

## Urban Diversity, Human Creativity and Technology Combination

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### **Abstract**

In recent years, there has been a heated debate as to which is better conducive to technological change and economic growth: local diversity or specialization of economic activity. Some authors argue that local diversity is more conducive to development through "interindustry knowledge spillover" effects, while others pretend to show that local specialization is generally more conducive to innovation. One of the reasons that this debate remains so controversial is that there is no clear understanding of the processes by which knowledge "spills over" from a particular application domain to others. The purpose of this paper is therefore to suggest an alternative approach to the study of these processes that is based on the study of human creativity. It is argued that if the main feature of technological change is that problems are solved through the combination of previously unrelated things, it logically follows that a diversified city can only increase the probabilities of new combinations being made and is therefore a better environment for innovative activities.

*Many features and qualities of the objects that a technologist thinks about cannot be reduced to unambiguous verbal descriptions; they are dealt with in his mind by a visual, nonverbal process. His mind's eye is a well-developed organ that not only reviews the contents of his visual memory but also forms such new or modified images as his thoughts require. As he thinks about a machine, reasoning his way through successive steps in a dynamic process, he can turn it over in his mind. The designer and the inventor, who brings elements together in new combinations, are each able to assemble and manipulate in their minds devices that as yet do not exist.*

*Eugene Ferguson (1977: 827)*

## **Introduction**

In recent years, there has been a heated debate as to which is better conducive to technological change and economic growth: local diversity or specialization of economic activity. Some authors argue that local diversity is more conducive to economic growth through "interindustry knowledge spillover" effects (Feldman and Audretsch, 1999; Glaeser et al, 1992; Harrison et al, 1996a; 1996b). Other scholars, however, argue that while localized diversity might be important in certain cases, local specialization is generally more conducive to innovation and growth (Bostic et al. 1997; Henderson, 1997; Henderson et al, 1995). One of the reasons that this debate remains so controversial is that there is no clear understanding of the processes by which knowledge "spills over" from a particular application domain to others. The purpose of this paper is therefore to argue that measuring causal relationships without addressing the specific processes by which human beings find new uses for their skills is not likely to give conclusive results. The first section reviews briefly the studies that support the diversity hypothesis and points out some of their flaws. The second takes a closer look at the work of Jacobs (1970) who originally articulated the importance of local diversity for economic development. One of the premises of her work is that economic classification systems are more confusing than helpful in understanding the processes of technology combination, a point that is given more support with the work of other authors in section three. The fourth section attempts to clarify and elaborate on Jacobs' work by introducing further insights developed by students of technological creativity. The last one discusses the advantages of a diversified city for the combination of previously unrelated things.

### **1. On the Empirical Study of "Geographically Localized Interindustry Knowledge Spillovers"**

In the last decade, many authors have tried to assess empirically the respective impact of local specialization and diversity on economic growth by focusing on "knowledge spillovers" (Feldman, forthcoming). While these studies raise important questions and provide innovative approaches to further our understanding of regional development, they have been the subject of a number of criticisms. For example, Glaeser et al. (1992) use wages and employment growth as dependent variables, assuming that they are measurable effects of innovation and new knowledge, when actually their results simply cannot be interpreted in terms of knowledge and education (Quigley, 1998: 136). This point is well understood by Coffey and Shearmur (1998)

who use a similar methodology with Canadian data, but conclude more cautiously that diversified local economies generate more employment than more homogeneous ones.

Other researchers use indicators that seem more adequate, but that nonetheless have some problems of their own. For example, Feldman and Audretsch (1999) rely on the United States Small Business Administration's Innovation Data Base, which was compiled from a wide variety of industry announcements and trade publications. While this indicator has several advantages over indirect measures of innovation such as patent data, the authors point out that several important qualifications must be made regarding its use. The most contentious issues are a bias toward unusual and special-interest product innovations and the considerable difference in the significance and quality of the innovations. Furthermore, their sample is probably biased toward the innovative output of larger firms who have more resources to advertise their new products. Harrison et al. (1996a; 1996b) use as their main indicators the adoption of a specific production process, computer programmable automation, by establishments belonging to 21 manufacturing industries (3 digit SIC level) whose product range extends from cars and aircraft to coffee grinders and scientific instruments. It is not clear, however, how a new the adoption of a new technology has more to do with "local diversity" than factors internal to an industry (including ideas originating from outside a given sector, but in another location) and firm (including multi-plant companies). It has also been pointed out that a major stumbling block of these recent papers is the tendency to make dynamic inferences from cross-sectional data (Malmberg, 1997).

