Generation and Diffusion of Innovation 21

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Abstract

Generation and diffusion of innovation are two distinct processes that are interlinked in several ways. First, innovation efforts of firms are stimulated by the diffusion of innovation ideas. Second, the market penetration of successful product innovations diffuse to user firms and consumers, providing users opportunities to adopt novel routines and to imitate new designs. Third, creative destruction develops when a novel product finds its way to customers and replaces earlier product vintages, and this phenomenon has the nature of

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a substitution process. All these processes are supported by knowledge flows which vary in intensity and diversity across the innovation milieu of functional regions. It is concluded that the milieu characteristics which stimulate innovation also stimulate adoption of novelties.

21.1 Introduction

The economic growth literature has, since the contribution of Solow in the 1950s, attributed productivity growth to processes of technical change, where economy-wide technical change is based on the generation of innovations and their diffusion across firms and regions, although innovation processes were not modeled as endogenous until the late 1980s (e.g., Romer 1986; Aghion and Howitt 1992). As firms develop new routines for their operation and design new products for the market, they do so with the objective to increase their productivity. Following suggestions in Nelson and Winter (1982) – building on Schumpeter (1934) – we shall consider three broad categories of innovations: (i) new *product varieties* with novel combinations of product attributes, (ii) new *firm routines*, comprising novel production and administration processes and techniques, and (iii) new markets including novel links to customers.

The research approach in the field of innovation studies has changed in important ways during the past two decades, primarily as a result of new data sources which contain firm-level micro data sets, allowing researchers to observe for individual firms' (i) firm characteristics, (ii) innovation efforts, and (iii) location characteristics. With information about the location of each firm, it becomes possible to consider information about the innovation milieu associated with different locations. An example of new data sources is the *community innovation surveys (CIS)*, in which data from the EU member states are collected on a regular basis with harmonized information (OECD 2005).

The objective of this chapter is to develop and examine a view on how firms generate innovations and what consequences innovations can have on firm performance and heterogeneity. A second task is to describe how innovations diffuse from innovators to other (user) firms and thereby affect the performance of the latter as well as the entire economy. In this endeavor the chapter presents a theoretical framework in which lasting differences in firm performance are related to persisting differences in firms' innovation and adoption behavior.

In the subsequent exposé, it will be shown that *regional milieus* that favor the generation of innovations also facilitate diffusion of novelties. As an example we may observe that a firm's generation of innovations is positively related to the knowledge intensity of the firm's employees. Likewise, the knowledge intensity of a firm's labor force increases its absorption capacity, augmenting the probability that novel techniques and product-attribute information will diffuse to the firm. The regional aspect follows when we observe that knowledge-intensive firms are more frequent in regions with a knowledge-intensive labor force.

A firm generates innovations in a process of innovation activities, of which *research and development (R&D)* efforts may be a major part. Innovation activities bring about new knowledge while at the same time using inputs from the conjunction of internal and external knowledge sources. The combination of internal and external knowledge accession is cumulated into knowledge about (i) firm routines, (ii) product variety attributes, (iii) markets and customers' willingness to pay for product attributes, and (iv) routines for how to organize and perform innovation activities.

The presentation will concentrate on three major aspects, namely, firm characteristics, innovation milieu characteristics, and innovation activities. The additional question is as follows: how do the three aspects affect firm performance, where these effects can be subdivided into direct and indirect innovation consequences? Direct effects concern new patents, markets and products, and sales of new products. Examples of indirect effects are factor productivity growth, sales per employee, labor productivity, and profitability. The reader should also recognize that the output from a firm is products, comprising both services and goods.

As a way to amalgamate established findings in the literature, the presentation will focus on the following set of theses associated with making innovations and adopting innovation:

Thesis 1: Innovation and adoption activities are two interlinked and overlapping firm renewal phenomena. As a rule both activities require that the pertinent firm renews its routines. In all essence, such routine adjustments should be classified as routine or process innovations.

Thesis 2: Both innovation and adoption activities are fuelled by inputs from internal and external knowledge sources. Part of the external knowledge is disseminated according to classical diffusion.

Thesis 3: *Knowledge flows* reduce in volume and intensity as the distance between origin and destination grows. This form of spatial discounting implies that localized knowledge is a fundamental characteristic of a functional region. In the sequel each functional region will be categorized with regard to its accessibility to different knowledge sources.

21.2 Innovations and Heterogeneity of Firms and Places

In order to maintain its competitiveness, a firm has to renew itself over time. As emphasized in Thesis 1, such renewal has two forms. The first is more proactive and is based on R&D and innovation efforts, where the firm in the spirit of Schumpeter generates product and process (routine) innovations. The second form of firm renewal is rather reactive and consists of a firm's search for novel product ideas and for new technical solutions developed elsewhere in the economy.

Continued and repeated *firm renewal* is the key factor for a firm's survival and eventual growth. In renewal efforts firms develop and adopt new technologies, using knowledge components that are paid for as well as knowledge that pass by as unintended consequences of current economic activities. To facilitate the combination of internal efforts and external interaction, firms can establish *networks*

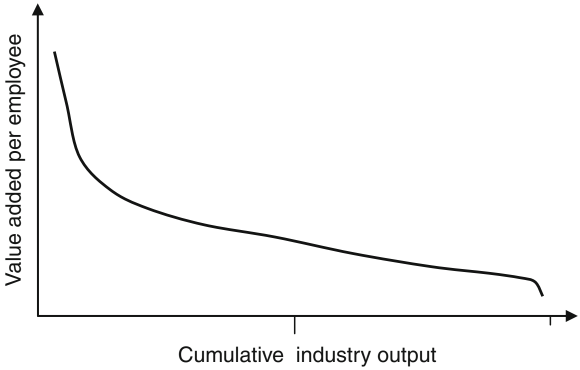

Fig. 21.1 Labor productivity cross tabulated against output of firms in an industry (OECD code 1) in productivity-descending order

for knowledge flows. The associated spillovers and organized knowledge flows stimulate innovation as well as adoption activities of firms and provide inputs to an ongoing process of firm renewal. Differences in firms' renewal intensity will cause heterogeneity among firms to sustain. Thesis 3 clarifies that proximity to knowledge sources matters.

