41. Localized technological change

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INTRODUCTION

The origin of the concept of localized technological change perhaps dates back to the famous Atkinson and Stiglitz (1969) article. This article does not provide a formal definition, but heuristically contrasts technological progress that is shifting the entire production function outwards with a local notion of technological progress that is locally shifting a part of the production function outwards or different parts to a different extent. It explicitly refers to activity analysis as the origin of the neo-classical production function:

> as the number of production processes increases (in an activity analysis model), the production possibilities can be more and more closely approximated by a smooth, differentiable curve. But the different points on the curve still represent different processes of production, and associated with each of these processes there will be certain technical knowledge specific to that technique. […] that if one brings about a technological improvement in one of the blue-prints this may have little or no effect on the other blue-prints. (Atkinson and Stiglitz, 1969, p. 573)

Learning is indeed a major source of technological knowledge and competence, but it does not concern the whole range of techniques available on each isoquant as implicitly suggested by the Arrovian intuition (Arrow, 1962). As a matter of fact, it enables improving only the specific techniques practiced at each point in time. Consequently, firms that rely on the tacit knowledge acquired by means of learning processes to innovate, can introduce new technologies only in the proximity of the techniques in place at each point in time.

Stiglitz (1987) spells out the link with the theory of learning. Technological progress is localized because the learning is localized. Learning by doing and learning by learning are examples of economies of specialization that provide a kind of externality. Stiglitz (1987, pp. 125, 133–134) stresses the necessity to analyze these non-convexities and the resulting imperfect competition and multiple equilibria.

LOCALIZED TECHNOLOGICAL CHANGE: CONCEPTUAL AND THEORETICAL DEVELOPMENTS

The notion of localized technological change plays an important role in the microeconomic and industrial economics framework developed by Antonelli (1995, 2003, 2008, 2019) in a series of books, complemented by some articles. The purpose of his work is to develop a unifying framework in which the Schumpeterian notion of technological innovation as a creative response and the model of localized and directed technological change can be integrated. In a Schumpeterian view, firms are in an out-of-equilibrium state of product and factor markets, and are inducing changes by innovation. Firms either react in an adaptive way by moving on the existing map of isoquants, or creatively by the introduction of technological changes as a response to mismatches between planned and actual conditions of factor and product markets. The latter option is associated with knowledge externalities and, if effective learning processes are available that make the generation of new technological knowledge possible at low costs, with the consequent introduction of changes in the input–output space.

The analysis of this creative response based upon localized technological change presupposes the central role of knowledge as an enabling factor. In the localized technological change approach to this creative response, knowledge plays a double role: (i) it is a necessary condition for the creative response to happen, and (ii) it shapes the direction of technological change. The introduction of biased technological change directed at increasing the output elasticity of the factor that is locally abundant has strong effects in terms of augmented total factor productivity and competitive advantage. The intensive use of a production factor that is locally cheaper with respect to other factor markets where competitors are based is a major source of competitive advantage.

The stock of technological knowledge capitalized as a component of the wide concept of capital is the current abundant factor and a new source of competitive advantage for advanced countries. The dynamics of factor cost equalization together with the globalization of factor markets has made capital available to industrializing countries at cost and conditions close to advanced countries. However, the relative distribution of the stocks of technological knowledge is far more asymmetric in that it is far more abundant in advanced countries because of the unique availability of quasi-public knowledge and the high quality of knowledge governance mechanisms.

This leads to persistent differences of advanced, developing and emerging countries, which are the focus of macroeconomic growth theory. Acemoglu (2015) relates the notion of localized technological change to the work of induced innovation and directed (factor-biased) technological change (Acemoglu 2002, 2007) in the context of aggregate growth. At the center of this work is a production function of the form

$$Y = F(A_L L, A_K K),$$

where A_L and A_K are distinct technology parameters that augment the production factors labor L and capital K differentially and therefore expand the production possibilities in different directions. Thus, the frontier function advances unevenly in the direction of labor if A_L grows faster than A_K and advances in the direction of capital if A_K grows faster than A_L. Therefore, the frontier function needs not evenly expand in all input directions.