Perhaps, however, the main problem of these research designs is that they do not adequately address the processes by which specific materials, production processes and products are adapted in new environments. As Feldman (forthcoming) points out in a review of this literature: "We do not know how social interaction is initiated, how it evolves into a working relationship and how economically useful knowledge is created." Such a claim is hardly surprising because no recent article goes significantly beyond the methodological approaches used in earlier work on "interindustry technology flows" and the measurement of local diversity, two lines of work whose conceptual foundations were largely deemed unsatisfactory. Reviewing the conventional economic analysis of interindustrial knowledge spillovers, De Bresson (1990: 833, my translation) writes that we do not know "what is measured, what assumptions and hypothesis underline the analysis, nor how innovation, invention or R&D are conceptualized in input-output

tables.” Malizia and Feser (1999: 92) make a similar assessment of earlier attempts to measure local diversity: “Economic diversity is the presence of multiple specializations. This definitional point deserves emphasis because the diversity literature is so confusing.” In another article on the topic, Jackson (1984: 103) is even more critical and points out that the issue of local diversity is typically “swamped by the measurement and estimation techniques employed” and that in the end “current diversity measures are deemed inadequate for regional policy makers.”

Most authors have so far dealt with “geographically localized interindustry knowledge spillovers,” or “Jacobs’ externalities” as some economists have dubbed them, by arguing somewhat vaguely that the spatial concentration of diverse individuals permits a great deal of personal interaction, which in turn generates new ideas, products, and processes.

Jacobs’ idea is that the crucial externality in cities is cross-fertilization of ideas across different lines of work. New York grain and cotton merchants saw the need for national and international financial transactions, and so the financial services industry was born. A San Francisco food processor invented equipment leasing when he had trouble finding financing for his own capital: the industry was not invented by bankers. In a more systematic account, Rosenberg [1976] discusses the spread of machine tools across industries and describes how an idea is transmitted from one industry to another. Scherer (1982) presents systematic evidence indicating that around 70 percent of inventions in a given industry are used outside that industry. Much evidence thus suggests that knowledge spills over across industries. Because cities bring together people from different walks of life, they foster transmission of ideas (Glaeser et al, 1992: 1131-32).

Jacobs effects are supposed to derive from the diversity of the local urban environment which surrounds an industry. Diversity enhances knowledge accumulation as producers in an industry can draw upon a greater diversity of ideas from other industries, through interacting socially and commercially (Henderson, 1997: 464)

Jacobs... argues that the most important sources of knowledge spillovers are external to the industry in which the firm operates and that cities are the source of innovation because the diversity of these knowledge sources is greatest in cities. Thus Jacobs develops a theory that emphasizes that the variety of industries within a geographic region promotes knowledge externalities and ultimately innovative activity and economic growth (Feldman and Audretsch, 1999: 412).

Such a casual treatment of “Jacobs’ externalities” is obviously not very satisfactory if one wants to interpret results derived from various proxies in terms of knowledge spillovers. This is especially amazing when one considers that Jacobs’ treatment of the processes of technology combination is much more subtle and complex, while she also cautions against the pitfalls of

traditional economic analysis in dealing with this issue. We will now review her case on behalf of local diversity in more detail.

## **2. Jacobs' Externalities, or Adding New Work to Old.**

Even though Jacobs deals primarily with urban development and growth, her understanding of technology combinations is firmly rooted in the study of human creativity. She summarizes her understanding of resource combination with the formula: "Adding new kinds of work to other kinds of older work" (Jacobs, 1970: 51), but she is always referring to specific human beings. Her case for urban diversity, however, goes beyond creativity and also includes entrepreneurship and agglomeration economies. Consider, for example, her discussion of the invention of the bra.

A custom seamstress, Mrs. Ida Rosenthal, was making dresses in a small shop of her own in New York. But she was dissatisfied with the way the dresses she made hung on her customers. To improve the fit, she began experimenting with improvements to underclothing and the result was the first brassiere. The customers liked the brassieres, and it became Mrs. Rosenthal's practice to give out a custom-made brassiere with each dress she made. Brassiere making, at this point, was still only a side issue to the dressmaking, a kind of accessory activity to the older work. But the fact was that Mrs. Rosenthal had become more interested in making brassieres than in making dresses, and while she was turning out dresses she was also making plans. She found a partner and together they raised enough capital to open and staff a workroom – a rudimentary factory – and Mrs. Rosenthal dropped dressmaking to devote herself to manufacturing, wholesaling and distributing brassieres. The new work now stood as an activity in its own right (Jacobs, 1970: 51).

Summarizing Jacobs' theory by focusing solely on "interindustry knowledge spillovers" is therefore misleading. Even though she doesn't refer to it, she would probably endorse Edison's famous motto that "invention is 1% inspiration and 99% perspiration," meaning that having an idea for a new device is only one small step on the way to a viable commercial product. Much work, most of it entrepreneurial in nature, still remains to be done and it might be that a diversified local economy is even more important at this point.

On the other hand, Jacobs does indeed describe the processes of technology combination in some detail. She points out that "the new work is added to older work first, and then sometimes its new divisions of labor are added to other appropriate varieties of older work" (p.52). Typically, however, "the new work is added directly onto only a fragment of the older work" (p.

