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New Growth Theory, Technology and Learning: A Practitioner's Guide

Joseph Cortright
Impresa, Inc

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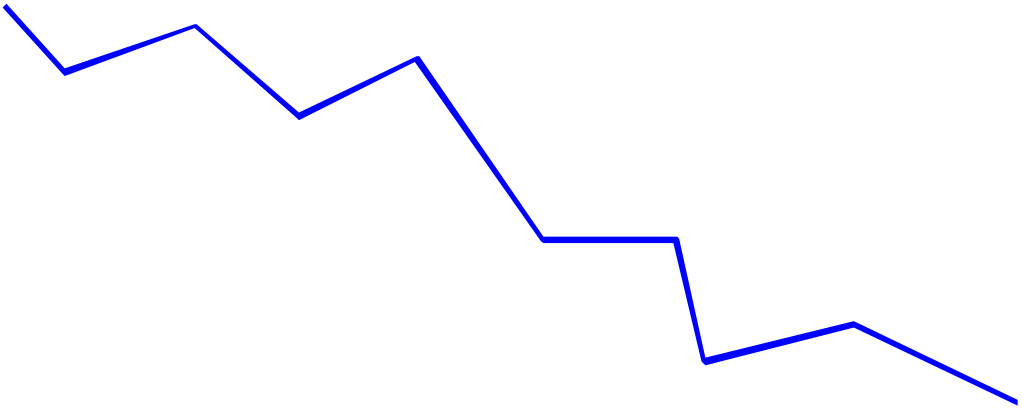

U.S. Economic Development Administration

New Growth Theory, Technology and Learning

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ABSTRACT

New Growth Theory emphasizes that economic growth results from the increasing returns associated with new knowledge. Knowledge has different properties than other economic goods (being non-rival, and partly excludable). The ability to grow the economy by increasing knowledge rather than labor or capital creates opportunities for nearly boundless growth. Markets fail to produce enough knowledge because innovators cannot capture all of the gains associated with creating new knowledge. And because knowledge can be infinitely reused at zero marginal cost, firms who use knowledge in production can earn quasi-monopoly profits. All forms of knowledge, from big science to better ways to sew a shirt exhibit these properties and contribute to growth. Economies with widespread increasing returns are unlikely to develop along a unique equilibrium path. Development may be a process of creative destruction, with a succession of monopolistically competitive technologies and firms. Markets alone may not converge on a single most efficient solution, and technological and regional development will tend to exhibit path dependence.

History, institutions and geography all shape the development of knowledge-based economies. History matters because increasing returns generate positive feedbacks that tend to cause economies to "lock in" to particular technologies and locations. Development is in part chaotic because small events at critical times can have persistent, long term impacts on patterns of economic activity. Institutions matter because they shape the environment for the production and employment of new knowledge. Societies that generate and tolerate new ideas, and that continuously adapt to changing economic and technological circumstances are a precondition to sustained economic growth. Geography matters because knowledge doesn't move frictionlessly among economic actors. Important parts of knowledge are tacit, and embedded in the routines of individuals and organizations in different places.

New Growth Theory, and the increasing returns associated with knowledge have many implications for economic development policy. New Growth Theory underscores the importance of investing in new knowledge creation to sustain growth. Policy makers will need to pay careful attention to all of the factors that provide incentives for knowledge creation (research and development, the education system, entrepreneurship and the tolerance for diversity, macroeconomic expectations, openness to trade). Because it undermines the notion of a single, optimal general equilibrium, New Growth Theory implies that economics will be less capable of predicting future outcomes.

CONTENTS

INTRODUCTION

A PRACTITIONERS GUIDE TO THEORIES FOR THE KNOWLEDGE BASED ECONOMY

The purpose of this paper is to provide interested readers, particularly economic development practitioners, with an accessible, non-technical summary of the newer theories of economic development. Our intent is neither to be exacting nor exhaustive in describing this literature, but rather to summarize and synthesize the various strains of the literature with a practical bearing on the policy choices confronting those who work to improve state, regional and local economies.

Most economic development practitioners labor in a world that is only distantly and unevenly connected to the complex and frequently arcane academic debates about economic growth. Much of the world-view of these practitioners (and in turn, policy-makers) is formed by experience and rule-of-thumb. Even those with formal training in economics often date their most recent studies to one or two decades ago, as an undergraduate. They may truly be, in Keynes' words, the slaves of some defunct economist.

The intent of this paper is not to suggest that the economics profession has coalesced around a new theory of economic growth and development. It hasn't; a lively debate continues between traditional neo-classical views and a range of suggested alternatives. Our hope rather, is that by introducing many new readers to the new thinking and theorizing about the economy, we will broaden and enrich this debate.

The scope of this paper, like the new theorizing about the economy, transcends a number of dimensions. The common focus is the role of new knowledge creation, and the way it plays out in driving economic growth, its mechanics, its geography, and the critical roles of culture and institutions.

We start with a close look at the New Growth Theory and the writings of one of its leading theorists, Paul Romer. Romer's work has ignited much of the intellectual attention to economic growth in recent years, and laid out a number of the important principles that underlie other aspects of the growth process. Specifically, careful distinctions about the nature of economic goods, the logic underlying the models and metaphors economists use to describe the world, and the central role for new ideas—knowledge—to shape our economic well-being are all explored.

The point here is not that neoclassical theory is wrong but that it is incomplete. In the jargon of the trade, the stylized facts that economists use to describe the world leave out much of what really matters. Neoclassical theory applies deductive logic to a set of assumptions about consumer behavior and the technology of production. Adding knowledge to these models complicates them, but makes them more realistic, and in the end, more useful.

I. WHAT IS NEW GROWTH THEORY?

New Growth Theory is a view of the economy that incorporates two important points. First, it views technological progress as a product of economic activity. Previous theories treated technology as a given, or a product of non-market forces. New Growth Theory is often called "endogenous" growth theory, because it internalizes technology into a model of how markets function. Second, New Growth Theory holds that unlike physical objects, knowledge and technology are characterized by increasing returns, and these increasing returns drive the process of growth.

This new theory addresses the fundamental questions about what makes economies grow: Why is the world measurably richer today than a century ago? Why have some nations grown more than others? The essential point of New Growth Theory is that knowledge drives growth. Because ideas can be infinitely shared and reused, we can accumulate them without limit. They are not subject to what economists call "diminishing returns." Instead, the increasing returns to knowledge propel economic growth.

New Growth Theory helps us make sense of the ongoing shift from a resource-based economy to a knowledge-based economy. It underscores the point that the economic processes which create and diffuse new knowledge are critical to shaping the growth of nations, communities and individual firms.

A. Increasing Returns to Knowledge Drive Growth

> Ultimately, all increases in standards of living can be traced to discoveries of more valuable arrangements for the things in the earth's crust and atmosphere . . . No amount of savings and investment, no policy of macroeconomic fine-tuning, no set of tax and spending incentives can generate sustained economic growth unless it is accompanied by the countless large and small discoveries that are required to create more value from a fixed set of natural resources (Romer 1993b, p. 345).

Today we tend to focus on the computer and the Internet as the icons of economic progress, but it is the process that generates new ideas and innovations, not the technologies themselves, that is the force that sustains economic growth.

Romer is credited with stimulating New Growth Theory, but as Romer himself notes, (Romer 1994b) there is really nothing new about the theory itself. The central notion behind New Growth Theory is increasing returns associated with new knowledge or technology. The cornerstone of traditional economic models is decreasing or diminishing returns, the idea that at some point as you increase the output of anything (a farm, a factory, a whole economy) the addition of more inputs (work effort, machines, land) results in less output than did the addition of the last unit of production. Decreasing returns are important because they result in increasing marginal costs (that is, at some point, the cost of producing one more unit of production is higher than the cost of producing the previous unit of production). Decreasing returns and rising marginal costs are critical assumptions to getting the mathematical equations economists use to describe the economy to be settling down to a unique equilibrium.

For economists, a world of decreasing returns has a number of useful mathematical properties. Economies resolve themselves to stable and unique equilibrium conditions. Moreover, assuming free entry of firms, the math of decreasing returns implies that individual firms are price-takers, that they have no control over the market level of prices, and that markets easily and automatically encourage the optimum levels of production and distribute output efficiently: Adam Smith's invisible hand.

While essential to microeconomic models—studies of the economics of individual firms—decreasing returns have some pessimistic implications for the economy taken as a whole. If we can expect ever diminishing returns to new machines and additional workers, this implies that economic growth will become slower, and slower, and eventually stop. This vision of an increasingly sluggish economy doesn't seem to square well with the historical record.