Firms in the same industry or firms supplying product varieties belonging to the same product group have as a rule heterogeneous characteristics and display different performance in terms of productivity, profitability, or growth, and they differ in their R&D and innovation efforts. In established microeconomic theory, such differences are predicted to vanish over time, based on the argument that only the best practice can survive. Empirical observations do not support this view (Dosi and Nelson 2010). To a large extent, interfirm differences remain over long time sequences.

Differences between firms in a given industry (or group of industries) may be identified for a panel of firm observations over time. Such a panel will contain differences for each individual firm at different points in time as well as differences between firms that remain basically unchanged along time. With reference to Geroski (1998), we may then calculate the total variance for a performance variable like value added or gross profit per employee and then in a second step determine how much of the variance is due to the variation between years for each individual firm, referred to as *within variance*. The remaining variance can then be conceived as a persistent difference between firms, referred to as *between variance*. This between variance is typically 3–4 times larger than the within variance (Andersson et al. 2012). Such observations demonstrate heterogeneity among firms in most industries while at the same time showing that differences between firms persist over time.

Figure 21.1 provides a picture of the labor productivity (2006) in an industry supplying differentiated products (OECD code 1), based on Swedish data. The horizontal axis measures the cumulative output from firms in the sector when firms are ordered according to descending productivity. The figure illustrates how the quartile with the highest productivity has a productivity which is 3–4 times as large as the lowest quartile. Such performance differences provide a strong motive to examine firm characteristics when assessing performance. Among such characteristics the literature has considered firms' behavior with regard to efforts to innovate and to adopt new technology developed by other firms. The first aspect associates with the process of generating innovation and the second with diffusion and adoption.

The presentation in this chapter makes use of a theoretical framework, in which lasting differences in firm performance are related to persistent differences in how firms generate their own innovations and how they adopt new equipment as well as current input flows. Thus, in a second perspective, we observe that there are also systematic differences between firms with regard to how large amounts of resources per sales and value added they commit to innovation efforts (R&D intensity). Such R&D shares display highly skewed distributions across firms, and the firm differences remain persistent over time (Klette and Kortum 2004). The picture that emerges is a system with different "species," where a large share of firms is not engaged in innovation and R&D activities, where some firms are innovation active only occasionally, whereas firms in still another group remain persistently innovation active over a sequence of years. In addition, firms that display alertness in buying or imitating innovations developed elsewhere can be expected to have a higher *absorption capacity* than the average firm.

As firms are located in different regions, one may also investigate to what extent a firm's local economic milieu affects its performance. Are there characteristics of a firm's economic environment that influence firm performance both in terms of economic outcome and innovation results? Before that question can be answered properly, it is necessary to consider how a region is defined and identified. This presentation refers to the concept *functional urban region*, where the regional boundaries encircle an area within which frequent face-to-face interaction can take place with short notice and without travel planning. In most practical cases, this requirement is satisfied for local labor market regions, for which labor market commuting between intra-regional areas is much more intensive than between areas in two different functional regions.

Heterogeneity among firms is a result of different development paths, and these paths are consequences of how well each firm manages to carry out its own innovations and to adopt technological novelties developed elsewhere in the economy. Innovation efforts of firms combine with knowledge flows of various kind including interactive communication between the firm and other actors such as suppliers, customers, competitors, university researchers, and other knowledge providers. Knowledge flows are equally important for a firm's efforts to acquire and adopt innovations. In the case of adoption, the driving incentive is to learn about new equipment and technical solutions as an input to making adoption decisions, and this makes knowledge flows vital. Similar observations apply to firms which imitate novel products with new attribute combinations.

Knowledge flows vary in content, diversity, and intensity between functional regions. In particular, the friction of knowledge diffusion and transfer is smaller inside a functional region than more long-distance flows. In this way we can explain the pronounced tendency of innovations and technology adoption to cluster in particular functional regions, caused by the heterogeneity of urban regions with regard to knowledge intensity of the labor force, the presence of R&D activities in firms and universities, the size of gross regional product (GRP) and level of GRP

Table 21.1 Illustration of urban region heterogeneity in Europe 2004

Rank order (GDP/cap)	Urban region	GDP/cap €	GDP €, million	Accessibility to GDP
1	Paris	67,500	146,000	823
2	Inner London	65,600	191,300	815
11	Copenhagen	38,300	46,100	178
33	Stuttgart	30,400	121,300	315
87	Glasgow	26,000	49,800	81
167	Skåne (Scania)	23,700	27,500	76

Remark: 640 NUTS 2/3 regions with PPS-adjusted GDP values (Eurostat)

per capita, the diversity of the region's export and import flows, etc. For the USA, such differences between urban regions are recognized and documented in, for example, Henderson (1997).

In their evolution urban or city regions remain different from each other and retain their idiosyncratic features including markedly different levels of income per inhabitant. As illustrated in Table 21.1, urban regions also differ in their human capital resources, which is reflected in the table by the knowledge intensity of the labor force, measured as the share of the labor force with at least 3 years' university studies. Three things are accentuated in the table. First, the *knowledge intensity* increases very fast between 1993 and 2007. Second, the relative difference between regions remains unchanged during the 14 years. Third, the larger the urban region is, the higher its knowledge intensity. Subsequently the presentation will emphasize a region's knowledge intensity as a determinant of its innovation as well as adoption intensity. High knowledge intensity is associated with two region features: (i) high absorption capacity of firms and (ii) intense knowledge flows and spillover phenomena, where pure spillovers are defined as unintended knowledge flows which occur free of charge.

21.3 Innovations, Diffusion, and Technological Development

As summarized by Mansfield (1987), technological change results in a change in the production function of an existing product (routine renewal) or in an addition to the list of technologically feasible products (product renewal). In practice both types of renewal may occur simultaneously. A firm's adoption of novelties may not be very different. As a firm purchases new equipment or imitates product innovations made by others, it may have to redesign its routines.