55). Besides, “when new work is added to older work, it calls for more tasks in its own cause” (p. 56). It therefore becomes clear that “the greater the sheer numbers and varieties of divisions of labor already achieved in an economy, the greater the economy’s inherent capacity for adding still more kinds of goods and services. Also the possibilities increase for combining the existing divisions of labor in new ways...” (p. 59). How do people get ideas for new combinations? She suggests that there are two different types of suggestions that will occur to creative individuals: 1) ideas suggested by the materials or skills already being used; 2) ideas that arise from particular problems in the course of the work (p.59). The two might sometimes overlap, but there is nothing automatic about these processes.

When new work arises from parent work, that in itself does not account for the new work. Many people do not attempt new solutions to the problems that arise in their work, nor do they glimpse new possibilities in the materials or skills they use. The creator of the new work must have an insight and, combining an idea or observation with the suggestion from the work itself, make a new departure. The point is that the logic of the process is supplied by the person who is adding the new work. And this logic comes in part from antecedent work which is almost always his own but, as we shall see later, is occasionally from someone’s else’s work that comes under his observation (Jacobs, 1970: 60).

In Jacobs’ view, the logic of adding new work to old is always the logic of the producer, not of his customers. Furthermore, she points out that these processes almost always cut across conventional classification systems: “The point is that when new work is added to older work, the addition often cuts ruthlessly across categories of work, no matter how one may analyze the categories” (p. 62). She therefore cautions against the use of economic classification systems: “These are useful categories for some types of economic analysis, but insofar as they are relevant at all to understanding how old work leads to new, they interfere with our understanding” (p. 61).

Most of the points made by Jacobs are well known to students of technological creativity, but they have not been properly addressed in the recent literature that builds on her insights. For example, the use of industrial classification systems to assess the importance of interindustry knowledge spillovers is still widespread. We will therefore deal with this particular issue before reexamining Jacobs’ case by taking a more systematic look at the processes by which individuals combine older things to create new ones.

### 3. Industrial Classification and Resource Combination

As many authors have pointed out, the combination of previously unrelated things is the main difference between "natural" and "artifactual" evolution (Basalla, 1988; Mokyr, 1990; Sahal, 1981; Weber, 1992). In short, with the exception of the microbe level, different biological species usually do not interbreed, while artifactual types are relentlessly combined to produce new entities.<sup>1</sup> The anthropologist Alfred L. Kroeber illustrated this critical difference between living and human-made things more than half a century ago by sketching a "family tree" of organic species and another of cultural artifacts (figure 1).

**Figure 1**  
Basalla, 1988

In Kroeber's illustration, the species that form the different branches in the tree of life do not readily mix, but they split to form new species and remain totally isolated from one another once the "speciation" process has been completed. By contrast, the branches of the artifactual tree fuse together to produce new types, which merge again with other branches. It could thus be said that a creative human being once had the idea to "mate" a tree and duck to produce a wooden duck decoy. Another way to look at this is to say that the internal combustion engine branch was joined with that of the bicycle and horse-drawn carriage to create the automobile branch, which in turn merged with the dray wagon to produce the motor truck. In principle, any invention can mate with any other invention, although the issue of commercial success is, of course, another matter.

On the other hand, the Standard Industrial Classification (SIC) system and the North American Industry Classification System (NAICS), with their definition of industry as a collection of firms producing a homogeneous product, are embedded in a "speciation" framework of evolutionary change. This approach is usually traced back to Alfred Marshall (1952 [1920]: 241), who did indeed built his industrial analysis on the concepts of "differentiation" and "integration" as understood by the biologists of his days. As he put it: "The general rule... [is] that the development of the organism, whether social or physical, involves an increasing subdivision of functions between its separate parts on the one hand, and on the other a more intimate connection between them." Such an approach can be useful to describe economic development at one point in time. It is not possible, however, to reconcile economic

classification systems with the fact that virtually all functional processes and materials continually cut across "industrial branches" and that firms producing widely different outputs often use related production technologies.<sup>2</sup>

Another problem with industrial classification data is that they hide the multi-product nature of virtually all firms of any significance, along with the varied capabilities of their human resources. New combinations within firms are therefore ignored, even though such processes occur on a routine basis. For example, some employees of Canon's electronics and optics division have combined their skills to create significant innovations in cameras and photocopying machines (Galunic and Rodan, 1997). Some of Sharp's employees developed the first commercially-viable liquid crystal display for pocket calculators from the fusion of electronic, crystal, and optic technologies (Kodama, 1992). The Nordic Gear Battery Heated Gloves were developed at the request of an offshore oil platform crew and required the combined expertise of an electrical engineer, a fabric specialist and an extreme weather specialist.<sup>3</sup> If the real economic diversity of a geographical area is therefore hidden when firms with diversified human resources are assigned a single code, it must also be kept in mind that industrial classification systems can hide the similarities between firms involved in the production of related products or services. For example, Porter (forthcoming) points out that Massachusetts' firms involved in the production of medical devices were "buried within several larger and overlapping industry categories, such as electronic equipment and plastic products." A case can therefore be made that a researcher trying to study local diversity is always the prisoner of the subjective criteria of the people who design industrial classification systems (Mills, 1992: 7). The very structure of the SIC was a case in point, for it used both "product" and "production process" criteria to delineate various categories (ECPC, 1993a) and it ignored as distinct categories important industries such as plastics and electronics (ECPC, 1993b). Rosenberg's (1976: 15) warning that "it is necessary to discard the familiar Marshallian approach" when one seeks to understand