In the 1950s, Robert Solow crafted theory that addressed this problem, building a model that kept diminishing returns to capital and labor, but which added a third factor—technical knowledge—that continued to prod economic productivity and growth (1957). Solow's model pictured technology as a continuous, ever-expanding set of knowledge that simply became evident over time—not something that was specifically created by economic forces. This simplification allowed economists to continue to model the economy using decreasing returns, but only at the cost of excluding technology from the economic model itself. Because technology was assumed to be determined by forces outside the economy, Solow's model is often referred to as an "exogenous" model of growth.

The model Solow devised—ultimately recognized in the 1987 Nobel Prize for economics—became a mainstay of the economic analysis of growth. A number of economists used the basic framework to make elaborate calculations of the relative contributions of expanding (and improving) labor supplies, and increased capital investment to driving growth. These efforts at "growth accounting" showed that most of the growth of the economy was due to increases in capital and labor, and, consistent with the Solow model, assumed that what couldn't be explained by these factors was "the residual" attributable to improvements in technology (Fagerberg 1994).

The world described by the Solow model provided not only the basis for economic theorizing, but also strongly shaped the policy recommendations of economists, what was taught in colleges and universities about economic development, and what kinds of policies many governments followed. Neoclassical theory has brought us a number of important ideas that we apply to the world of economic policy. Taken as a whole, neoclassical assumptions lead us to conclude that markets are generally very competitive, and don't tend toward monopolies, that left un-impeded, market processes usually result in optimum levels of production and allocation. They also imply that we have relatively limited opportunities for government to promote economic ends, other than encouraging market competition, providing adequate schooling and encouraging savings and investment.

The New Growth Theory challenges the neoclassical model in many important ways. The exogenous growth models developed by Solow and other neoclassical scholars largely didn't try to explain what caused technology to improve over time. Implying that technology "just happened" led to an emphasis on capital accumulation and labor force improvement as sources of growth. As Romer says: "We now know that the classical suggestion that we can grow rich

by accumulating more and more pieces of physical capital like fork lifts is simply wrong" (Romer 1986). The underlying reason is that any kind of physical capital is ultimately subject to diminishing returns; economies cannot grow simply by adding more and more of the same kind of capital.

New Growth Theory revived an old tradition of thinking about the effects of increasing returns. At least through the early days of the 20th century, economists were quite comfortable talking about increasing returns as both an actual and a theoretical possibility (Buchanan and Yoon 1994). But as economists moved to an ever stronger emphasis complex mathematical formulations of their theories, no one had the mathematical tools to model situations with increasing returns. Assuming diminishing returns produced economic models that could be solved with the tools of calculus at hand, and their systems of equations settled down to a single, stable equilibrium. If one assumed increasing returns, the equations blew up, leaving the greater part of mathematical economics in wreckage. As a result, economists restricted themselves to diminishing returns, which didn't present anomalies, and could be analyzed completely (Arthur 1989).

Recent economic developments have underscored the relevance of increasing returns in the world of business. Software and the Internet, both relatively new inventions, have very high initial or fixed costs (the cost of developing the first disk or initially programming a website) but very low (or nearly zero) costs of serving an additional customer or user. The first copy of Microsoft windows might cost tens of millions of dollars to make, but each additional copy can be made for pennies.

B. Special Characteristics of Knowledge

> The physical world is characterized by diminishing returns. Diminishing returns are the result of the scarcity of physical objects. One of the most important differences between objects and ideas . . . is that ideas are not scarce and the process of discovery in the realm of ideas does not suffer from diminishing returns (Romer quoted in Kurtzman 1997).
>
> Unexpressed but implicit in Adam Smith's argument for the efficiency of the market system are assumptions about the nature of goods and services and the process of exchange—assumptions that fit reality less well today than they did back in Adam Smith's day (DeLong and Froomkin 1999).

The centerpiece of New Growth Theory is the role knowledge plays in making growth possible. Knowledge includes everything we know about the world, from the basic laws of physics, to the blueprint for a microprocessor, to how to sew a shirt or paint a portrait. Our definition should be very broad including not just the high tech, but also the seemingly routine.

One special aspect of knowledge makes it critical to growth. Knowledge is subject to increasing returns because it is a non-rival good. Non-rival goods are very different from those considered in most economic textbooks. Economists generally focus their analyses on the production and allocation of ordinary goods and services. Two key properties of ordinary goods and services are rivalry—only one person can use them or make use of them at a given time—and excludability

— one has the ability (often established in law) to exclude others from using the goods that are yours.

Not all goods and services are rival and excludable. Economic theory has treated goods and services that are neither rival nor excludable as a special case—"public goods"—things like national defense, lighthouses and malaria eradication. Once provided for one person these services are equally available to all. In neither case does having an additional consumer for these services deprive others of its value (i.e. there is no rivalry) and neither can anyone be effectively prevented from benefiting from the service (i.e. they are not excludable).

Free markets, economists admit, don't do a good job of providing public goods for two reasons. The first is the so-called "free rider" problem: because we can't exclude anyone from receiving the benefits of these goods and services, we don't have any effective way of forcing anyone to pay. Anyone who has endured a public broadcasting fundraiser will be familiar with this problem. Some will pay for a service out of a sense of value received or civic obligation, but many who use the service, choose not to. A second and related problem is that free markets don't produce enough public goods. Because there is no way to capture revenue equal to all the benefits people receive from public goods, they don't get produced even though they would produce a real value to consumers in excess of their cost of production. This "market failure" provided a reasonable justification—to economists—for government funding for many public goods, like national defense.

The standard approach economists use has been to divide the world into two parts: private goods—excludable and rival, and produced by markets—and public goods—non-excludable, non-rival, and produced by government, or other non-market means, like charities. While an important exception to the rule that markets produce optimum results, public goods tended to be viewed as a very limited exception: we can rely on markets to produce the overwhelming majority of goods and services, and turn to the public sector only in a few special cases.

To the extent that economic theory addressed knowledge at all, it generally tended to assume it was simply a public good. If one makes a fundamental research breakthrough, like $E=mc^2$, or observes the super-conducting properties of a particular combination of metals, then this information becomes equally available to all.

But not all ideas are pure public goods. While they are non-rival—many people can use them at once without depriving others of their use—economically valuable ideas are at least partially excludable. And most importantly, their excludability is more a function of socially determined property rights than it is a function of the intrinsic character of the idea. Patents, trademarks, and copyright law allow individuals to have certain rights to exclude others from the benefits of the ideas they have created. Keeping ideas secret—trade secrets, confidential business information—also allows their owner to exclude others from their benefits.

Because ideas are intangible, when we look at a good like a machine or a service, we don't think about the ideas embedded in it. But digital technologies have sharpened our perception of the difference between ideas and products. Software programs, at their core, long sequences of 1's and 0's encoded in magnetic media, are as close to a pure idea as one can imagine. Software is plainly a non-rival good. The microeconomic analysis of idea production is clear. Because they

are non-rival, their marginal cost of production is near zero —the incremental cost of making software available to an additional user is pennies for the diskette and nothing for the program itself.

The non-rival quality of ideas is the attribute that drives economic growth. We can all share and reuse ideas at zero, or nearly zero cost. As we accumulate more and more ideas, knowledge about how the world works, and how to extract greater use out of the finite set of resources with which the world is endowed, we enable the economy to develop further.

C. Implications of Increasing Returns

The increasing returns associated with the non-rival aspect of ideas have a number of important implications for economic theory and how economies work. Some of these implications are a cause for optimism; others make life more difficult, especially for economists.

1. Opportunities for Growth May be Almost Limitless

The source of economic progress is ideas. We have basically the same stock of physical resources we have always had. Our higher standard of living stems from our improved ability to rearrange these physical objects into forms that provide greater value. Today's Pentium 4-based computer has about the same quantities of copper, plastic, fiberglass, silicon and other materials as did 1982's IBM PC, but it's a hundred times faster and capable of far more functions because all of these materials have been re-arranged into a slightly different form.

Unlike the critics of the patent office at the turn of the 20^{th} century who believed it could be closed because nearly everything useful had already been invented, it is extremely likely that we will never come close to discovering all or even a very significant fraction of all of the possible useful products, inventions and processes we might create from the physical objects available to us.

The potential for ideas to change things is enormous. Romer illustrates this with the example of a child's chemistry set. If one has 100 different chemicals in the set, there are more than 10^{30} possible combinations of 2 or more chemicals one can make (ignoring the opportunities for varying the proportions of the ingredients). The possible number of combinations is staggering: by Romer's calculation if everyone on the planet had tried one combination a second for the last 20 billion years—the age of the universe—we still would have tested less than one percent of the possible combinations (Romer 1992).

This aspect of ideas should fundamentally change our notions of the opportunities for economic progress. Traditionally, economics has been regarded as the dismal science, because it kept suggesting that we would eventually run into serious limits to growth in our finite world. Concerns about environmental deterioration associated with the increased consumption of natural resources have revived and heightened these concerns. New Growth Theory implies, however, that we continue to increase living standards for centuries to come by steadily improving our knowledge of how to produce more and better goods and services with ever-smaller amounts of physical resources (Grossman and Helpman 1994).