If an innovation leads to an advancement of the frontier function at a particular capital–labor ratio and also improves the frontier function at neighboring capital–labor ratios, as presented in Figure 2 of Atkinson and Stiglitz (1969), but leaves the frontier function at more distant capital–labor ratios unaffected, then this is associated with the notion of directed technological change with differential changes of A_L and A_K as pointed out by Acemoglu (2015, p. 444).

The basic concept of directed technological change is exploited by Acemoglu in a vast number of papers, and part of which is reviewed in the second part of Acemoglu (2015). Particularly interesting is the analysis of Acemoglu and Zilibotti (2001) where they show that technologies developed in advanced countries are less suitable to the factor endowments of developing countries. The reason is the absence of incentives for advanced countries to invent technologies adapted to the factor endowments of developing countries because of the weak institutions for property rights enforcement there. This explains the large and persistent productivity differences between both groups of countries.

LOCALIZED TECHNOLOGICAL CHANGE: EMPIRICAL WORK

Turning back to microeconomic empirical work in this section we build upon axiomatically founded nonparametric deterministic frontier-based technologies (see Färe et al., 1994a; Hackman, 2008). The use of these methods allows, in principle, one to define precise measurement tools for measuring the notion of global and localized technological change. This work is based on the definition of discrete-time productivity indices (e.g., the Malmquist) and indicators (e.g., the Luenberger) which can be decomposed into technical change (i.e., movements in the production frontier) and efficiency change (i.e., movements towards or away from the production frontier). The literature is immense and continues expanding. To give some flavor of this literature, we make a selection of the few studies we are aware of that explicitly appeal to the notion of local technological change.

Bernard et al. (1996) examine the innovators and technological change in French machinery industry using a nonparametric approach under a convex production technology. They argue that the technological knowledge and local technological change both have impacts on the evaluation of firms and the innovators can promote technological progress in a particular field. Cantner and Westermann (1998) also apply a nonparametric convex approach to analyze the innovations in German industries. They empirically measure technical efficiency and the shift of production technology for machinery, electronics and chemical corporates. Their results indicate that the technological progress is localized. Naturally, the assumption of heterogeneity among industries prevails which is opposite to the homogeneous production function advocated by neoclassical theory. Similarly, Westermann and Schaefer (2001) analyze the technological efficiency and labor costs in manufacturing sectors using a convex production frontier. They find a positive relation between innovative firms and employment growth. They argue that although the effect of labor costs is generally negative, the companies with increasing labor costs have an insignificant impact on technologically leading industries. The technological changes vary across 12 manufacturing sectors.

In addition, the transition of global and local technological changes is informally discussed in literature. For example, Bonaccorsi et al. (2005) investigate the technological progress in the commercial jet aero-engine industry. The technological discontinuities and a convergence progress of technological frontier are observed. This implies overall evolution (global technological change) can be aggregated by incremental improvements (local technological change). Timmer and Los (2005) investigate the labor productivity growth across Asian countries. Their results show that the technology innovation is localized in agricultural and manufacturing sectors. In the agricultural sector, the technological progress usually appears when the capital intensity is high while the innovation has a more significant impact on labor productivity change in manufacturing sector. López-Pueyo and Mancebón (2010) explore the labor productivity changes in the information and communication technologies sector in advanced countries. They argue that the localized innovation is an additional driving force of worldwide productivity growth divergence across countries. Their results imply that labor productivity growth is mainly due to technical change and capital intensification.

Besides the assumption of convexity for the production technology, some investigations are conducted within a nonconvex approach. Los and Verspagen (2009) evaluate technological change and carbon emissions by passenger cars using a nonparametric nonconvex model. Their results show that the rates of technological change and diffusion have a significant disparity between segments of the car market. They argue that better policies should be derived on the diffusion of best-practice technology.