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1. A researcher can, however, take genes out a fish and put them in a strawberry. [*ploguer citation de Reason*]

2 This was probably obvious to Marshall who, as will be pointed out later in this paper, was well aware of the "interindustry" nature of technical innovations. It must also be noted that Levinthal (1998: 218) defines "speciation" as "the separation of reproductive activity" and argues that "the application of existing technological know-how to a new domain of application" is a speciation event. Such an assertion, however, seems incorrect because the main characteristic of speciation is that the new organisms created through that process can no longer mate together to produce offsprings.

3 This illustration is taken from an advertisement for this product.

how “certain functional processes... cut entirely across industrial lines” should have therefore been given more consideration in recent years.

A more interesting framework to deal with technology combinations is the patent classification system which is based primarily on technological and functional principles and is rarely related to the economists’ notions of products or well-defined industries. Thus a subclass dealing with the dispensing of liquids contains both a patent for a water pistol and for a holy water dispenser. Another subclass relating to the dispensing of solids contains patents on both manure spreaders and toothpaste tubes (Griliches, 1990: 1666). Patent data, however, have important limitations, both in the way they are structured and in the limited coverage of technology that they provide.<sup>4</sup> Their main problem for the study of how new combinations of resources are actually achieved is that they typically do not tell us the “industry of origin” of an invention and often suggest a variety of uses that will never be materialized. Schmookler (1966: 23) put the problem concisely many decades ago.

[A major] deficiency arose from the fact that I could not assign many [patented] inventions to a single industry. In part this resulted from my own ignorance, but often it reflected the interindustry character of technology. Thus, a given improvement in the diesel engine may be used in generating electricity or driving a locomotive, a given bearing may be used in shoemaking machine or a lawn mower, and a given knife may be used in harvesting or in kitchens. In consequence, the patent statistics used below generally do not include power plant inventions, electric motors, bearings, or other instruments or materials whose industry of origin was either multiple or simply not evident. Unfortunately, this means that the railroad data do not include inventions in the field of the steam or diesel engines, and that neither the farm nor the construction data include inventions on tractors.

Some patent office employees, most notably in Canada, have tried to correct this deficiency by assigning various industries of origin and of use to patent data. Patent office employees and inventors, however, can typically only guess some of the potential uses of a new device or material, for it is often the case that the most important use of an invention is very remote from its initial purpose (Basalla, 1988; Jewkes et al, 1969; Smith, 1982). In the end, as Griliches

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4 In short: 1) not all innovations are patentable; 2) not all patentable innovations are patented; 3) there are strong biases in the propensity to patent depending on the industry of origin, the size of the firm and the type of invention; 4) there are important reliability problems in patent data; 5) some patents prove to have an economic value, but the vast majority do not; 6) many patents are of a purely defensive nature; 7) patent requirements have evolved drastically over time and geographical space (Desrochers, 1998; Griliches, 1990).

(1990: 1667) points out, "most of the basic questions of classification still remain to be answered."

One possible way to gain a better understanding of the processes of localized resource combination is to drop conventional economic indicators such as firms, classification and patent systems, and to focus instead on human creativity. It is true that individuals work for firms and that much of their value to their employers is related to their belonging to various networks, some of which are local. On the other hand, even though each innovation depends on one person's previous knowledge and skills, individuals follow a limited number of patterns when they combine different things.<sup>5</sup>

#### **4. Human Creativity and Resource Combination**

The etymological root of the Latin verb *cogito* (to think) is "to shake together", while that of *intelligo* is "to choose among" (Koestler, 1969). The fact that all innovations are essentially novel combinations of existing devices and materials has therefore long been recognized. Not surprisingly, the adaptation of specific materials, processes and products from one area of industry to others unrelated in terms of final products has also been held to be an important aspect of technological innovation for a long time (Langrish et al., 1972; Rosenberg, 1976; Twiss, 1980; Smith, 1982). It is thus believed that the bow-drill, which was used as much for drilling holes as for starting fires, probably lead to the bow (McNeil, 1996). In the last century, the concept of a production chain was adapted in flour mills, slaughterhouses and machine-tool, canning, railroad and car assembly factories (Hounshell, 1991; Klemm, 1966; Mokyr, 1990). In addition to its cooking uses, baking soda can be used for deodorizing refrigerators and cleaning teeth. Laser is now used in, among other things, printers, telecommunication equipment, navigational instruments, textile machinery, surgery, precision measurement, weapon systems, sound systems and cash registers (Lipsey et al., 1998; Rosenberg, 1996).