2. Markets Tend to Under-Invest in Knowledge

> In the physical economy, with diminishing returns, there are perfect prices; in the knowledge economy, with its increasing returns, there are no perfect prices (Romer quoted in Kurtzman 1997).

One virtue of the market system is that it is thought to provide the right signals to producers and consumers about whether to use more or less of a commodity. High prices tell consumers to consume less, and producers to produce more. Low prices discourage production and encourage consumption. Markets thus tend toward equilibrium—the cost of the last unit produced is always just equal to its value to the person consuming it. To the economist's eye, this results in the optimal levels of production and consumption of every given commodity.

But in the case of knowledge, markets may not send the right price signals. The social benefits and the private costs of new knowledge creation diverge. Because additional use of knowledge has zero marginal cost, once the knowledge is created, any positive price for knowledge is too high. Because knowledge isn't fully excludable, entrepreneurs get paid less than the social value of their knowledge, and they don't have sufficient incentives to distribute it widely or invest in creating more.

The difficulty and uncertainty of being able to capture the value associated with an invention is a real problem. Xerox may have invented the mouse and the graphical user interface for computers, but Apple and Microsoft made all of the money associated with selling the products that incorporated these ideas (Jarboe and Atkinson 1998). Knowledge spillovers mean that investors have smaller incentives to invest in knowledge than they do in more tangible things, like machinery, that they can control.

As a result, many socially valuable investments in knowledge may not be made. Rather than investing in knowledge creation which may have huge returns (which an investor can only partly capture), private investors find it more profitable to invest in less valuable investments from which they can appropriate more of the gains. The gap between the social returns of research investment and their private returns is evidence of the inability of firms to capture the benefits of their research (Nelson and Romer 1996). Careful econometric studies have repeatedly shown that the social rate of return to research (the value of all of the economic benefits received by society) is typically two to five times higher than that private rate of return (the profits accruing to the individual or the company that pioneered the innovation) (Jarboe and Atkinson 1998).

The traditional solution to dealing with spillovers, granting strong property rights for the fruits of an invention, may also have negative consequences. Letting someone have a patent on the blinking cursor or on iterative looping in a computer program, would likely stifle the development of technology (Nelson and Romer 1996). As a result no simple market arrangement will result in the optimum incentives for both the discovery of new knowledge and, at the same time, its most efficient allocation throughout the economy.

3. Knowledge-Based Economies Tend Toward Monopolistic Competition

> We must recognize that ideas are economic goods which are unlike conventional private goods and that markets are inherently less successful at producing and transmitting ideas than they are with private goods (Romer 1992, p. 89).

A market for knowledge has different competitive dynamics than a market for ordinary goods and services. Because knowledge has increasing returns (continuously declining marginal costs), having the largest market share produces the highest profits. As the leading producer faces permanently declining costs—the next unit of output can be produced even more cheaply than the last—whoever has the leading position in the market can maintain and extend it. Eventually, it is likely that a single firm will dominate or monopolize the market. This is exactly the concern raised in the federal anti-trust case against Microsoft.

This outcome is different than is the case with physical goods that have decreasing returns. As the largest firms increase production in an industry with diseconomies of scale, they face increasing costs. The next unit of output costs more than the last unit, and they find it difficult to undercut the prices charged by their competitors. In contrast, for products characterized by increasing returns, leading firms tend to build up insurmountable advantages (their larger output gives them ever lower costs), and new entrants face the difficult prospect of starting out with much higher costs that their established competitors. The result is that markets with increasing returns tend to be characterized by monopolies.

Knowledge-based economies tend towards what economists call monopolistic competition. Businesses compete with one another, not based on the price of similar products, but based on their monopoly position with a particular differentiated product or service. Competition occurs not based on cutting prices, but in augmenting product characteristics—variety, quality, features—and introducing new products. This is a competitive market, but a very different one from the smoothly adjusting equilibrium model of neoclassical economics. While this kind of competition may have negligible effects in certain markets—like sales of popular music—it could have huge implications for the economy in others—operating systems software.

This was a relatively small problem when most of the economy was composed of goods, and only a relatively small fraction of economic output was knowledge based products and services, like software. In today's economy, knowledge is coming to represent a larger fraction of the products and services we consume (Arthur 1996).

4. Economic Outcomes are Indeterminate; Multiple Equilibria are Possible

> Once we admit that there is room for newness – that there are vastly more conceivable possibilities than realized outcomes – we must confront the fact that there is no special logic behind the world we inhabit, no particular justification for why things are the way they are. Any number of arbitrarily small perturbations along the way could have made the world as we know it turn out very differently (Romer 1994b, p. 9).

One of the corollaries of the nearly limitless opportunities for growth implied by New Growth Theory is that the world we live in is only one possible arrangement of people, technologies and institutions that is conceivably possible.

As Plato noted long ago, there is a natural tendency on the part of humans to assume that the world that we inhabit turned out the only way it could have. We tend to believe in plenitude, the notion that the world is complete, and that everything that can exist does exist (Romer 1994b). It is difficult to comprehend all of the different possibilities, for human development and for technology that might have occurred had things been even slightly different. Suppose that the comet that hit the earth 65 million years ago had missed: life on earth would undoubtedly look very different than it does. We look at things as they are, and assume that they are the product of an inexorable, determinate process. To realize just how tenuous and improbable just technological developments have been, one needs only look at the arcane and unpredictable paths that have led to the world's major scientific discoveries (Burke 1978).

Traditional economic theories exhibit this bias. As Romer points out, the standard microeconomic model echoes the notion of plenitude, assuming that all goods and services already exist, and that the sole job of markets is to allocate them among competing uses. The notion of a unique equilibrium implies that market processes are deterministic: that they automatically select the single best outcome (Romer 1994b). Increasing returns, however, imply the possibility of multiple equilibria.

This line of reasoning quickly leads to the domain of chaos theory. A number of economists have drawn the connection between economic development and the application of chaos theory in biology and physics (Arthur 1996). Chaos theory models the behavior of complex systems of interacting independent agents that exhibit spontaneous self-organization, positive feedback and learning and an indeterminacy of outcomes (Waldrop 1992). While some believe that chaos theory should lead economics to abandon its traditional equilibrium models, others believe that essential aspects of chaos mechanics can be incorporated into the microeconomic framework. (Krugman 1996). The theoretical debate on this point has apparently only begun.

Although increasing returns pose enormous difficulties for theorists and modelers—the future really is unpredictable—they may be a hopeful sign for policy makers. If small actions taken at the right time can produce disproportionate and lasting returns, and if there are many possible efficient futures for the economy, there may be room for public policy to influence which road we take.

II. IMPLICATIONS OF NEW GROWTH THEORY

The New Growth Theory has impressed economists to the point that it is likely to lead academics to revise textbooks. But should policymakers care? There are a number of practical implications from New Growth Theory that should guide us as we think about how to formulate programs designed to stimulate economic growth. If we accept the theory, it should lead us to change our views of the importance of history in shaping development trajectories, in the role of institutions in providing a framework for growth. It should also revive our interest in the importance of place to development.

A. History Matters

> When they are used together, economic history and New Growth Theory give a more complete picture of technological change than either can give on its own. . . The key theoretical observation is that larger markets and larger stocks of resources create substantially bigger incentives for discovering new ways to use the resources. This simple insight explains why the techniques of mass production emerged in the United States during the first half of the 19th century (Romer 1996, p. 1).

New Growth Theory leads us first to think differently about the role of history in shaping economic growth. The increasing returns associated with knowledge produce "path dependence": future options are constrained by past actions. New Growth Theory is also broadly consistent with an evolutionary view of how the economy changes. This evolution, moreover, happens not smoothly but in abrupt steps, as new ideas and new businesses replace old ones in a process of creative destruction.

1. Increasing Returns Produce Path Dependence

The New Growth Theory emphasizes the importance of increasing returns to the overall opportunities for economic growth. Increasing returns imply tremendous opportunities for growth, and the need for policy to deal with resulting monopolies and market imperfections. But increasing returns have important implications for the process of development as well. An economy dominated by increasing returns will develop very differently than and economy characterized primarily by diminishing returns.

Economists have only recently begun to systematically explore the developmental implications of increasing returns. One of the most interesting examples of path dependence is literally right at our fingertips. Almost every computer keyboard in the western world follows one cryptic arrangement in use for more than a century, with the letters QWERTY in the upper left-hand corner. This design dates to the 1870s, and was chosen to prevent the long levers that pressed the type against the ribbon from clashing with one another, and so, it is said, that a salesman could type the word “typewriter” using only the keys on the top row.