There is a strand of macroeconomic empirical work focusing on the nonparametric measurement of (total factor) productivity change by using a Malmquist index. Key articles in this strand include Färe et al. (1994b), Ray and Desli (1997), Kumar and Russell (2002), Henderson and Russell (2005), Krüger (2003, 2020) among others. These contributions exploit the decomposition of the Malmquist index mentioned above. The magnitude of components can be different for different positions in the input–output space which fundamentally makes the measurement of productivity become local.

Caselli and Coleman (2006) investigate directed technological change in a production function setting with skilled and unskilled labor as inputs in addition to capital. They rely on a parametric CES production function with calibrated parameters. Their main finding is that developing countries are relatively more efficient in using unskilled labor whereas advanced countries are more efficient in using skilled labor. Although this analysis is static, the efficiency differences have their heritage in differential long-run rates of technological advancement. This finding can be confirmed by Krüger (2017) using nonparametric methods of efficiency measurement without specifying a functional form. Jones (2005) and Krüger (2016) provide related analyses.

TOWARDS MORE OPERATIONAL DEFINITIONS AND CONCEPTS

In this section, we focus on two representative strands in the literature that shed some light on the formal definition of global and local technological change.

To the best of our knowledge, the article of Kerstens and Managi (2012) offers the first attempt to provide an operational definition for the notion of localized technological change. These authors utilize a primal Luenberger productivity indicator based on deterministic, nonparametric production frontiers to measure global and local technical change and decompose it into technical efficiency change and production frontier change.

Global technical progress is defined as resulting from efficient observations at two time periods relative to a convex frontier that do experience positive technological change between these two time periods relative to the same convex frontier. Local technical progress is defined as resulting from efficient observations at two time periods in terms of a nonconvex frontier that are both inefficient with respect to a convex frontier and that that do experience positive technological change in terms of a nonconvex frontier between these two time periods. The same authors also defined weaker versions of the same definitions whereby an observation is only efficient in one of the two time periods considered.

Both these definitions are illustrated with the help of Figure 41.1. We observe two production frontiers in a single input and single output space: one pertains to time period t, while the other is related to the next time period t+1. The convex technology is drawn as a dash-dotted line. The nonconvex staircase-shaped technology is indicated as a full line. Observe that the production frontier in period t+1 has shifted mainly upwards and to the left, although observation 1 is in common with both period *t* and period *t*+1. Observe that for the convex technology only observations 1, 3, 5 and 7 are situated on the frontier: all other observations are technically inefficient. Observe that for the nonconvex technology all the observations from 1 to 7 belong to the frontier: no observation is technically inefficient. Now, while observations 3, 5 and 7 satisfy the conditions for global technical progress, observations 2, 4 and 6 meet the conditions for local technical progress. Thus, in Figure 41.1, more observations satisfy the conditions for local technological change than the ones for global technological change. But, it should be realized that this is not a mathematical necessity: it simply depends on the empirical structure of the sample.

The empirical results in Kerstens and Managi (2012) for a sample of 933 oil fields over a 50-year time horizon in the Mexican Gulf indicate that about 62.8 percent more observations satisfy the conditions for local technological change compared with global technological change. We are also aware of two other articles applying this same method proposed by Kerstens and Managi (2012) to distinguish between global and local technological changes.

First, Barros et al. (2015) analyze the productivity growth for 14 Chinese commercial banks during the period 2003–2010 using a Luenberger productivity indicator based on both convex and nonconvex technologies under the assumption of variable returns to scale. It turns out from their Table 4 that, overall, most banks in the sample experience global technical change rather than local technical change: now 42.8 percent more observations satisfy global technological change rather than local technological change. There is only one among 17 periods where local technological change is slightly bigger than global technological change.