Figure 21.2 provides a stylized picture of how a firm renewal can affect firm performance and how a firm's innovation and adoption activities depend on:

- The characteristics of the firm which includes its innovation capabilities and innovation strategy
- The characteristics of the firm's *innovation milieu*, where the latter primarily corresponds to the possibility of knowledge interaction in the functional region where the firm is located

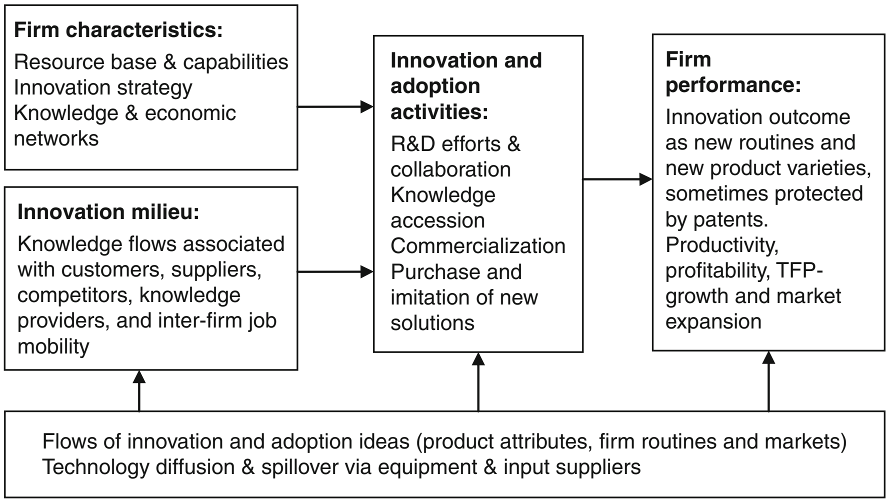

Fig. 21.2 Factors influencing the size and consequences of innovation and adoption activities

The figure illustrates the statements in the first and second theses of this chapter and attempts to connect the basic concepts for the analysis of innovation and adoption activities while putting the variety of diffusion processes in focus. First, as observed in the figure, diffusion of innovation and adoption ideas stimulates firms to make innovation efforts and to adopt new technical equipment. In addition, when a firm introduces a product innovation, then the market penetration of its new product can be modeled and analyzed as a diffusion process. Diffusion of new products that are sold to firms and households or imitated by user firms also represents economy-wide renewal which is usually labeled technological development. It also associates with *product cycle* dynamics (Vernon 1966).

21.3.1 Renewal Activities and Firm Performance

Figure 21.2 depicts how innovation activities can influence *firm performance*, subdivided into innovation outcomes and economic outcome. The first type of performance focuses on the innovation output of a firm, and the associated performance indicators comprise measures such as number of new products and patents, sales of new products, and sales of new export products. These are direct outcomes of renewal efforts to innovate and adopt novelties in the economic environment. The second type of performance refers to indirect consequences of renewal activities, measured by the economic result of the firm as reflected by the level and change in productivity and profitability, growth of total factor productivity (TFP growth), and increasing value of the firm and its market expansion. These are all different returns to renewal activities. As will be evident in Sect. 21.5 of this chapter, the economy-wide returns to an industry's R&D are greater than the returns to the typical single firm. As recognized early by Mansfield (1968), this is due to the role played by technology diffusion and spillovers between firms and industries as firms buy improved equipment and intermediaries.

An important message in this presentation is that a firm's development is the result of its *renewal activities* which include innovation and adoption. These two phenomena overlap without a clear demarcation line. We first observe that a firm that introduces new product varieties also has to adjust its production processes and thus make a routine innovation, indicating that product and process innovations are complementary (Nyström 2006). Such routine innovations are equally probable, irrespective of whether it is a matter of a product innovation or an imitation. Moreover, the adoption of new technical solutions in the form of new equipment also stimulates the firm to make routine innovations. Hence, innovation and adoption are intermingled. This reflects the chapter's second thesis saying that innovation and adoption activities are part of a firm's overall renewal efforts, and this view is reflected in the CIS specification of innovation efforts, which includes the following list of innovation and adoption activities: (i) internal R&D work, (ii) external R&D work, (iii) acquisition of new equipment and associated cost, (iv) accession of external knowledge, (v) allocation of time for human resource development and training, (vi) marketing and commercialization efforts associated with new products, (vii) product development and design, (viii) development and maintenance of links to external actors for R&D collaboration, and (ix) scanning external knowledge sources for innovation and adoption efforts (OECD 2005).

A firm's possibilities to carry out renewal activities depend in a critical way on the resource base and associated capabilities of the firm. These are durable and difficult-to-imitate capacities. The literature in this area (e.g., Teece 2010) emphasizes the capability of an innovating firm to develop, maintain, and orchestrate its resource base to adapt in an ever-changing business environment. The *knowledge intensity* and the firm's experiences from previous innovation and adoption efforts are the core determinants of firm renewal. The associated knowledge assets are based on learning how to organize and establish *routines* for conducting innovation activities.

21.3.2 Characteristics and Performance of Firms

Firm characteristics can be organized under the headings *strategy*, *renewal capabilities*, and *networks*. The characteristics influence what the firm is capable of doing but also what it intends to do. Intentions and objectives may be reflected by the firm's innovation strategy which comprises the firm's commitment to systematic R&D and its ambitions to develop capabilities and networks for knowledge flows over time. Recent studies suggest that firms display permanent heterogeneity that can be grouped into no, occasional, and persistent engagement in R&D and other innovation activities. With persistent engagement, the firm is rewarded with learning routines for how to conduct R&D, and this leads to firm knowledge and experiences that improve performance. Another strategy aspect is the size of innovation expenditures, often proxied by R&D intensity.

R&D intensity is usually calculated as the ratio between R&D expenditures and sales or between R&D expenditures and value added. In studies of the impact of R&D on firm performance, the measure R&D intensity controls for size. With this approach heterogeneity is revealed by the observation that as much as half of the variation in R&D intensity is explained by fixed firm effects. In view of this, one may remark that the two most widely used indicators of firm characteristics – cash flow and the degree of diversification – explain much less of interfirm differences in R&D intensity. Thus, the fixed firm effects indicate strongly that differences between firms' innovation efforts have a tendency to remain invariant over time. This can also be interpreted as a finding saying that firms employ different innovation strategies.