The reasons behind the persistence of the typewriter keyboard tell us much about the development of technology, argues historian Paul David. Three characteristics of QWERTY and

similar technologies produce this sort of lock-in: technical interrelatedness, economies of scale, and quasi-irreversibility (David 1985). Technical interrelatedness is the complementarity between the physical arrangement of the typewriter keyboard and the typist's human capital of touch-typing. Both the keyboard and the typist have to standardize on the same arrangement of keys in order to achieve efficiency. Economies of scale refer to the relationship between the number of users of a particular technology and the incentives facing new adopters. In the case of QWERTY, early touch typists chose to be trained on what was initially the most common keyboard arrangement. Similarly, typewriter manufacturers looked to produce models that could be used by the largest number of trained typists. While early on there were several competing arrangements for keyboards, by the mid-1890s, QWERTY had become virtually universal. That this situation persisted—for more than a century now, in spite of the transition to an entirely new technology, computers—is a product of the quasi-irreversibility of the investments by manufacturers and touch typists. While manufacturers could easily change the layout of the computer keyboard (and even end users can now do so by software), and keyboard users can retrain themselves in a new layout, no one does because all the other keyboards and computer users in the world have standardized on the QWERTY design.

The presence of "QWERTYnomics" has been noted in a wide variety of other technologies. The triumph of VHS standard video recorders over what many regarded as a technically superior Beta technology clearly followed the increasing returns dynamic: a small lead in market share prompted broader availability of products on VHS and further increased demand for VHS recorders. Eventually VHS drove Beta from the market.

QWERTYnomics implies path dependence: where economies end up is a product of the development path that they follow. Small chance events occurring at the right time can have persistent long-term effects. Economies can lock-in to particular, often inefficient, technologies or other arrangements, and market forces will not automatically correct these inefficient outcomes (Arthur 1987).

Increasing returns are becoming more important to the economy and economic theory because of technological change. In the 19th century, the most important industries, like manufacturing and agriculture, were characterized by decreasing returns. As agriculture expanded, it would move on to less productive land and confront rising costs or diminishing demand for its product. In contrast, many of the technologies of the twentieth century are characterized by increasing returns: huge initial costs to create knowledge needed to produce the first product, but much smaller costs for each additional unit of output. The economics of producing jet airliners and computer software seems to follow these trends. Because of declining costs and technological lock-in, firms that gain early market share in an emerging technology can gain virtual monopolistic control of a market. Arthur notes that exactly this phenomenon occurred in the computer industry, where after getting an initial lead thanks to its adoption by IBM (for the first PC), the DOS operating system came to dominate personal computing. The lock in of users and computer makers to DOS enabled Microsoft to earn huge profits (Arthur 1996). This argument underlies a key portion of the anti-trust case brought by the federal government against Microsoft (Cassidy 1998).

Notwithstanding the intuitively appealing examples, some economists are skeptical of the importance and extent of increasing returns. While they concede that there are many network

effects, some question whether these are really externalities that distort market outcomes (Liebowitz and Margolis 1994). Critics question how important technological lock-in is in causing the economy to deviate in a major way from an optimal state. Advocates of QWERTYnomics argue that the entire framework of economic progress is driven subtly and pervasively by chance, and that conventional economic theory focuses primarily on a static view of the world that, by its nature, obscures the effect of these processes (David 1997).

While much of the debate about QWERTYnomics has revolved around issues of technology, the theory can be applied to industrial location. Because of the complementarities between producers and suppliers and employers and workers, firms in a single industry may find it advantageous to be located in the same community. Once a particular location is established as a center for a particular industry, new firms and new workers have powerful incentives to locate there. Paul Krugman has used this notion to build several sophisticated models of industrial location. The same concept has applicability to international trade as well; industries that exhibit increasing returns may not simply be dominated by one company or one city, but by a single nation as well (Krugman 1991). (We explore the connection between lock-in and industrial location more full in Part C of this section).

What are the policy implications of QWERTYnomics? Because small historical events can play a decisive role in the development of technology or the location of industry, it is possible that government interventions can produce a potentially better set of outcomes than the market alone. For example, policies to support an emerging industry can create a self-reinforcing cycle that leads to the development of enduring competitive advantage in that industry (Krugman 1994). In thinking about technological development, it may be wise for public policy to discourage markets from prematurely locking in to a particular technology before its costs and the implications for further development are understood (David 1997). And while it is certainly theoretically possible that governments might make better choices than the market, economists are almost universally skeptical that they will do so.

2. Economies Exhibit Evolutionary Tendencies

The economy is an evolutionary system, not a Newtonian balance that always seeks equilibrium. Both the micro behavior of economic actors (firms, workers and consumers) and the overall path of economic development can be pictured by invoking analogies to biological evolution. Individual actors don't maximize their utility in ceaseless calculations of alternatives; they muddle along, relying on previously successful behaviors until they are proven unsuccessful, and then trying alternatives that draw from their own experience. The result, when multiplied over the scale of the entire economy, is an economic system that evolves.

The science of economics arose, hand in hand, with the Enlightenment in the 17th and 18th centuries. Adam Smith, wrote *The Wealth of Nations* in 1776. One of the dominant scientific paradigms of that day was Newtonian physics—the notion that natural systems, ranging from the infinitesimal to the cosmic, could be imagined as a series of elaborate balances always tending toward equilibrium. Arguably the models and metaphors of 18th century physics were imprinted on the great economic thinkers of that time, and were reflected in the vision that economists had of the system they sought to explain.

Many economists have sought to add an evolutionary component to economic theory. More than a century ago, Thorstein Veblen asked why economics—a discipline that analyzes the behavior of biological actors (humans)—was not an evolutionary science (1898). While his models emphasized the mechanics of the economy, even Alfred Marshall saw that the ultimate objective or "Mecca" as he described it for economics, was to model the economy as an evolutionary system (Marshall quoted in Nelson 1995).

The most prominent advocates of the evolutionary view of economic change are Richard Nelson and Sidney Winter. Their 1984 book, *An Evolutionary Theory of Economic Change*, posed a new view of economics. Nelson and Winter's evolutionary theory departs from the neoclassical approach by noting that firms are now just profit maximizers and that the economy is not always in equilibrium (Nelson 1981). The evolutionary model sees firms as wanting to maximize profits, but being constrained in doing so by the limits of what they know and by the habits they have acquired from their previous experience, what Nelson and Winter call organizational inertia.

Nelson and Winter do not assume that economic actors have perfect information and that they always make rational, profit-maximizing decisions. Instead, they suggest that economic actors, particularly business firms and their managers, are creatures of routine. They formulate and follow certain beliefs and behaviors, and pursue them as long as they continue to be successful. Businesses change their routines only when they fail to work (and some do not change them at all, and go out of existence).

As firms revise their routines, they undertake search processes to find or develop new routines. Typically, these search processes are not the open-ended profit maximizing envisioned by classical economic theory. Businesses are constrained in their search for new routines and most often look for new routines that are similar to the ones that they have already adopted. Finally, the economy functions as a selection environment. Over time it selects successful routines and marginalizes or eliminates less successful ones, in the same way biological environments select successful species.

In this evolutionary view routines are the equivalent of the economy's genetic material. Over time the economy selects businesses that have DNA that is well adapted to the existing business environment; routines that don't lead to successful behavior are eliminated from the gene pool. Continuing the analogy, though, evolutionary economics is Lamarckian, in that the environment can produce changes in businesses routines, which may in turn be passed on to successor businesses.

Thus, unlike the neoclassical theory, which has a difficult time explaining technological change, evolutionary theory deals with it explicitly. Firms start out with a set of routines, they explore variations in those routines, and their choices of new routines are shaped by past experience and their current competitive environment.

In the view of the evolutionary economists, change isn't the smooth and continuous adjustment at the margin, but is rather the abrupt and often uneven displacement of the one technology by another. Economic growth is a dis-equilibrium process, and as the competitive environment changes, development and improvement of new techniques and changes in markets cause some

firms to grow and others to shrink. Economies move ahead by successively generating new experiments and trials. A critical policy implication of this work is that encouraging experimentation and learning is essential to economic progress. A corollary is that a diversity of firms and institutions helps encourage and sustain experimentation (Nelson and Winter 1982).

Such evolutionary theory is closely related to path dependence. As Arthur points out, the non-linear qualities of increasing returns models of the economy have distinct parallels to the evolutionary theory of punctuated equilibrium (Arthur 1989). Because development is path dependent and the future cannot be predicted with any precision, business managers will have to emphasize adaptive behavior rather than optimization (Arthur 1996).