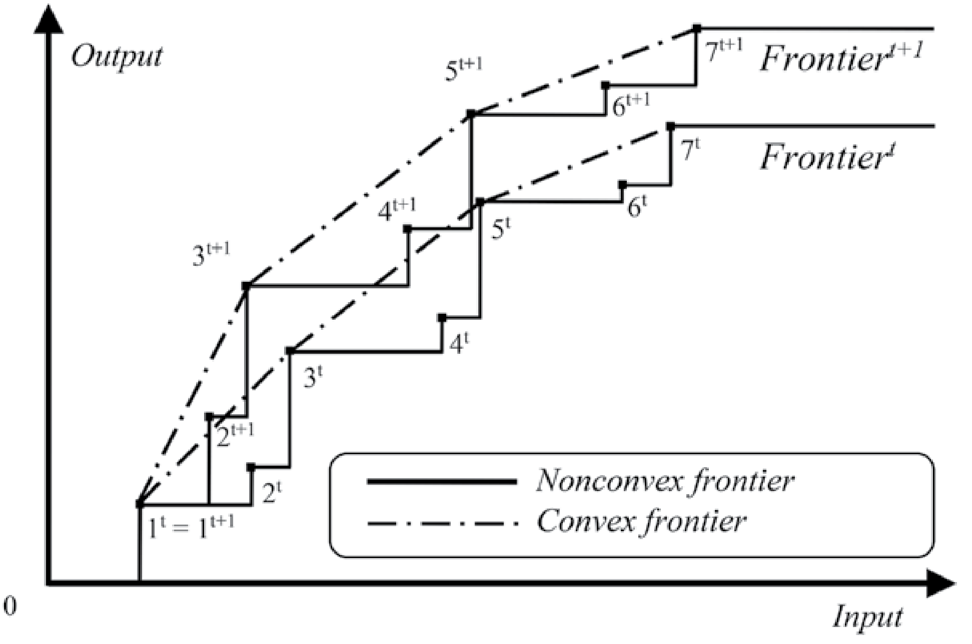

Figure 41.1 *Global and local technological change under nonconvex and convex technologies*

Second, Fujii et al. (2015) use exactly the same methodology as in the previous article to analyze 16 Japanese manufacturing sectors over the 2008–2010 period. The relative importance of global and local technological change varies across sectors and also across the two-year time periods. In brief, there is no clear pattern to discern.

A major problem with this approach is that it exploits differences between convex and nonconvex technologies to define some notion of local technological change. However, this approach fails to recognize that both in the case of convex and nonconvex technologies one may conceptualize both global and local technological change. This needs to be remedied in future work.

There is a second strand of literature based on nonparametric frontier methods that can offer some perspective on the problem of local technical change. When computing productivity indices and indicators such as the Malmquist index or the Luenberger productivity indicator, it is not always possible that the efficiency measures can be achieved. The corresponding (linear) programming problems can be infeasible.

To grasp the intuition behind this case, let us study Figure 41.2. Again, we observe two production frontiers in a single input and single output space for a time period t and the next time period t+1. We only consider convex technologies drawn as a full line. The frontier in period t is spanned by two observations and the frontier in period t+1 is spanned by three observations. Observe that the two frontiers have one point in common, which lets them conform to the basic idea of Atkinson and Stiglitz (1969). We see that the technology in period t+1 has locally moved outwards to the left towards point 1^{t+1} and upwards towards the point 3^{t+1}.

It is intuitively clear that if we measure the distance between point 3^{t+1} and the frontier in period t to assess the change in productivity, then this distance cannot be achieved when we measure in the input orientation (meaning cost minimization). A similar reasoning can be