Having reached this point, one may ask: what about Schumpeter's suggestion that firm size affects its innovation intensity? Cohen and Levin (1989) and many other survey contributions suggest that it is difficult to reject the hypothesis that R&D efforts are proportional to firm size. Andersson and Johansson (2010) argue in a model with product variety innovations and multiple export markets that firms are large as a consequence of variety and market innovations in the past, not the other way around. Instead, cumulated innovation experiences affect a firm's probability of innovating in the future.

In order to develop its *innovation capabilities*, a firm has to invest in such capacities, and as a consequence we find that firms with a large share of knowledge-intensive employees spend more than average resources on innovation activities, and they do this in a more persistent way than the average firm. A firm with an offensive and sustainable strategy of this kind may also have more favorable economic outcome than average. Obviously, this also reflects dynamic interdependencies with ambiguous causation. In cross section as well as panel data analyses, one can observe that the likelihood of making innovation efforts is associated with the same variables as those which are associated with the economic result of these efforts. Such variables which correlate with higher innovation intensity and higher returns to innovation include (Andersson et al. 2012):

- Knowledge intensity of the labor force (human capital).
- Physical capital.
- Repeated innovation efforts.
- The firm belongs to a multinational company group.
- Market extension and export experiences.
- Import intensity and import links to foreign suppliers.

Instead of extending the review to consider other ways of relating firm performance to characteristics of firms, the presentation will focus on the conditions enumerated above to examine their association with location characteristics and innovation milieu of the innovating firm. Empirical observations suggest that the intensity and composition of knowledge flows are basic in explaining a firm's innovation engagement and economic return to its efforts. Table 21.2 provides an overview of different knowledge sources, of mechanisms influencing generation and transfer of knowledge of various character, and of spatial aspects of these mechanisms.

The table traces a broad set of *knowledge sources*, including knowledge exchange with collaborators' purchase from knowledge providers, pure knowledge spillovers as a side effect of ordinary transactions, knowledge that moves from one firm to another

Table 21.2 Knowledge intensity in the private sector of the economy. Sweden 2007

Functional region	The entire private sector 1993, %	The entire private sector 2007, %	Inhabitants 2007 (region average)
Stockholm metropolitan region	17.3	28.1	2.3 million
Götborg – Malmö regions (average)	13.6	23.8	1.0 million
Medium-sized urban regions	10.3	18.6	0.2 million
Country average	8.6	14.7	0.1 million

Remark: Knowledge intensity is the share of the labor force with at least 3 years of university studies.
Source: Elaborations from Statistics Sweden (Johansson et al. 2010)

when persons switch from one employer to another, entrepreneurs that leave employment and start new firms, active search for *knowledge-accession* possibilities, and knowledge flows in long-distance networks such as internal links inside a multinational corporation. Many of these phenomena can be understood as diffusion of creative ideas, and we can identify network externalities when firms establish network links to carry both intended and unintended knowledge flows.

21.3.3 Proximity and Networks

While relying on its cumulated resource base and associated knowledge assets, the innovating firm is characterized by its capacity to exploit in-house knowledge in conjunction with external knowledge sources. The latter are characterized in Table 21.3, from which it is obvious that a firm's proximity to external knowledge affects the opportunities to acquire useful inputs to the firm's innovation activities.

As outlined in Johansson and Quigley (2004), there are two principle ways that can simplify and stimulate knowledge interaction and exchange of associated information. The first principle is the *proximity advantage*, which is based on the fact that the frequency of face-to-face (FTF) interaction between two or several parties decreases as the (time) distance between the location of the parties increases. This principle implies that an innovating (and adopting) firm benefits from being located in an environment with rich and diverse knowledge flows and with a multiplicity of relevant knowledge sources and knowledge exchange actors like R&D-intensive firms, knowledge-intensive producer services, and research organizations, including universities.

The second approach to facilitate knowledge exchange between two parties is to invest in links (communication channels) between the parties. According to this principle, a firm can invest in links and entire networks of interaction links to reduce the friction and costs of interaction over long distance. This opportunity may be termed *network advantage*. Thus, when a proximity solution is not at hand in a given location, then a firm can choose to invest in links to distant collaborators (such as suppliers, customers, and other knowledge providers) as a means to compensate for

Table 21.3 Origin of knowledge flows that are inputs to a firm's innovation activities

Origin or source of knowledge flows	Generation and transfer of knowledge	Spatial aspects and co-location in the same region
Knowledge interaction	Collaboration with customers, suppliers, universities and other knowledge providers	The interactive efforts are facilitated when partners are co-located in the same region
Purchase of knowledge (e.g., from knowledge-intensive producer services suppliers)	Knowledge transactions may require links of trust between buyer and seller	Location proximity facilitates the establishment of contract-like links between actors
Spillovers from normal transactions between a firm and its customers and suppliers	The firm's interplay with customers, suppliers and other actors open up for unintended knowledge flows	A firm's transaction links extend across region and country borders, but intra-region links are more likely to establish in large urban regions
Job mobility bringing the firm new labor embodying knowledge achieved in previous job(s)	Recruitment inflow to a firm may be the basic source for unintended spillovers. Such flows decline with increasing distance	The frequency of job switching is more frequent (i) among knowledge-intensive labor and (ii) in large urban regions
Scanning and searching for knowledge accession opportunities	Renewal in the form of innovation and adoption is fuelled by the conjunction of internal and external knowledge	Firms located in urban regions which host many and diverse knowledge sources offer the local firms external knowledge advantages
Internal knowledge flows between units of a company group, especially multinationals	The internal networks of a multinational company group can overcome long distance and protect knowledge from leakage	The multinational subsidiaries can engage in knowledge accession and local networks in selected global set of nodes
Investment in R&D collaboration networks locally and globally	These networks include strategic alliances as well local links based on trust	Collaboration links reduce the friction of knowledge exchange and the payoff becomes higher and longer the planned interaction frequency is

the lack of feasible proximity options. In many cases lumpy investments in long-distance links complement investments in links for short-distance interaction. The advantage of a location in an agglomeration is that (i) the need for lumpy link investments is smaller in an urban agglomeration, while such investments at the same time are more easy to establish inside an agglomeration. In particular, when two actors are located in the same functional region, the cost of forming an interaction link should generically be smaller than when the same actors are more distant from each other. This conclusion can be motivated in the following way:

Consider that two actors strive to develop a mutual interaction link which has the form of an implicit contract underpinned by trust (based on positive experiences) and a joint capacity to communicate complex messages in a reliable way. We can assume that such relations require repeated face-to-face (FTF) contacts between the two parties as an input to the link formation, while maintenance comes naturally as a consequence of using the link. In this view, a link is less costly to establish for firms which are colocated in the same region than for firms hosted in different regions.

A firm can be defined as *innovating* for periods during which it is engaged in innovation activities. Innovating firms have an advantage from being located in a large agglomeration with many opportunities to interact and many opportunities to establish local interaction links. This observation opens questions about the geography of diffusion, which is a field where a major contribution was made by Hägerstrand in the beginning of the 1950s. Hägerstrand (1967) used a huge set of observations to demonstrate the statement in the third thesis of this presentation. This statement stresses that ideas, production methods, and new products diffuse across geographical areas in spatial processes exhibiting clear regularities, where the novelties diffuse faster along short distances from the original source. In this sense the Hägerstrand model has been considered to stress neighborhood effects in the spreading process while observing that large and dense places represent a greater potential of neighborhoods.

Hägerstrand investigates several alternative explanations of innovation diffusion processes. For example, one may assume that (i) the entire population (of potential adopters) becomes informed about the innovation simultaneously, whereas acceptance of the novelty occurs in a random order of precedence. This may be varied by considering unevenly distributed capacities to accept the novelty, and this may in turn be associated with the presence of "innovation centers" and followers ordered in a hierarchy. From this we may conclude that (i) if receptiveness or propensity to adopt is unevenly distributed, spatial diffusion will unfold accordingly, and (ii) if the generation of novelties is more frequent in certain places, neighborhood effects will affect the *spatial diffusion* pattern.

21.4 Innovation, Regional Milieu, and Networks

Empirical observations suggest that innovation is spatially concentrated. Innovation combines invention and commercialization, and this may explain why innovation is more concentrated than invention and more concentrated than production. However, the basic observation in this section is that knowledge is spatially sticky. In every particular case of *knowledge diffusion* (spillover as well as commercial transfer), the friction cost will vary because of communication distances. This friction is augmented when knowledge is complex (Beckmann 2000) and when it is tacit (Polanyi 1966). In both cases messages are difficult to encode and decode, and the tool to overcome this obstacle is frequent *FTF interactions*. This makes knowledge spatially sticky (von Hippel 1994).

21.4.1 A Functional Region Is an Arena for Face-to-Face Contacts

In previous sections of this chapter, the presentation argues that an innovative firm has to rely on both internal knowledge workers and the presence of knowledge-intensive labor in the environment. A firm's accessibility to knowledge intensity in its nearby environment can benefit the firm in two different ways. First, a large local supply of labor with university education facilitates the matching of supply and demand with regard to qualifications and competence profiles. The second aspect is that a region with a wide spectrum of knowledge resources provides rich opportunities for knowledge exchange and creative interaction with other actors in the urban region.

The above observations refer to both pecuniary and other knowledge flow externalities. First, transaction costs for recruiting employees with a desired profile reduce in a large urban region. Second, transaction costs also reduce in processes of knowledge accession. Third, pure *knowledge spillover* can be expected to increase as the size of an urban agglomeration expands. A large urban region can afford diverse and frequent FTF contacts at low costs, and this explains the reduction of knowledge transaction costs and the augmented likelihood for spillovers.

Ohlin's early discussion of urbanization economies was reemphasized in the contributions by Jacobs (1969), where large urban agglomerations are depicted as places with diversity in competence, ideas, product innovations, and variation-rich import flows. Such milieus, Jacob argues, foster creativity and innovation activities, especially since they concretize Schumpeter's vision of *novelty by combination*.

If urbanization economies obtain in a milieu of complex diversity, localization economies may be characterized as a milieu with a spectrum of input suppliers and other support factors that are designed to improve colocated firms in the same industry, firms supplying varieties that belong to the same product group or firms which share the same categories of customers and suppliers. Cluster milieus with localization economies may be considered as the agglomeration phenomenon that can develop in small- and medium-sized urban regions, whereas urbanization economies is a characteristic of large urban (metropolitan) regions. In Capello (2002), it is argued that industry clusters are prevalent in large urban regions, while observing that in a metropolitan region there can be many types of clusters, making the economy a "cluster of clusters."

Especially for *cluster* phenomena, the literature has stressed the role of communication links between firms extended to complex networks for knowledge exchange among firms in the same cluster. A prerequisite is of course that the pertinent firms must have enough knowledge to exchange. In this view the network is rather an infrastructure for product and process development activities.

Firms belonging to a multinational company group have the internal network of the group as an infrastructure for knowledge interaction. First, such company group networks are especially designed to protect knowledge from leaking to competitors in undesired ways. Second, the global location of subsidiaries makes it possible for individual firms in a group to tap knowledge from different knowledge centers around the world.

21.4.2 Urbanization and Localization

Agglomeration of firms can theoretically be divided into two forms. The first case is obtained when several firms in the same industry colocate or cluster in the same urban region. In the second stance, agglomeration refers to colocation in the same urban region of firms that belong to different types of industries. Clustering of similar firms is assumed to bring about localization economies with diversity within a specialized field, whereas agglomeration of firms adhering to a variety of industries is assumed to cause urbanization economies, where size and diversity of demand are expected to attract a diverse supply. This distinction between localization and urbanization economies was made by Ohlin (1933) and was later studied by Henderson (1997) and many others.