3. Creative Destruction is an Intrinsic Part Of Economic Progress

The conventional view of economics, crystallized by Alfred Marshall in the late 19th century was of the economy as a well-balanced system, always tending toward equilibrium. All of the forces acting on the economy generated signals or reactions that tended, over time, to push the economy toward an optimal state. A shortage of some particular good or service was associated with a rise in its price, which in turn called forth additional resources to produce it, ultimately triggering a greater supply and a reduction in its price. The view of economic change afforded by this model of the economy is one of smooth and continuous adjustment.

This view was challenged by Joseph Schumpeter, who argued that economic change was almost exactly the opposite: abrupt and discontinuous, rather than smooth and orderly. Schumpeter proposed that the search for higher than normal profits (quasi-rents, in economic jargon) led individuals and firms to innovate, to seek unique new practices and technologies. New products, almost by definition, give the businesses producing them a monopoly, if only a temporary one, and enable firms to earn higher profits until their product is successfully imitated by a competitor or displaced from the market by yet another new product. New businesses, with new ideas, changing the definition of markets, not simply lowering the price of some commodity, are the driving force behind change.

In this view, economic change is not the result of slow movement from one equilibrium to another, but is driven by the pursuit of the quasi-monopolistic profits that accrue to innovators. Economic change is propelled by the succession of technologies and practices that destroy old, inefficient arrangements as newer more efficient ones are created. New ideas are frequently created by new firms: the business that builds the first railroad is seldom the business that previously operated the stagecoaches (Schumpeter 1934). New businesses develop new ideas that displace the old ones. The result is what Schumpeter calls “creative destruction.”

Paul Romer echoes Schumpeter’s argument about the disruptions inherent in economic progress. We achieve higher productivity by instituting new processes, procedures and organizations that invariably displace old ones. The displacement produces real losses to those whose jobs or investments were tied to old ways of doing things, but absent this creative destruction, there is no technological improvement. Romer offers a metaphor drawn from physical training. Swimmers work to improve their speed by a combination of physical training and modifications to their technique. Using any given technique, once a swimmer has achieved a high level of physical conditioning, it is no longer possible to generate improvements in performance. The only option

is to modify the technique. But modifying a technique almost always produces a short-term decline in performance as the swimmer struggles to become as precise and effective with the new stroke as she was with the old (Romer 1994a).

Romer maintains the same tradeoff—short-term dislocation to learn techniques that are ultimately more efficient "no pain, no gain"—applies with equal force to the economy. Rearranging the economy to produce new goods or services, means some of the firms, workers, and equipment used in the current production will be displaced.

Most of Romer's work focuses on the long run: how much economies grow over periods measured in years, not the quarter to quarter fluctuations that get media attention. But New Growth Theory also has important implications for how we view business cycles. Recessions are in large part a period of time in which the job losses caused by destruction of the old are concentrated, and for that time exceed the job gains from the ongoing creation of the new.

Schumpeter and his fellow Austrian economists maintained this view of the need to tolerate, even welcome dislocations, even in the face of the Great Depression of the 1930s. Their view was that the depression was a natural, even beneficial process of change that shouldn't be interfered with, and that if it was, future efficiency would suffer. Romer has made a similar argument about recessions: layoffs and downsizing in recessions represents, in part, a clustering of the job destruction occurs when the vulnerabilities of technologically weak firms are exposed by declining markets (Romer 1994a).

The economy is in a continuous state of upheaval, with new businesses being created, existing businesses expanding (and contracting) and other firms failing. While this occurs even in good times, there is evidence that the process of failure and contraction is even more pronounced in recessions (Davis, et al. 1996). In Romer's view, much of this job destruction is part of the natural process of replacing outmoded technologies. Businesses that are marginalized by technological change may continue to function in good economic times, but are too weak to weather recessions, resulting in increased rates of layoffs and business closures.

While he was skeptical of those who argued that we would run short of the new ideas needed to advance the economy, in his later work Schumpeter became pessimistic about long-term prospects for growth. He feared that gradually capitalism would sow the seeds of its own destruction, as the rising scale of business replaced entrepreneurs with bureaucrats, diminishing the social support for innovation. Over time, he feared, established firms and industries would use their size and political power to win subsidies and regulations discouraging change, undercutting the incentives and opportunities for new entrepreneurs to unleash further gales of creative destruction (Schumpeter 1942). The surging growth of venture capital, and the rapid ascendance of new, technology driven corporations—the Microsofts, Intels, Amazons, Cisco Systems and thousands of dot.coms—seems however to vindicate Schumpeter's original optimistic views about the dynamism of entrepreneurs.

Creative destruction has a straightforward policy implication. Efforts to maintain the current arrangements of firms, markets and technologies may have the effect of retarding the development of more efficient and sustainable activities. Places seeking economic development need to assure that they are good locations for the development of new ideas, and often the

formation of new firms, if they are to be able to succeed in an increasingly global, knowledge-based economy.

B. Institutions Matter

> The problem with the classical description of laissez-faire is its suggestion that the best of all possible arrangements for economic affairs has already been discovered and that it requires no collective action. The lesson from economic growth is that collective action is very important, and that everything, including institutions, can always be improved (Romer 1993b, p. 388).
>
> The most important job for economic policy is to create an institutional environment that supports technological change (Romer 1994a, p. 21).

Are governments obstacles to economic growth or instigators of growth? Is the government that best befits the economy one that gradually withers away, or a strong one? Much economic theory gives the impression that governments are needed only when markets won't work, to address market failures, or provide public goods like national defense, and to achieve purely social aims, like taking care of the poor and elderly. Governments that do more than the minimum, the conventional wisdom goes, sap the economy of its strength. New Growth Theory gives us a new view of the role of institutions in creating the necessary conditions for growth in an economy driven by new knowledge.

What are institutions and why should they matter? If we think of the economy as a game, institutions are the rules of the game and the processes by which rules are determined and enforced. Formal rules, like constitutions, statutes and regulations, and governmental bodies, like courts and legislators, are institutions. So too, are informal rules that shape and limit transactions, like common business practices, cultural attitudes and values, and reputation, and the social constructs that guide and enable interpersonal and business relations.

History influences the pace and trajectory of knowledge creation. But knowledge creation is not purely the product of market forces. Non-market forces, particularly institutions can also influence what kinds of knowledge are created. A number of economists have begun to consider the role that different institutional arrangements play in economic development.

1. Institutions Shape the Incentives for the Creation Of New Knowledge

Economic historian Douglass North won the Nobel Prize in Economics in 1993 for his work on the role of institutions (broadly defined to include governments, culture, and a range of non-market organizations) in shaping the prospects for economic growth. North observes that in all of human history, successful, rapidly growing, wealth-creating economies have existed for only a few centuries. The story of most of our civilizations (and most of the Third World today) is one of social systems that only sporadically meet the basic needs of their populations, and which regularly fail to generate sustained economic progress.

Traditional neoclassical economic analysis deals chiefly with the allocation of scarce resources among competing ends at any point in time. How can societies most efficiently produce and

distribute goods and services to meet the desires and needs of their diverse populations? The general answer provided by theory is that unfettered price auction markets will be the most efficient system; producing the greatest good for the greatest number of people. The chief role of government in this view is to assure that there is a fair and effective system for defining and enforcing property rights.

The problem with neoclassical theory, North argues, is that it fails to explain how successful economies come into being, and how they develop over time. Most societies throughout history have gotten stuck with a set of institutions that failed to evolve the kinds of beliefs, behaviors and practices that allowed the development of a modern economy. Modern societies not only have very different economies than did more primitive societies, but different, and far more complex sets of institutions as well.

The cumulative learning of societies, reflected in culture and the shared mental models of how the world works, guide people's interpretations of economic and political problems and opportunities. Beliefs about the value of new knowledge, risk taking, and the trust in social institutions influence the rate and type of economic growth in a society. The structure of incentives in society is shaped by institutions, which means that ultimately the effectiveness of markets is dependent on collective, political processes. Markets alone cannot produce the set of conditions needed for the efficient function of a market economy (Olson 1996).

Over time, the problems that societies face change. Population growth, war, disease, technological change and other factors change the optimal economic arrangements for any society. In the 18th century, economic activity was organized largely at the family and individual level. Extended families ran businesses, one's children provided old-age support, and most people worked for themselves. Absent institutional innovations like the private corporation, social security and unemployment insurance, individuals would find it much more difficult to organize and participate in large-scale economic activity than they do today.

One reading of neoclassical economics, frequently reflected in political discourse, is that government actions that do more than specify property rights invariably hinder the efficient operation of markets. But if effective institutions play a central role in enabling progress, this creates the opportunity for improving government and other institutions as a way of promoting development.

Many important institutional innovations deal with the creation and diffusion of knowledge. Some of these institutions, like patents and copyright law, have relatively long histories. Universal public education is a relatively recent development. So too are public land grant universities, peer-reviewed academic research and public-private research partnerships. As Paul Romer points out, there are many conceivable sets of institutional arrangements that can be developed to encourage the further development and deployment of economically valuable new ideas (Romer 1993b).