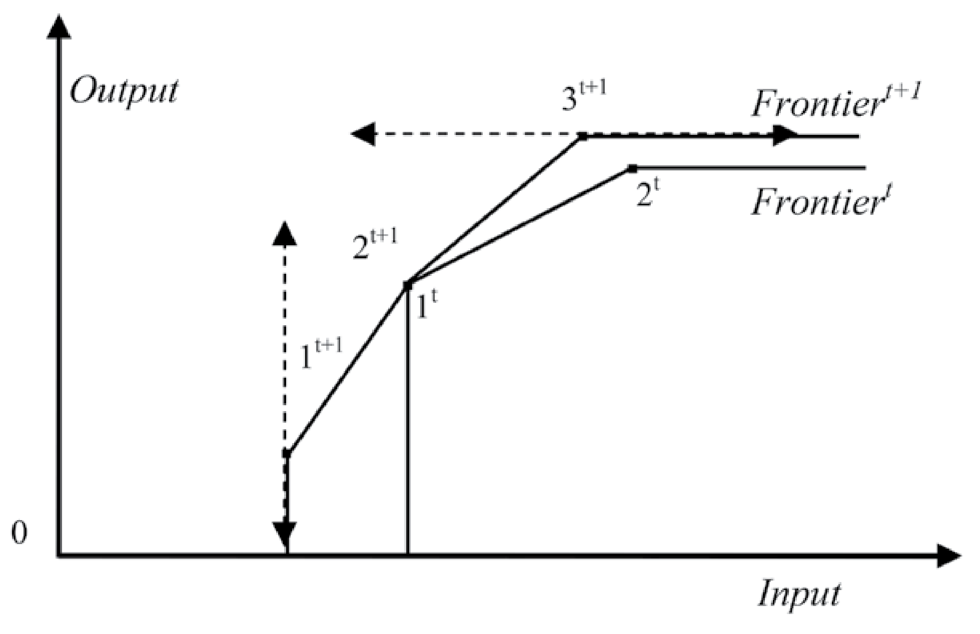

Figure 41.2 Technological change under convex technologies: infeasibilities

made with respect to point 1^{t+1}. If we want to measure the distance between point 1^{t+1} and the frontier in period t to assess the change in productivity, then this distance cannot be achieved when we measure in the output orientation (meaning revenue maximization). In mathematical programming language: the corresponding (linear) programming problems are infeasible as indicated by the double arrowed dashed horizontal (vertical) line emanating from point 3^{t+1} (1^{t+1}).

The precise conditions under which the efficiency measures being part of the Malmquist index or the Luenberger productivity indicator become infeasible have been analyzed in Briec and Kerstens (2009). However, in the literature there has been a tendency to mask the problem of infeasibility by making stronger assumptions on the technology, e.g. imposing constant returns to scale. The extent of these infeasibilities has been reported in a multitude of studies, see for example Kerstens and Van de Woestyne (2014).

THE REGIONAL DIMENSION

Within innovation economics there is another strand of literature which considers local agglomerations of industries within a certain geographical area (regional clusters) as another dimension of localization (see Antonelli, 1995, 2000; Boschma, 2005, inter alia). The firms within the agglomeration benefit from external spillover effects realized by information exchange and also by local labor flows (e.g. by scientists changing employers). In general, this is easier within a limited geographical area than across more distant regions. The benefits of local agglomerations are that they lower adjustment costs and generate complementarities by mutual fertilization of ideas and easing the establishment of user-producer relationships. This fosters technological diffusion by spillover effects which are largely confined to the firms within an agglomeration. In the end, this leads to a faster accumulation of knowledge, massive increasing returns, more innovations and new products.

This mainly describes Marshallian (or Marshall–Arrow–Romer, MAR) externalities due to Marshall (1890), Arrow (1962) and Romer (1986) which are related to the agglomeration of firms within the same industry or technological area. Another form of externalities due to Jacobs (1969) emphasizes the importance of the variety of the industrial structure in an agglomeration and knowledge spillovers across firms in different industries. More recently, Frenken et al. (2007) have introduced the concept of related variety with its explicit focus on inter-industry knowledge spillovers (see Content and Frenken, 2016, for a recent survey).

THE WAY AHEAD

While some limited progress has been made to distinguish between global and local technological change in the literature, it is rather surprising that up to now nobody has managed to come up with universally accepted formal definitions for global and local technological change that are valid for general nonparametric technologies under a wide variety of assumptions.

Future work could furthermore focus on accumulating more evidence on the empirical incidence of global and local technological change, on developing dual cost function-based measurement of global and local technological change, on transforming the infeasibility into a measurable indication of local technological change, among others.

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