
McMillan, G.S., F. Narin, and D. Deeds. 1999. An analysis of the critical role of public science in innovation: The case of biotechnology. *Research Policy* 29, no. 1: 1–8.
Metcalfe, J.S. 1989. Evolution and economic change. In *Technology and economic progress*, ed. A. Silberston, 54–85. Basingstoke: Macmillan.
Metcalfe, J.S. 1995. The economic foundations of technology policy. In *Handbook of the economics of innovation and technical change*, ed. P. Stoneman, 409–512. Oxford: Blackwell.
Metcalfe, J.S. 2001. Institutions and progress. *Industrial and Corporate Change* 10, no. 3: 561–86.
Metcalfe, J.S., J. Foster, and R. Ramlogan. 2006. Adaptive economic growth. *Cambridge Journal of Economics* 30, no. 1: 7–32.
Miozzo, M., and V. Walsh. 2006. *International competitiveness and technological change*. Oxford: Oxford University Press.
Mortimore, M., and W. Peres. 2001. Competitividad empresarial en América Latina y el Caribe. *Revista de la CEPAL* 74: 37–59.
Nelson, R., ed. 1993. *National systems of innovation*. Oxford: Oxford University Press.
Ocampo, J.A. 2005. The quest for dynamic efficiency: Structural dnamics and economic growth in developing countries. In *Beyond reforms: Structural dynamics and macroeconomic vulnerability*, ed. J.A. Ocampo, 3–43. Stanford: Stanford University Press.
Pavitt, K. 1984. Sectoral patterns of technological change: Towards a taxonomy and a theory. *Research Policy* 13, no. 6: 343–75.
Pavitt, K. 1987. The objectives of technology policy. *Science and Public Policy* 14, no. 4: 182–8.

Pérez, C. 1985. Micro-electronics, long waves and world structural change: New perspectives for developing countries. *World Development* 13, no. 3: 441–63.

Pinto, A. 1970. Heterogeneidad estructural y modelo de desarrollo reciente de la América Latina. In *Inflación: raíces estructurales*, 104–40. México, DF: Fondo de Cultura Económica.

Pinto, A. 1976. Naturaleza e implicaciones de la heterogeneidad estructural de la América Latina. *El Trimestre Económico* 37 (1), no. 145: 83–100.

Pisano, G. 2006. Can science be a business? Lessons from biotech. *Harvard Business Review* 84, no. 10: 114–25.

Posner, M.V. 1961. International trade and technological change. *Oxford Economic Papers* 13, no. 3: 323–41.

Prebisch, R. 1981. *Capitalismo periférico: Crisis y transformación*. México: Fondo de Cultura Económica.

Rodríguez, O.1977. Sobre la Concepción del Sistema centro-periferia. *Revista de la CEPAL* (First Semester), no. 3: 203–47.

Rosenberg, N. 1976. *Perspectives on technology*. Cambridge: Cambridge University Press.

Rosenberg, N. 1982. *Inside the black box*. Cambridge: Cambridge University Press.

Rothaermel, F., and M. Thursby. 2007. The nanotech versus the biotech revolution: Sources of productivity in incumbent firm research. *Research Policy* 36, no. 6: 832–49.

Schumpeter, J.A. 1939. *Business cycles*. New York: McGraw-Hill.

Setterfield, M. 2002. A model of Kaldorian traverse: Cumulative causation, structural change and evolutionary hysteresis. In *The economics of demand-led growth*, ed. M. Setterfield, 215–33. Cheltenham, UK: Edward Elgar.

Setterfield, M., and J. Cornwall. 2002. A neo-Kaldorian perspective on the rise and decline of the golden age. In *The economics of demand-led growth*, ed. M. Setterfield, 67–86. Cheltenham, UK: Edward Elgar.

Silverthorne, S. 2006. Science business: What happened to biotech? *HBS Working Knowledge*, November 13.

Sunkel O. 1978. La dependencia y la heterogeneidad estructural. *Trimestre Económico* 45, no. 1: 3–20.

Teece, D. 1998. *Strategy, technology and public policy: The selected papers of David Teece*, vol. 2. London: Edward Elgar.

Teece, D.J., G. Pisano, and A. Shuen. 1990. Firm capabilities, resources, and the concept of strategy. Working Paper, University of California at Berkeley.

Teitel, S. 1984. Technology creation in semi-industrial economies. *Journal of Development Economics* 16, no. 1–2: 39–61.

Teitel, S. 1987a. Science and technology indicators, country size and economic development: An international comparison. *World Development* 15, no. (9): 1225–35.

Teitel, S. 1987b. Towards conceptualisation of technological development as an evolutionary process. In *Structural change, economic interdependence and world development*, ed. J. Dunning and U. Mikoto. London: Macmillan.

Teitel, S. 2004. On semi-industrialized countries and the acquisition of technological capabilities. ICER Working Paper, No. 19-2004, Torino, Italy.

Teubal, M. 1984. The role of technological learning in the exports of manufactured goods: The case of selected capital goods in Brazil. *World Development* 12, no. 8: 849–65.

Thirlwall, A.P. 1979. The balance of payments constraint as an explanation of international growth rates differences. *Banca Nazionale del Lavoro Quaterly Review* 28, no. 1: 45–53.

Vernon, R. 1966. International investment and international trade in the product cycle. *Quarterly Journal of Economics* 80, no. 2: 190–207.

Wade, R. 1990. *Governing the market: Economic theory and the role of government in east Asian industrialisation*. Princeton: Princeton University Press.