2. Dynamic Adjustment to Changing Circumstances is Required for Continuing Progress

Not only are institutions important to the effective functioning of an economy at any point in time, institutions have to change *over time* to produce the incentives and rules required by new

markets and technology. The ability of institutions to adapt to the changing economic situation, and to develop new rules and practices to guide transactions shapes the ability of economies to continue to progress.

North argues that it is this *adaptive* efficiency, the ability of economies and institutions to change over time to respond to successive new situations—and not static efficiency, the optimization of the allocation of resources at any given time—that is the critical factor shaping economic development. North explains:

> Adaptive efficiency . . . is concerned with the kinds of rules that shape the way an economy evolves through time. It is also concerned with the willingness of a society to acquire knowledge and learning, to induce innovation, to undertake risk and creative activity of all sorts, as well as to resolve problems and bottlenecks of the society through time. We are far from knowing all the aspects of what makes for adaptive efficiency, but clearly the overall institutional structure plays a key role to the degree that the society and the economy will encourage the trials, experiments and innovations that we can characterize as adaptively efficient. The incentives embedded in the institutional framework direct the process of learning by doing and the development of tacit knowledge that will lead individuals in decision-making processes to evolve systems that are different from the ones that they had to begin with (North 1990, pp. 80-81).

Traditionally, economics focuses on allocative efficiency—the allocation of scarce goods and services among competing ends. The typical definition of allocative efficiency is "pareto optimality"–there exists no situation in which one person can be made better off without making someone else worse off). But efficiency in allocation doesn't necessarily imply efficiency in adaptation.

One critical element in adaptive efficiency is the tolerance for new ideas. As Schumpeter observed, change often entails the creative destruction of the existing economic and political order. The willingness of societies to tolerate new ideas that challenge the current arrangements of business and government has varied over time, and still varies considerably among (and within) nations. In a historical sense, the openness of the West to new knowledge in the Renaissance and the Enlightenment produced the new ideas that led to the industrial revolution; the particular institutional arrangements of the United States (the Constitution, the interstate commerce clause) led to the development of a national economy. Similarly, among nations today, the relative openness to new ideas in some nations (Singapore, Taiwan) may have much to do with their recent economic success.

Governments have a crucial role to play in setting up the right structures for economies to evolve over time. Many of the most critical changes will deal with the incentives for knowledge creation. As technologies change and economies grow, our institutions will continue to need to devise new arrangements and solutions for economic problems, from allocating the electromagnetic spectrum to refining the law governing patents (Thurow 1999).

New Growth Theory emphasizes the central role that new ideas play in driving economic progress. The careful study of history and contemporary international comparisons of

development highlight the role that new ideas for arranging institutions can play in shaping the direction and pace of economic development.

C. Place Matters

> "As the world becomes more and more closely integrated, the feature that will increasingly differentiate one geographic area (city or country) from another will be the quality of public institutions. The most successful areas will be the ones with the most competent and effective mechanisms for supporting collective interests, especially in the production of new ideas."(Romer 1992, p. 89).

Idea creation, new business development and economic change all happen in specific places. The world is diverse and not homogenous in its characteristics. While much of the theorizing about economic development looks at differences among nations, economic differences within nations are often equally striking. Globally competitive firms in any given industry are not only found in particular nations, but are frequently concentrated in particular regions within those nations, often in the same city (Porter 1990).

Differences among places are particularly important in thinking about knowledge spillovers, which as we have seen, are at the heart of the New Growth Theory. Spillovers occur because knowledge is non-rival and not completely excludable, meaning that some of the benefits of new ideas flow to persons or economic actors other than those who create the new knowledge. At the scale of the whole economy these spillovers provide increasing returns, which drive the processes of growth. Spillovers also happen in particular places, with the result that the New Growth Theory has definite implications for the geography of economic activity.

Alfred Marshall first made the connection between knowledge spillovers and local economic development. Noting the agglomerations of or clusters of industries in particular locations, Marshall observed than in addition to the advantages of labor force pooling and access to specialized suppliers, having a group of firms in a similar activity in a particular location, like Sheffield's steel district, meant that knowledge was in the air (Marshall 1920).

Interest in Marshall's arguments about the external economies of knowledge spillovers was heightened in the 1980s, following a number of studies of small but industrial districts in northern Italy. Dense clusters of small firms, typically located in a single community, managed to compete successfully in international markets by specializing in the production of certain products, tiles, fashion apparel, and industrial machinery. Careful studies of the development of these districts highlighted the strong networks, social linkages and information flows among the producers (Piore and Sabel 1984).

At the aggregate level, New Growth Theory usually addresses the means of the flow of new information in terms of openness to foreign investment (Romer 1992), or foreign trade (Romer 1994b). Whether and to what extent ideas can move freely from place to place is an issue of considerable importance to shaping knowledge spillovers.

Not everyone agrees that knowledge spillovers are critical to explaining the existence of clusters. Paul Krugman has constructed an elaborate theoretical model of industrial location that produces

industrial agglomerations solely as a product of labor market pooling behavior: firms and workers find it profitable to seek out locations where each are found in abundance, leading them to converge on and cluster in locations that have an early lead in a particular industry (Krugman 1991). Krugman also argues that because agglomeration is fairly common in all industries, including low-tech manufacturing, one need not even invoke knowledge spillovers to try to explain clustering—the implicit assumption being that knowledge spillovers are unimportant except in high technology. But as Edward Glaeser points out, Krugman's work shows that a clever theorist can model industry clusters without knowledge spillovers, but it isn't clear why one would want to ignore the kinds of face-to-face interactions that are such an interesting and integral part of cities (Glaeser 1999).

1. Knowledge is Partly Codifiable, and Partly Tacit

The advent of increasingly sophisticated high capacity communications technologies, particularly the Internet, reinforces the perception that information can be moved costlessly from place to place. Popular books have proclaimed the "death of distance" and led some to predict geography, borders, and time zones are all rapidly becoming irrelevant to the way we conduct our business and personal lives (Cairncross 1997).

But if we look more closely, it's apparent that even the current revolution in technology will not completely erase the importance of distance to knowledge spillovers. To understand why, it is helpful to divide knowledge into two types, codifiable knowledge—that which can be written down—and tacit knowledge—which is learned from experience and can't easily be transmitted from one individual to another. Credit for the distinction between these two types of knowledge is generally given to Michael Polanyi."(Polanyi 1967). Codifiable knowledge is blueprints, mathematical formula, operations manuals, and tables of statistics, organization charts and facts. Tacit knowledge is how to hit a baseball, ride a bicycle or know how to work with a specific group of people on a team. At key part of our knowledge is tacit in the sense that we can figure out whether to safely pass another car on a two-lane road without stopping to solve the system of simultaneous equations needed to prove a that a collision will not occur (Dosi 1996).

The distinction between tacit and explicit knowledge has drawn increasing attention among those studying business and the economy. Management experts studying innovation and competitive strategies of Japanese manufacturing firms noted the role of the development of tacit knowledge as a key step in designing new products. One of the keys to successful product development has been encouraging employees to understand and develop their tacit knowledge of particular problems and their solutions (how to knead bread) and then to work to translate and codify this information so that it can be used by the entire organization (to design a bread making machine) (Nonaka and Takeuchi 1995). Acknowledging the economic importance of tacit knowledge requires little more that admitting that it requires more than a good accent and a copy of *LaRousse Gastronomique* to operate a successful French restaurant.

While the distinction between tacit and codifiable knowledge is a useful one for thinking about knowledge spillovers, it is useful to recognize that knowledge can be transformed from one type into the other. Economic forces prompt firms to undertake the steps (developing procedures, training, evaluating) needed to achieve this transformation.

2. Tacit Knowledge is Less Mobile

Recognizing the difference between tacit and codified knowledge helps incorporate geography into the knowledge economy. If we think only about codifiable knowledge, it is increasingly difficult to visualize any barriers to the easy diffusion of new ideas throughout the globe. As the pundits tell us, anything that can be written or digitized can easily be put on the Internet and be made freely available to the large (and still rapidly growing) fraction of the world's population with Internet access.

Tacit knowledge is clearly different. Because it is embedded in the minds of individuals and the routines of organizations, it doesn't move easily from place to place. Similarly, a base of tacit knowledge is frequently a pre-requisite for making use of any particular bit of codified knowledge.

The distinction between codifiable and tacit knowledge helps explain why technology doesn't completely erase the importance of proximity in transmitting ideas. Simply having access to codifiable information doesn't mean you have knowledge. A formula specifying the solution to Fermat's last theorem—a centuries-old mathematical puzzle—would be information, but it wouldn't be knowledge unless you were one of the few hundred mathematicians who possessed the tacit knowledge to understand it (Dosi 1996).