When a set of firms in the same industry are colocated in the same functional region, they benefit from *localization economies* due to mutual stimuli to improve production routines and to develop novel products. The consequence of such colocation can be augmented productivity of the pertinent firms. Localization economies are often thought of as an externality generated by colocation of several firms that have similarities with regard to markets (customers), intermediary inputs, technology and equipment, distribution systems, and the like. Having much in common, those colocated firms can mutually exchange and spill over adoption and innovation opportunities and technical knowledge. This phenomenon can be expected to have a significant role to play in smaller (urban) regions which may develop an environment of interlinked firms and their specialized suppliers of services and other inputs and associated institutions like trade associations and universities.

Obviously, a successful regional cluster may in the long term be affected by negative lock-in effects, such that they develop into mutual stiffness while evolving along a life-cycle path, starting with a juvenile period of expansion, followed by stagnation and eventually decline. In contradistinction we observe that large urban agglomerations in principle are protected against this phenomenon by having a broader spectrum of specialized fields and diversification as its basis. As emphasized by Jacobs (1969), the urban diversity constitutes an environment that boosts creativity and opens an avenue that facilitates the cross-fertilization of ideas. A very similar view was put forward by Vernon (1966) when he suggested that new product cycles frequently are initiated in metropolitan regions with rich knowledge sources, intense knowledge flows, and competent and demanding customers side by side with alert input suppliers. In this view innovations are generated where *urbanization economies* prevail and foster communication externalities.

A long range of empirical studies can be summarized by suggesting that large urban agglomerations are more innovative while at the same time being among the most productive places. These studies also suggest that metropolitan-region advantages are caused by economies of scope. These regions attract talented persons with creative occupations to migrate into metropolitan regions, and hence it becomes troublesome to which extent higher productivity and higher wages are caused by a metropolitan region's productive milieu or by a selective in-migration of skilled persons.

21.4.3 Accessibility to Knowledge Sources

Consider an economy which consists of a set of urban regions, $r \in R = \{1, \ldots, \bar{r}\}$, as specified earlier in this chapter, and assume that each region consists of one or several urban areas, $i \in r$, where each such area, however small, represents a spatial concentration of economic activity. Many early studies have examined how aggregate knowledge sources and R&D activities inside an urban region generate spillovers and affect innovation activities and innovation outcome of firms located in the region. The conclusion from many of these contributions is that knowledge flows and *spillovers* are spatially bounded in the sense that the likelihood of knowledge flows reduces as distance between origin and destination grows.

Let G_i be the amount of a knowledge resource located in urban area i, and consider that we can measure the time distance, t_{ij} between any two pairs of locations i and j. Let λ be a parameter reflecting the time sensitivity of FTF contacts between the two locations, and assume that $\exp\{-\lambda t_{ij}\}G_j$ is a measure of the potential for knowledge flows (including spillovers) from knowledge sources in urban area j to area i. This formulation, which can be derived from a random-choice specification (Andersson and Gråsjö 2009), implies that the potential for knowledge flows on the link (i, j) reduces in value as the time distance increases. The total knowledge flow potential of firms in urban area i, A_i, can be calculated as

$$A_i = \sum_r \sum_{j \in r} \exp\{-\lambda t_{ij}\}G_j \tag{21.1}$$

while the intra-regional potential equals $A_i^r = \sum_{j \in r} \exp\{-\lambda t_{ij}\}G_j$. One may interpret A_i as the overall *accessibility* to knowledge sources of firms in urban area i, while A_i^r represents the intra-regional accessibility to knowledge sources for firms in area i in region r. The measure of A_i in Eq. (21.1) represents an alternative to using an aggregate G-value for an entire urban or metropolitan region. In particular, the A_i-measure is not based on an arbitrary (administrative) delineation of the boundaries of an urban region.

Andersson and Gråsjö, (2009) employ a model with a knowledge production function (KPF), with patent applications of firms representing output, whereas internal and external knowledge sources comprise the inputs. The knowledge production is assumed to depend on R&D activities (man years) in other firms and R&D activities in universities (man years). The influence from these external knowledge resources is discounted according to the principle described in Eq. (21.1), but separated into local, intra-regional, and extra-regional influences. The study demonstrates that such an accessibility approach takes care of the spatial interdependencies by including them in the model. The described approach demonstrates a way to model spatial *knowledge interaction* opportunities, and for each given place, it provides a measure of the potential for diffusion of ideas from the surrounding environment to the selected place – in line with the model contributions of Hägerstrand as presented in Sect. 21.3.3. With another econometric technique, Fischer and Varga (2003) also provide evidence in favor of Hägerstrand's conclusion about distance decay effects.

21.5 Diffusion of Ideas and Technical Solutions

Technological diffusion has primarily been studied in the narrow perspective of firms starting to use a new method of production or, in other words, the adoption of a new production technique. Mansfield (1968) observes that until the end of the 1950s, economists allocated little attention to factors that may determine the rate of diffusion of a new technical solution. Studies during the following decades brought a considerable amount of information about the rate of diffusion (see Batten and Johansson 1989). All these studies also confirm that the diffusion approximates a sigmoid pattern, which can be mimicked by a logistic equation.

Technological diffusion of the kind referred to above plays a prominent role in a country's economic development, since it spreads new technical solutions that are applied across firms and regions. The diffusion can have the form of an innovation that is commercialized and sold in the form of new machinery equipment, information and communication technology (ICT) routines for logistics and administration, etc. In this case the diffusion is partly the result of marketing and sales efforts made by the innovator. The innovation may also originate from a firm which makes an invention to be used in the firm's own operation, while this innovation diffuses to other users through imitation. In this second case, the diffusion may take place in spite of efforts from the innovator to keep the innovation secret.

21.5.1 The Diffusion Model

Technology diffusion is just one of several diffusion processes that have been studied. We may, for example, consider the "epidemic" diffusion of social norms and consumer behavior. In the sequel we will consider diffusion of innovation ideas, representing knowledge that can be input to firms' efforts to develop new product varieties. Moreover, imitation of new products across firms and regions also has the character of a diffusion process. Such spread processes include the establishment of Chinese restaurants in cities over the globe in the 1960s and 1970s, as well as Sushi bars in the following decades.