Many contemporary social scientists have dealt with this issue by offering frameworks and concepts such as "technological convergence," "technoeconomic paradigms," and "general purpose technologies" (Lipsey et al., 1998). A case can be made, however, that these

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<sup>5</sup> In a recent case study, Shane (forthcoming) points out that different individuals find different uses for a single innovation based on their idiosyncratic prior knowledge. This is undoubtedly true, although it must be pointed out that the historical importance of "simultaneous discoveries" reminds us that at any given point in time, many

approaches are more descriptive than explanatory, because their authors usually don't elaborate on the reasons for these transfers and the circumstances that are conducive to them. The point of departure of each new combination is nonetheless very simple. As Petroski (1992: 22) puts it: "The form of made things is always subject to change in response to their real or perceived shortcomings, their failures to function properly. This principle governs all invention, innovation, and ingenuity; it is what drives all inventors, innovators, and engineers." Furthermore, "since nothing is perfect, and, indeed, since even our ideas of perfection are not static, everything is subject to change over time. There can be no such thing as a "perfected" artifact; the future perfect can only be a tense, not a thing" (idem). In the end, as Fores (1979: 853) points out, the main thrust of an engineer or a technician is "to gather knowledge from diverse places in order to help solve technical problems."

Gutenberg's invention of the printing press affords a well-known illustration. At the dawn of the fifteenth century, printing was no longer a novelty in Europe. Printing from wooden blocks on vellum, silk and cloth apparently started in the twelfth century, and printing on paper was widely practiced in the second half of the fourteenth. Oddly enough, though, the starting point of Gutenberg's invention was playing-cards on which a few words has been printed by way of rubbing wood-blocks on a sheet of paper. As he wrote in his correspondence to a clergyman:

Well, what has been done for a few words, for a few lines, I must succeed in doing for large pages of writing, for large leaves covered entirely on both sides, for whole books, for the first of all books, the Bible. How? It is useless to think of engraving on pieces of wood the whole thirteen hundred pages... What am I to do? I do not know: but I know what I want to do: I wish to manifold the Bible, I wish to have the copy ready for the pilgrimage to Aix-la-Chapelle. (Koestler, 1969: 122).

Gutenberg then searched for a device more resistant than wood-block, which lead him to notice the seals used to authenticate documents, but rubbing them on paper did not give a clear print. He found the solution one day, while attending a wine harvest near his city.

I took part in the wine harvest. I watched the wine flowing, and going back from the effect to the cause, I studied the power of this press which nothing can resist... God has revealed to me the secret that I demanded of Him... One must strike, cast, make a form like the seal of your community; a mold such as that used for casting your pewter cups; letters in relief like those on your coins, and the punch for

producing them like the foot when it multiplies its print. There is the Bible (Koestler, 1969: 123-24).

Gutenberg, like all innovators relating known facts to each other in unconventional ways, followed a few transfer mechanisms. Without getting into the details of the work of students of technological creativity,<sup>6</sup> it can be pointed out that in combining resources, an individual uses his previous know-how and his capacity of observation and learning. He therefore has only two ways of combining different resources: 1) he can incorporate a new type of material/process/product to a previously unrelated material/process/product; 2) he can find a new use for a material/process/product. Gutenberg thus already knew how to work metal, a skill that he learned as the child of the Archbishop of Mainz's goldsmith. This skill undoubtedly facilitated the transition from wooden to lead moveable types, a process that required steel for letter punches, lead for molds, a tin-zinc-lead alloy for types and brass or bronze alloys for dies. On the other hand, his observation and subsequent learning about a particular wine press provided the final breakthrough needed for the creation of the first functional printing press.

Despite the fact that inventions like the printing press may seem to be the work of a single human being, all innovations can ultimately be traced back to earlier products and techniques. Gutenberg thus had ready access to paper, presses, inks and scripts. Furthermore, most innovations typically require the collaboration of individuals possessing different skills. If more than one individual is required to solve problems of any complexity, there is no point in denying that all human minds function separately. As the psychologist Robert Weber (1992: 56) puts it: "Almost all important inventions are the work of multiple minds. But once we extract principles behind their development, it is possible to incorporate those principles into the individual mind, thereby giving us a leg up on the inventive process." We will now look at how individuals possessing very different expertise collaborate with one another, whether by working with other individuals in a firm, by collaborating with individuals working on different things for other employers and by moving among establishments producing different final goods.

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<sup>6</sup> See, for example, Detterman and Sternberg (1993), Glover et al. (1989); Petroski (1992), Weber, (1992); Weber and Perkins (1992).

## **5. Human Action and Resource Combination**

### *5.1 Human Creativity and Multidisciplinary Team Work*

It has long been recognized that multidisciplinary teams, by helping individuals overcome the blinders created by their particular expertise, are one of the best ways to associate concepts developed in one technology to the problems arising in another (Schroeder et al., 1989; Twiss, 1980). As Twiss (1980: 69) puts it:

One of the reasons for the effectiveness of the multidisciplinary team is that it brings together people working within different mental constraints. An extreme case of this comes from a large American research organization where one of the most creative members is a former theologian. Inevitably many of his ideas cannot be translated into practical terms, but, occasionally, however, he does come up with a proposal which would not have resulted from the normal thought processes of his technological colleagues and yet proves to be technically feasible.