Although they haven't always specifically acknowledged the distinction between tacit and codifiable knowledge, many economists have incorporated this insight into their analysis of economic geography. Edwin S. Mills noted that some types of incomplete or ambiguous information cannot effectively be communicated in writing or through more formal types of communication, but can be addressed much more easily in face-to-face settings (Mills 1987). Robert Lucas looked at the economic rationale for cities and concluded that, "If we postulate only the usual list of economic forces, cities should fly apart. The theory of production contains nothing to hold a city together. A city is simply a collection of factors of production: capital, people and land - and land is always far cheaper outside cities than inside. Why don't capital and people move outside, combining themselves with cheaper land and increasing profits?" (Lucas 1988, p. 38) The answer is that knowledge spillovers from the human capital in cities provide higher productivity that holds cities together.

Empirical data support the notion that knowledge creation tends to be quite localized. Studies of the patterns of patent activity in Europe, for example, find that innovative activity, measured by new patents issued, is considerable more concentrated that economic activity (Caniels 1997). Audretsch and Feldman, who examined data on new product innovations in the U.S., found that they were most highly concentrated in a few regions in those industries in which new knowledge plays an important role (Audretsch 1998).

The empirical analysis of knowledge flows within and across nations strongly confirms the insights of this theory. Unlike capital expenditures and employment patterns, knowledge flows leave few measurable traces for analysts. One of the few indicators of knowledge spillovers is patent citations. One leading study found that cited predecessor patents were about five to ten times more likely to come from the same metropolitan area than were similar patents from a control group (Jaffe, et al. 1993). A cross-national study of the diffusion of innovations found

that technological knowledge is to a substantial degree local, not global, and that the benefits from foreign knowledge spillovers declined with distance on average, a 10% higher distance to a major technology-producing country such as the U.S. was associated with a 0.15% lower level of productivity (Keller 2000).

As a result of the interdependence between codifiable and tacit knowledge, even explicit innovations like those covered in patents don't flow freely from one nation to another. Frequently, in order to take full advantage of the insights provided in a patented (codified) invention, one needs also to have the complementary tacit knowledge to apply it to a particular product or process. One analyst concluded that successful imitation requires the same kind of investments in research and development as are required for innovation in the first place (Pavitt 1992).

Much as there are national innovation systems, a number of geographers have begun studying regional innovation systems. Knowledge is neither evenly distributed across nations nor equally accessible in every location. Although the boundaries of regional innovation systems aren't always clear, research tends to show that they conform most closely to the boundaries of particular metropolitan areas (de la Mothe and Paquet 1998). Despite the fact that knowledge flows most easily to nearby firms, economic benefits do not flow automatically to the regions where research occurs. To take advantage of academic research, a region also needs to have a local industry base that makes use of the ideas; otherwise they are likely to flow to other, established industry centers (Fogarty 1999).

3. Diversity and Specialization Shape Knowledge Spillovers

> Our remote ancestors did not expand their economies much by simply doing more of what they had been doing: piling up more wild seeds and nuts, slaughtering more wild cattle and geese, making more spearheads, necklaces, burins and fires. They expanded their economies by adding new kinds of work. So do we. Innovating economies expand and develop. Economies that do not add new kinds of goods and services, but continue only to repeat old work, do not expand much nor do they, by definition, develop (Jacobs 1969, p. 49).

For several decades, the iconoclastic urbanist, Jane Jacobs has argued that cities play a decisive role in economic growth. Not an economist by training, but rather a shrewd observer of the urban environment and reader of history, Jacobs maintains that new knowledge created in cities drives human economies and progress. In two books, *The Economy of Cities* (1969) and *Cities and the Wealth of Nations* (1984), Jacobs describes the process by which cities generate new forms of work. In particular the scale of cities and their diversity of inhabitants creates the interactions that generate new ideas.

In Jacob's view, the diversity of economic actors within cities, and their high levels of interaction promote the creation and development of new products and new technologies, or in her terminology "new work" that is the source of development (Jacobs 1969). At the crossroads of trade, cities promote the mixing of a wide range of people, ideas, and products, generating new work, and triggering productivity and growth. Economic development is therefore an urban

process. Rural development hinges on knowledge creation in cities not on improvements in the productivity of resource-based industries.

Jacobs challenges the popular view that modern cities resulted from rural agricultural productivity. She begins at the beginning. How did early man move from a nomadic, hunter-gatherer existence to permanent settlements and ultimately cities? Many have thought some breakthrough in agricultural productivity made it possible to settle in one place and live off the cultivation of plants (and animals) in a small area, rather than continuously roaming in search of food. Cities arose, in this view, on the shoulders of agriculture. Jacobs disputes this. In her imaginative tale of how things could have happened, she describes the development of a settlement she calls New Obsidian, which begins as a place of assembly for nomadic groups, where bartering of diverse commodities and crafts, leads to the establishment of a permanent settlement. The settlement then becomes a place, not just for trade, but also for animal husbandry, inadvertent cross-pollination of grains, the refinement of crafts and tool making, and ultimately increasingly sophisticated production. In Jacobs' story, the creation of "new work" in cities leads to higher productivity in agriculture and stimulates development.

What began in New Obsidian continues in cities to this very day. Large cities juxtapose people with a wide variety of knowledge and experience in a range of economic interactions. These interactions result in new, different and frequently better ways of doing things, or in Jacobs' terminology "new work." Organizing to undertake the new work stimulates further changes that reinforce the growth of the city. Interaction in cities drives the process of inventing new things, and also creates the systems needed to make these new inventions widely available, resulting in economic growth, initially in cities, and then spreading through the whole economy.

Although initially greeted with some skepticism in the academic community, Jacobs's views have begun to get increasing credence. University of Chicago economist and Nobel laureate Robert Lucas broadly endorsed Jacobs's view of the role of cities in the creation of human capital (Lucas 1988).

Statistical investigations of knowledge spillovers in urban areas have tried to quantify the relative importance of specialization (spillovers from the concentration of a particular industry in an urban location) and diversity (spillovers from having a range of different industries). Jacobs emphasizes urbanization economies, the advantages stemming from the greater diversity of activities in larger urban areas. Same-industry spillovers, or localization economies, are often called "Marshall-Arrow-Romer" externalities, acknowledging Marshall's discussion of spillovers in industrial districts, Arrow's identification of the importance of learning-by-doing, and Romer's analysis of increasing returns. These are contrasted with urbanization externalities, which are the spillovers from diversity, which are called Jacobs externalities.

Different studies have come to conflicting opinions about which types of spillovers are more prevalent. Early work by Glaeser (Glaeser, et al. 1992) and (Rauch 1993) emphasized the relative importance of urbanization economies. Later work by Glaeser (Glaeser 1997), however, underscores the growing importance of localization economies, as concentrations of industry in particular locations stimulate face-to-face learning. Similarly, Henderson found little evidence for positive impacts of diversity on productivity at the industry level, but found strong impacts to own-industry concentration, particularly in the same county (Henderson 1999).

4. Local Institutions and Cultures Shape Knowledge Flows

The economic literature of agglomeration looks only at the aggregate concentrations of firms in particular locations, and assumes that knowledge spillovers are a function of physical proximity. A variety of studies, though, suggest that culture and institutional factors influence knowledge flows among firms that are located close to one another.

While there are important variations in institutions and business practices among nations, there are also frequently significant regional variations within nations. A number of studies of industry clusters have pointed out the role of local institutions and business cultures in shaping knowledge creation.

Industrial districts often have their own culture and business practices. These features can encourage and promote cooperation among firms in production (reciprocal sub-contracting among small firms), in marketing (industry-wide market research and promotion activities) and other areas. Often groups of cooperating local firms work to influence local governments to provide a favorable regulatory environment, or to provide services that promote the industry's further development. All of these activities tend to enhance knowledge flows among local businesses.

Robert Putnam's comparative study of Italian regions argued that the flourishing of cooperative behaviors in successful industrial districts was in large part a product of a strong and effective civic tradition in these communities (Putnam, et al. 1993). An active, informed citizenry, open and responsive local governments, and widespread participation in community organizations formed "social capital" in northern Italian communities that enabled the commercial cooperation in industrial districts, and supportive public policy. In contrast, Putnam found that struggling regions in southern Italy typically lacked the civic engagement and norms of trust and reciprocity, and so had few industrial districts, and limited economic success.

According to Annalee Saxenian, California's Silicon Valley triumphed over Boston's Route 128 because of differences in the business culture of the two regions. In the late 1970s, Boston's Route 128 and Silicon Valley were of roughly equal size. But the late 1980s, Silicon Valley firms had dwarfed their eastern competitors; indeed, many Boston area leaders (DEC, Wang, Data General) were in serious trouble (Saxenian 1994). Saxenian emphasizes differences in business organization and strategy, social acceptance of risk taking, and inter-firm collaboration and labor mobility as key factors in shaping this outcome. She argues that Silicon Valley firms more quickly adapted to changing technologies and markets because firm's had more informal internal practices (supporting innovation), worked well with outside firms (enabling them to move more quickly), and that the region had more entrepreneurs and stronger networks (because people felt free to start their own firms). In contrast, firms in Route 128 were less collaborative and open, inhibiting innovation.