Irrespective of the nature of what is being diffused, empirical observations provide evidence that the process follows a similar pattern in almost all cases. To make this obvious, a share variable, z, can be introduced, where for each point in time, z refers to (i) the share of a firm's operations that makes use of a specific technique, (ii) the share of all potential users of a new technique (or a new type of current input) who are employing the new technique, (iii) the share of a specific market that a new type of product has managed to conquer, or (iv) the market share a firm has obtained for a specified product segment. Frequently the variable z is referred to as the share of adopters or the market penetration share.

Consider now the development of z as described by the following differential equation:

$$\dot{z} = cz(1 - z) \tag{21.2}$$

where $c \geq 0$ is a given constant that describes the speed of change and $\dot{z} = dz/dt$. When z is small, the share of non-adopters, $(1 - z)$, is large, thereby providing opportunities for the novelty to "randomly" find potential adopters. As z grows and becomes larger, the uncertainty about the novelty is reduced and the propensity to adopt goes up, although the share of non-adopters, $(1 - z)$, is gradually becoming smaller. The outcome is the well-known sigmoid curve in Fig. 21.3, as depicted by graph A.

The Verhulst equation in Eq. (21.2) describes a logistic growth path of, and it can be solved to obtain $z/(1 - z) = \exp\{c(t - \tilde{t})\}$, where $\tilde{t}$ denotes the time it takes for $z(t)$ to reach the value 0.5. Rearranging once more, the share at time t has the value $z(t) = [1 + \exp\{-c(t - \tilde{t}\}]^{-1}$.

For the model of technology *diffusion*, $z(t)$ can for an industry reflect the share of all potential adopters which at time t have already started to use the new technical solution. For the individual firm, z may instead measure the ratio between how much the firm has installed of the new technique relative to a complete installment.

In a seminal study by Griliches (1957), the diffusion of hybrid corn during 1932–1956 is shown to follow *S-shaped* paths for each of five states in the so-called Corn Belt of the USA. Moreover, the introduction of this novel hybrid seed method took place in a sequential order, with Iowa as the initiator or forerunner and with other states following with different time lags vis-à-vis Iowa. The study provides clear indication that the introduction started earlier for states in which the new method had higher profitability, and it also spread at a faster pace in places with higher profitability.

21.5.2 Technology Diffusion and R&D Spillovers

A firm's production is based on internal resources and on inputs (equipment and intermediaries) bought from other firms. Typically the intermediaries account for at least half of the sales value, where outsourcing strategies of firms leads to an increasing share of intermediary inflows and a reduced share of value added. By means of its own R&D, the individual firm can increase its value added and reduce its cost of intermediary inputs. This type of change process improves the firm's performance over time. However, there is a parallel process which also affects firm performance. Firms that supply inputs also spend resources to improve their deliveries, and these improvements have the capacity to affect input-buying firms' performance. This secondary effect has been labeled R&D spillovers.

R&D spillovers refer to the direct knowledge gains of input-buying firms from the R&D of input-supplying industries. An early contribution to this form of analysis is from the 1960s, followed by studies that calculated measures of the amount of R&D embodied in customer firms' inputs, based on information about capital purchases made by one industry from other industries. A step further was taken in the 1980s in studies using the product R&D made by input suppliers to obtain a measure of R&D spillovers.

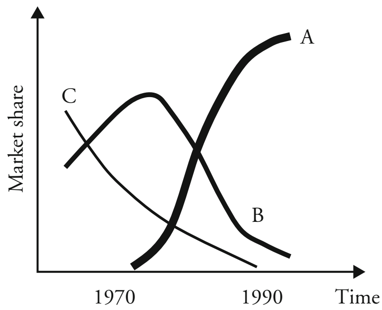

Fig. 21.3 Market share development for (*C*) mechanical typewrites, (*B*) electrical typewrites, and (*A*) word processing equipment. Sweden 1970–1990 (Johansson and Karlsson 1991, p 21)

Wolff (1997) applies a measure of *embodied* technical change which is a weighted average of the TFP growth of the supplying industries, using the customer industry's input–output coefficients as weights. This can be referred to as direct productivity spillover and reflects the idea that spillover flows are proportional to inter-sector flows. The same study indicates an even stronger effect on an industry's rate of technical progress when input flows are constrained to be equipment deliveries. Results of this kind seem to indicate that disembodied knowledge flows follow the same patterns as equipment-embodied technology diffusion.

Technology spillovers is a partly misleading notion since an important share of knowledge flows through the economy has the form of purchased knowledge, often embodied in equipment and systems that are acquired by and installed in user firms. Two aspects are important to contemplate. First, when new equipment and new types of current inputs are being developed, the purchasing firm has to find out which are the suppliers offering suitable solutions and which are not. In this context certain firms are more capable and have more advanced absorption capacity. This may be described as firms' search for input suppliers that offer the best practice. This type of knowledge search and accession is not R&D but has many characteristics in common with innovation efforts. In particular, when a firm assesses new equipment options, it may also have to consider new routines and technical solutions and add own innovation efforts.

Second, the opportunities to scan and collect information about input alternatives and novel equipment vary between each innovation milieu associated with a specific location, where innovation milieu signifies the localized knowledge-accession and innovation-collaboration opportunities in the environment of the location. In this context a location is identified as a particular urban region. In an environment of alert input suppliers, the likelihood of finding relevant input alternatives is generally higher than when information has to be collected from more distant sources. Proximity to suppliers brings greater opportunities to communicate and interact with established and potential suppliers. In this way *proximity* may lead to the formation of interpersonal communication networks that can facilitate learning and development. Adams and Jaffe (1996) found that the effects of parent R&D on plant-level productivity were diminished by geographic distance as well as with technological distance, providing further evidence in favor of Thesis 3 in this chapter.