In short, as West (1991: 201) puts it: "Sometimes it is good not to know beforehand all the reasons why something will never work and why it will never sell." Such teamwork is, of course, not limited to the private sector. For example, the history of Johns Hopkins University offers many similar illustrations of collaborative work between investigators based in one or a few areas of inquiry. Physicians from the Medical School and professors from the Engineering school thus worked together in the development of ultrasonic instruments for eye and brain surgery and the use of telemetry and computers to monitor hospital patients. Meanwhile, researchers based in the School of Hygiene and Public Health entered in an unlikely alliance with faculty at the Peabody Institute – a music conservatory – to work on the area of environmental sound studies (Schmidt, 1986). Rosenberg (1994: 152) points out, however, that the managers of the best industrial laboratories, unlike university research authorities, have traditionally placed a high value and considerable recognition on individuals who are useful in solving the problems encountered by colleagues in fields other than their own. The private sector has thus so far proven much more efficient at technology fusion than academia.

Apart from such "in-house" resource combinations, four other types of interindustry knowledge spillovers can be observed: 1) a firm's employees add to, or switch, their product lines; 2) individuals move from one type of production to another and incorporate their previous know-how in a new activity; 3) individuals observe a product/process in another setting and incorporate it in their production; 4) individuals with different skills working for firms dealing with

very different end products collaborate with one another to create a new process/product. We shall now look briefly at each one of these.

### *5.2 A firm's employees add to, or switch, their product lines*

As Weber (1992: 104) has argued, finding new purposes for existing products and know-how is the "freest lunch that technology can offer," even though sometimes substantial amounts of time and resources might be needed to achieve a commercially successful result. Expanding production lines is therefore characteristic of the history of virtually all firms of any significance, for in countless instances creative entrepreneurs and employees developed a new technique in response to a particular problem and later noticed that this know-how was applicable to other ends. Rosenberg (1976) describes many instances of that phenomenon in the 19th century American and British machine-tool industries. Lichtenberg (1960) similarly reports that during the first half of the nineteenth century New York's shipbuilding manufacturers branched out into making carriages, steam engines, and locomotives. Hounshell (1991) points out that in the 1890's, numerous buggy, railroad, toy, agricultural equipment, firearms and sewing machine manufacturers turned to the production of bicycles. Closer to us, Crevoisier (1993) describes how in the last decades numerous Swiss clock and watch manufacturers have expanded their product lines to such items as surgical tools, pacemakers, pens and insulin pumps, among other things. In some circumstances, however, some skilled employees will have to change jobs to find a new use for their know-how, as will now be illustrated.

### *5.3 Individuals move from one type of production to another and incorporate their previous know-how in a new activity;*

Whether initiated by employers or workers, the movement of skilled personnel between different types of production is conspicuous throughout history. The importance of European workers who had been trained in clock making and then transferred these skills to numerous other activities in the late Middle Ages and early Renaissance is well known. The same phenomenon, but in different industries, is also documented in the early British industrial expansion, most notably through the famous tool makers "Bramah" dynasty (Mokyr, 1990; Smiles, 1863; Thomson, 1991). Hounshell (1991) and Hoke (1990) similarly describe how American mechanics who had learned to create highly productive factories passed those ideas on to others, who expanded and spread them to everything from the fabrication of axes to that of

locks, from mechanical reapers to typewriters and sewing machines. This phenomenon was also obvious to Alfred Marshall (1923: 10) who wrote in his classic Industry and Trade:

Modern work is more narrowly specialized, in so far as the number and variety of the operations performed by a modern worker are on the average less than those of elementary skilled handicraftsman; but it is less narrowly specialized, in the sense than an operative, who has mastered the accurate, delicate and prompt control of machinery of any kind in one industry, can now often pass, without great loss of efficiency, to the control of similar machinery in an industry of a wholly different kind, and perhaps working on different material.

This phenomenon occurs everyday, as many detailed studies on technological change remind us. Consider, for example, the following illustration given by Langrish et al (1972: 44):

An example of technological development of a new person joining [a] firm is to be found in English Electric's development of fuses for the protection of semiconductor devices. E. Jacks, then Chief Engineer in the Fusegear Division, had identified the area of printed circuit technology as an area which might provide an answer to manufacture of the fuse elements. Progress was, however, held up because no one in the development team possessed enough skill in the use of photofabrication techniques. This need was overcome when, "by sheer luck," Jacks was interviewing an electrical engineer for a job and the applicant happened to mention casually that he had some skill in industrial photography which he had developed as a hobby. Photofabrication techniques were applied with great success and resulted in a completely novel process in the manufacture of fuse elements.

The changes brought about under such circumstances might often look radical to people unfamiliar with a particular technique adapted to a new situation, but it is probably fair to say that people who were previously knowledgeable about it are more likely to judge it incremental. Hence the widespread belief in 19<sup>th</sup> century England that "major inventions were all the work of "outsiders"" (McLeod, 1992: 290). Again, applying a particular know-how or material to a new situation might sometimes require considerable developmental efforts.

#### *5.4 Individuals observe a product/process in another setting and incorporate it in their production*

Gutenberg's invention of the first functional printing press is a well-known example of an individual observing a process in another setting and incorporating it in his own invention. Almost equally famous is the case of the car industry. It is thus generally acknowledged that the success of the Ford Motor Company owed much to previous developments in other industries, such as the production of interchangeable parts, the idea of continuous flow and the rise of an efficiency movement (Hounshell, 1991; Klemm, 1966). One industry that provided Ford's

technical people a model of efficient material handling was the meat packing industry. According to the historian of technology David Hounshell (1991: 241), William Klann, head of the engine department at Ford, recalled touring Swift's Chicago slaughterhouse and suggesting to superintendent P.E. Martin: "If they can kill pigs and cows that way, we can build cars that way and build motors that way." Klann also stressed that the Ford flow production drew upon the mechanical conveying system of both the flour milling and brewing industries: "We combined our ideas on the Huetteman & Cramer grain [conveying] machine[ry] experience, and the brewing experience and the Chicago stockyard. They all gave use ideas for our own conveyors" (idem). According to Hounshell, the process technology employed in food canning might also have given ideas to some of Ford's employees.

It would be a mistake, however, to consider that only industrial artifacts are useful in this respect. Consider, for example, the following anecdote related by A. Belotserkovsky, a Soviet Candidate of Technological Sciences:

For the ideal liquid for the hydraulic extrusion two mutually exclusive demands have to be met: in its zone of action for preparation the liquid should be non-viscous and should transmit hydrostatic pressure well, but in the zone of sealing and friction (where the plunger enters the container) the liquid should be highly viscous with good lubricating properties. We made numerous attempts to combine such a liquid of various components, we turned to the chemical institutes, patiently studied the literature and patents but did not succeed in finding a suitable liquid. The solution came unexpectedly and at an institution most unsuited for scientific creativity, a cocktail bar. One Saturday evening we were distractedly looking at the manipulations of the lady bartender who was skillfully pouring multilayered drinks. At that time a stupidly simple idea came to me: what if a "cocktail" were to be made in the container for hydraulic extrusion too... We tried out and really it all went off excellently (Altshuller, 1984: 252)

#### *5.5 Individuals possessing different skills and working for different firms collaborate to create a new process/product*

Exchange of technical information and informal collaboration between the employees of *competing* firms is widespread (Von Hippel, 1988). It therefore seems likely that collaboration between individuals involved in totally different lines of work is even easier to accomplish. There is indeed some evidence to that effect. In the 1980s, aerospace manufacturers began using carbon composite material instead of aluminum to make tail sections, wings, noses and fuselages. Used first in tennis rackets and skis, composite material is just as strong but typically

only weighs about half as much as aluminum. But it is also far more expensive and much more difficult to handle because if the composite material is not kept properly refrigerated before being cut to the proper shape, the material will be wasted. Properly refrigerating a huge aircraft while in production, however, was no simple task. When production managers at Northrop began wrestling with this practical dilemma, one of them decided to call upon the refrigeration specialists at Sara Lee. Not long after that, knowledge and expertise gathered through decades of refrigerating large facilities became part of modern aircraft production technology (Rothschild, 1990). Another illustration is given by an engineer working on the development of quantitative radiography for the “Star Wars” defense initiative. One Jose Hernandez thus describes how he and his colleagues adapted their know-how to develop a more reliable digital mammography system for the early detection of breast cancer: “We had the answer, but we were looking for the question. We zoomed in into the medical imaging arena... We were convinced they were using 20-year-old technology.” The researchers, affiliated with Lawrence Livermore National Laboratory, teamed up with an industrial partner having expertise in that field, Fischer Imaging Corp, in order to develop a commercially viable technology (Mellado, 1999: 24). Similar examples are found, among others, between individuals working for electronic and fiber optic firms (Kodama, 1992), as well as electronic and biomedical firms (Miller and Côté, 1987).

The importance of combining different resources in order to solve problems is nothing short of overwhelming. It will now be argued that if geographical proximity between people possessing very different knowledge bases is not always necessary, it can nonetheless facilitate these processes.

## **6. Urban Diversity and Resource Combination**

For more than a century, many geographers and economists have developed theories relating to the spatial agglomeration of economic activity in response to three empirical observations. First, a large portion of world output is produced in a limited number of highly concentrated core regions. Second, firms in similar or related industries tend to co-locate in particular places. Third, both of these patterns seem to be sustainable over. It has more recently been emphasized that the geographical concentration of related firms balance cooperative and competitive forms of economic activity, leading to greater innovation and flexibility, while also facilitating workers’ mobility, new business formation, the development of trust relationships and easier access to start-up capital (Malmberg, 1996; 1997). If these postulates are true for similar

firms, they are doubtless valid for the processes described in the previous section. It is thus likely that a diversified local economy facilitates workers mobility between sectors along with the collaboration of individuals working on different things.