In regional science the importance of the innovation milieu has been studied for a long period, with one strand focusing on cluster formation in smaller urban regions – also referred to as localization economies – and a second strand following the theory of agglomeration economies – also recognized as *urbanization economies*. The arguments for how cluster and agglomeration economies foster technology diffusion and adoption run parallel to those focusing on the generation of innovations. A *cluster* may be rich in specialized input suppliers in view of a particular industry. Agglomeration economies offer diversity of different categories of specialization and can, as a consequence, foster a richer variety of novel combinations.

As we have seen, the sources of technology diffusion and spillover can be fostered by a milieu of local suppliers that have clustered in the same functional region. An important contrast is that also imports bring technology spillovers as was recognized in Coe and Helpman, (1995), later followed by additional studies that avoid some of the econometric problems in the contribution by Coe and Helpman. The emerging understanding is that the more R&D intensive the imports are from other countries, the more can a region and a country accumulate of foreign R&D capital. Thus, import flows from countries with high R&D intensity seem to spur productivity growth in the importing country (and region) more than other imports. One may also distinguish import flows in general from imports of capital or equipment goods, and such studies indicate that the latter have a more distinct influence than overall imports. These different findings suggest that an individual firm benefits from knowledge embedded in import flows. Moreover, they suggest an advantage for functional urban regions in which firms collectively have rich and diversified imports from R&D and innovation-intensive origins. In these regions firms are positively stimulated in their renewal activities (Keller 2004; Andersson and Johansson 2010).

The basic idea of studies of technology spillovers is to find out how intra-firm (and intra-industry) R&D together with R&D of input suppliers combine to generate firm (and industry) *TFP growth*. As reported in Wolff (1997, 2012), the social rate of return to R&D is considerably larger than the direct *return to R&D*. These studies are frequently using industry level data and do not disentangle input-embodied innovation from knowledge flows in a more general sense.

21.5.3 Innovation Ideas and New Products

A product innovation leading to the marketing of a new good or service may have firms and/or households as major customer groups. Although the basic needs of consumers may be limited, there are myriads of changes occurring at the intermediate stages of production as well as in the individual choice processes of households. Regardless of whether we consider intermediate or final users, advancing sophistication and technological evolution consists mainly of substituting new means of consumer satisfaction for old ones. Under these circumstances the diffusion model has to be extended to take the form of a substitution model, recognizing that the introduction of novelties generates the disappearance of established products. Ultimately new product attributes replace old attribute combinations (Batten and Johansson 1989).

Studies of knowledge flows and diffusion may focus on how such flows are more frequent and faster for certain types of product as well as process innovations, for certain types of firms, and/or for certain regional innovation milieus. Recent contributions emphasize that it is not enough to characterize firms and their capabilities and firm-specific networks. The innovation milieu and its knowledge flows play a fundamental role as innovativeness depends critically on a firm's possibility to combine internal and external knowledge resources.

A *product innovation* has to be marketed and commercialized. This part of the innovation effort brings us to product cycles that may be identified for a specific product group as well as for individual product varieties which belong to the same product group. As discussed earlier in this chapter, it is frequently claimed that product cycles with high frequency are initiated in metropolitan environments in which new product ideas are more prevalent and diverse than elsewhere. Large urban regions also host producer-service suppliers across a range of specialization, and these suppliers are important supporters in the commercialization process. As new products successfully penetrate domestic and foreign markets, they often reach a state of maturity in which knowledge intensity has a reduced role to play and many decomposed activities may be relocated to smaller urban regions or regions which have favorable factor prices for other reasons.

The diffusion phenomenon as described by Eq. (21.1) may be applied to depict a novel product's penetration of geographic markets. Penetration of this kind develops along an *S-shaped* curve like A in Fig. 21.3. For a given product or product variety, the exact curvature will vary with regard to trade links between a supply origin and relevant destinations.

The main message from Fig. 21.3 is that *market penetration* involves two interlinked processes, combining into a substitution process in which a novel product group B is substituted for an old one C. The oldest group in the figure is an aggregate of mechanical typewriter varieties which lose their joint market share as the new group of electrical typewriter varieties gradually gains an increasing market share. The third step is the simultaneous market share decline for electrical typewriters as these are replaced by word processing equipment. In addition, the reader already knows that the word processors rather quickly were replaced by personal computers (PCs).

21.6 Conclusions

Section 21.2 of this chapter has a discussion of the heterogeneity of firms. The conclusions will instead emphasize that functional urban regions are heterogeneous. However, we first have to stress that innovation is a firm activity and so is adoption of technical solutions. These activities rely on a firm's innovation strategy, its innovation efforts, and its renewal capabilities, where the strategy comprises ambitions to develop capabilities, resources for innovation expenditures, and networks for knowledge flows.

The innovation milieu of the firm can be viewed as an innovation and R&D infrastructure, which facilitates the innovating firm's attempts to combine internal knowledge resources with knowledge sources in the firm's environment. The implicit suggestion of this chapter is that regions differ markedly in their supply of knowledge-intensive labor, knowledge exchange partners, knowledge-based producer services, and knowledge flows in general.

One may formulate a long list of characteristics of an urban region that make the region innovation supportive, providing the region's firms with favorable preconditions. With a shorter list, the regional innovation milieu can be advantageous in the following dimensions:

- The region can attract human resources (knowledge-intensive, creative, and talented individuals).
- The region can attract firms which benefit from access to knowledge sources and R&D activities in firms and universities in the region.
- The region can attract firms which are stimulated by an economic milieu where firms have extensive export networks and associated experiences.
- The region can attract firms that benefit from the regional presence of firms with well-developed import networks as well as import agencies and other firms specialized in selective import for local customers.

The enumerated (and related) characteristics create problems for empirical studies because of grave multicollinearity patterns. At the same time, they represent a particular form of "endogeneity": the composition of the firms which have the same region as a host constitutes the most essential attraction factor of the region. The result is a process of cumulative dynamics which maintain and develop favorable milieu characteristics in certain regions (in which the cumulative causation works in the desired direction), while the dynamics may cause milieu deterioration in other regions.

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