Perhaps, however, is geographical proximity between people working in different lines of work even more important in one respect. As many scholars have pointed out, geographical proximity greatly facilitates the transmission of tacit knowledge by allowing frequent face-to-face communication between people with similar background working on similar problems. If there is much evidence pointing toward the importance of geographical proximity for communication between people sharing common cognitive ground, it seems obvious that its importance is even greater for people possessing diverse backgrounds. Feldman (1994: 21) thus points out that individuals with different expertise have different cognitive schemata. Interpreting and synthesizing information in this context involves constant questioning and interpretation through a process of trial, feedback and evaluation that is facilitated by face-to-face communication. Because most of the time individuals with different backgrounds working on the same problem do not even share key concepts, there is typically a need to develop a common language in order to coordinate search and development procedures. Former Johns Hopkins president, Milton D. Eisenhower, describes how such a situation occurred many decades ago.

[Applied Physics Laboratory director Frank McClure] initiated a collaborative attack by engineers, physicists, and medical scientists on problems in opthalmology, cardiology, prosthesis, radiology, and diagnostic medicine, among others... The initial problem had to do with cataract patients who sometimes could have unsuccessful operations because one could not tell in advance whether the optic nerve at the back of the retina was viable or had degenerated and thus could not transmit messages received through the lens of the eye to the brain. In the first conference, medical and APL scientists could not understand one another. The modern Tower of Babel – the specialized jargon of each intellectual discipline – was a barrier. But three long discussions produced a common language and genuine understanding. Out of interdisciplinary understanding came the building of a machine with... a laser, prisms, lenses, mirrors, and other devices, the conglomerate resembling a Rube Goldberg cartoon. But it worked (Eisenhower, 1973: 26-27).

Raymond Kurzweil, a pioneer in the field of electronic music synthesizers, relates similar difficulties in getting linguists, signal-processing experts, VLSI [very large scale integration] designers, psycho-acoustic experts, speech scientists, computer scientists, human-factors

designers and experts in artificial intelligence and pattern recognition to work together in his plant:

Each one of these fields has very different methodologies and different terminologies. Very often a term in one field means something else entirely in another field. Sometimes we even create our own terminology for a particular project. So, enabling a team like that to communicate and solve a problem is a significant challenge. If you look at the entire company, you bring in even more disciplines: manufacturing, material-resources planning, purchasing, marketing, finance, and so on. Each of these areas has also developed sophisticated methodologies of their own that are as complex as those in engineering. My challenge is to provide a climate in which people with different expertise can work together toward a common goal and communicate clearly with one another (Brown, 1988: 243-44).

Furthermore, if innovation is understood as the combination of previously unrelated things, it seems obvious that diversified cities will be more likely to generate innovation than specialized ones. As Aitken (1985: 15-16) points out in his history of the radio:

A hypothesis worth testing is that the points of confluence of information flows define the social locations where there is a high probability of new combinations being made... Such an approach avoids determinism: it gives no warrant for asserting any kind of necessity in the process. But neither are we thrown back into blind chance. It is a matter of probabilities: the probabilities of new combinations being formed is higher at the points of confluence than it is elsewhere.

Specialists of regional growth, however, have almost never before adopted this perspective, stressing on the contrary that competition is always likely to promote the regional specialization of economic activities. Such a view, however, is plausible only in a static world where resources are given and allocative efficiency is the main driving force. In a dynamic world where new things are created and make older ones obsolete, regional specialization is ultimately self-defeating for it dries up the pool of potential ideas and skillful people on which innovators can draw upon to combine unrelated things. The thesis that local specialization might be more conducive to innovation must ultimately rest on the belief that new ideas are useful only within an industry. This is obviously untenable, both in view of how individuals generate new know-how and how quickly some individuals have always found new uses for specific innovations. The theory of comparative advantage, and its application at the regional level, are based on the sound principle that the division of labor leads to greater efficiency. Yet, as Jacobs points out, it can readily be observed that developing cities are always getting more complex, with numerous new goods and services being constantly created. Perhaps, then, the division of labor should

be more often understood in terms of the particular skills that individuals possess rather than the final goods they produce. An individual possessing specialized know-how should therefore always be free to find new uses for it and it seems obvious that a diversified city is one of the best settings to achieve this.

## **Conclusion**

One of the least controversial aspects of technological change is that problems are solved through the combination of previously unrelated things. Despite the fact that specific materials, products and processes continually cut across "industrial sectors," specialization has long been held by students of regional growth as the optimal economic setting to promote development and growth. One of the few authors to strongly dissent from that view is Jacobs (1969) who argues, among other things, that local diversity increases the probability of combining different resources. Further study of human creativity and the history of technology indeed suggest that a diversified city is likely to facilitate the transfer of know-how from one area of industry to others that are unrelated in terms of final products. By offering a greater number and variety of problems to be solved, as well as a much wider pool of expert knowledge and other resources to draw from, a diversified city can only increase the probabilities of new combinations being made. A better understanding of the processes by which creative individuals combine existing resources in different ways will, however, require that familiar research designs be reconsidered and at the very least supplemented by insights derived from until now unrelated fields.

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**Figure 1**