III. LESSONS FOR ECONOMIC DEVELOPMENT POLICY

The New Growth Theory has a number of practical implications for economic development policy. Most importantly, it reinforces the notion that creating new knowledge is the key driver behind economic growth, both for the economy as a whole, and for particular areas. It also emphasizes the role that institutions and policies can play in creating the circumstances for innovation and the diffusion of knowledge.

For state and local governments, New Growth Theory suggests five broad strategies:

- Economic strategies should focus on creating new knowledge, not just in universities and laboratories, but by businesses as well.

- States and communities are not powerless to influence their economic destiny. Positive feedbacks and chaotic development patterns of knowledge-based growth mean that some actions will have big paybacks. Even so, it will be difficult or even impossible to know what will work.

- The path dependent quality of growth means that even in an Internet economy, the opportunities for future growth will depend, in large part, on the current local base of knowledge and expertise, and communities should seek to build on this in their strategies.

- Ideas of all kinds, large and small, play a role in economic growth. In many ways, structuring businesses to encourage innovation by front-line workers is as important to the knowledge economy as undertaking scientific research.

- Economic development is not a zero sum game; knowledge-based growth can stimulate a self-reinforcing cycle, in which faster growth triggers additional knowledge creation, and more growth.

A. Creating Knowledge is Central To Economic Development

> Any proposal for sustaining or increasing the rate of growth must take careful account of these interactions [between the private marketplace and academic research] and must not treat science as if it operated in isolation. In particular, we must not presume that devoting more resources to the basic research end of the process will automatically lead to economic gains (Romer 1998).

A simple reading of the lessons of, New Growth Theory would be that we ought to work just at creating more knowledge. Much of the thinking about the role of research, particularly basic research, has reflected a linear model of technological change (Malecki 1997). Basic research (in universities) produces new scientific insights that in turn lead to applied research that refine the idea; development involves reducing the refinements to practical application, and then they are diffused into widespread use. For example, insights from sub-atomic physics eventually enable makers of computer disks to fit ever information ever more densely on magnetic disks.

Many in economic development believe in a geographic parallel to the linear model—that new industries invariably arise from nearby scientific research (Goldberg 1999).

But the relationship between science and technology is actually not one-directional, nor is it as passive as the linear model makes it seem. Scientific insights frequently stem from the need to solve practical problems or explain the observations gained from applying a particular technology in practice. As Romer has pointed out, the science of thermodynamics emerged from the learning associated with the tinkering inventors did to steam engines in the 18th and 19th centuries. If you believe in the linear model, it should have happened the other way around: scientists discovering the principles of thermodynamics and then inventors using this knowledge to build steam engines (Romer 1998). Practical experience is more than just a source of conundrums seeking theoretical resolution. Practical problems often challenge scientific inquiry. The scourge of smallpox prompted Pasteur to research microbes.

The many practical problems that workers and businesses face and solve each day are a source of new knowledge creation. Businesses and places that provide good environments for understanding problems and creating knowledge are just as important to the new economy as are those conducting scientific research. New Growth Theory suggests both that we should bolster basic research, and that we should do all we can to stimulate application of knowledge and learning by doing.

B. Strategic Opportunities Exist to Influence Economic Growth

The insights afforded by neoclassical economic theory offered very limited sets of policy advice to states and communities seeking to influence their economic destinies. Aside from making sure that private property was secure and that taxes were not too high to discourage productivity activity, about all economists advised governments to do was encourage "more schooling and more saving" (Romer 1992). In the traditional view, geographic patterns of economic activity are driven, in a deterministic way, by the distribution of natural resources and the efficient operation of markets.

In contrast, if we assume that knowledge creation is central to growth—that it is characterized by increasing returns, and leads to path dependent growth processes—small events at key times can reshape the direction of economic growth and the geographic pattern of economic activity. In this view, economic growth is not deterministic, but is chaotic, unpredictable and shaped by the choices made by economic actors.

Knowledge spillovers shape these chaotic patterns of development. If the spillovers from knowledge creation happen more quickly within countries than among them, this produces a situation in which countries can create a comparative advantage for particular industries (Grossman and Helpman 1990). Countries, regions or cities that are among the first to develop a particular industry may benefit from the positive feedbacks or increasing returns that encourage the industry to become more concentrated in a particular location, resulting in an enduring pattern of economic activity.

Many economists will admit that small intentional actions can have dramatic long run effects. The creation stories of Silicon Valley, one of the most important knowledge-creating industrial

agglomerations, generally highlight the importance of one man, Fred Terman, Dean of the Electrical Engineering School at Stanford in the 1930s, in encouraging and supporting the formation of new firms. While they may be comfortable acknowledging that a university official might consciously do something that would change the direction of the local economy in a favorable way, economists are almost universally skeptical of the public sector's ability to make similar decisions (Krugman 1994).

Whether policymakers are always savvy enough to make similar good decisions is an open question. Theorists bristle at the notion that New Growth Theory can be used to justify substituting political decisions for those of the marketplace. While some policies (big technology projects link the breeder reactor and coal gasification) have been colossal failures, some government programs have produced enormous benefits (major advances in aerospace, computers, semiconductors and the Internet were all fueled by federal research spending and defense procurement).

C. Every Community has Different Opportunities

One of the paradoxes of the global economy is the increasing importance of the unique attributes of local communities. Local strengths are not only still important, but perhaps more important in a global economy.

> Indeed, falling communication and transportation costs and the reduction in barriers to trade and international competition make locational advantages of industry innovation even more significant, because firms with true competitive advantages are more able to penetrate other markets. While classical factors of production are more and more accessible because of globalization, competitive advantage in advanced industries is increasingly determined by differential knowledge, skills and rates of innovation, which are embodied in skilled people and organizational routines. The process of creating skills and the important influences on the rate of improvement and innovation are intensely local (Porter 1990, p. 158).

As more and more knowledge is codified (written down or digitized) and as advancing technologies like the Internet ease the dissemination of this codified knowledge throughout the world, businesses that rely on such knowledge face more competition. Any type of knowledge that is ubiquitous is unlikely to be a source of competitive advantage for a business, particularly one located in a high cost area. New knowledge, tacit knowledge, and ideas that are hard to communicate or imitate are a much more durable source of competitive advantage (Maskell 1998).

Underlying regional differences in behavior and culture shape the particular kinds of businesses that develop in a particular region. The English passion for gardening and the Italian love of motor-racing have helped trigger and sustain the development of world class industry clusters in both of those nations (Porter 1990). The relatively higher concentration of "beautiful people" in southern California and avaricious business people in New York City explain, in part, the development of the film and fashion industries in the former and finance in the latter (Krugman 1999). Many of the best opportunities to develop sustainable businesses in an increasingly

global market may emphasize the unique qualities of the place in which it is produced (Kilkenny 1999). While these regional variations in the environment are important for shaping local development, they also play a key role in overall economic progress. The ecological niches created by regional variety are important to reinforcing the processes of trial and experimentation that drive economic growth (Maskell and Malmberg 1999).

As Douglas North points out, the development opportunities of any region are constrained, not just by its economic situation, but by the its institutions, its political system, its belief systems and its past history (North 1995). This works against one-size-fits-all prescriptions for economic development. The set of feasible and effective policies and economic opportunities available to one economy are likely to be very different from those in another. One important role for planning should be to identify existing and emerging knowledge strengths on which future development is likely to build.

D. Everyone Can Create Knowledge

> . . . under the new system, firms will increasingly take advantage of each person's innate curiosity and willingness to experiment. . . . every worker in an organization, from top to bottom, can become a "knowledge" worker if given the opportunity to do so (Romer 1993a, p. 72).

While we tend to view economic progress as the product of the big scientific breakthroughs—the wheel, the steam engine, and the computer chip—it is equally true that millions of small innovations also drive economic growth. Many productivity improvements come from the application of fairly simple ideas in bold or novel ways: Federal Express builds an overnight parcel service, Frito-Lay develops an enormously efficient distribution system, Toyota slashes inventory and raises quality by using lean production and just-in-time deliveries. Most of the economic gains from technological breakthroughs (steam engines, electricity, lasers) are realized only decades after their discovery or initial demonstration, and only after a considerable amount of further refinement, innovation, and complementary changes in the organization of economic activity to realize the full benefits of the technology.

The scope for the improvement of products and processes is enormous. As Paul Romer pointed out, there are far more useful ideas and inventions to be discovered than human beings will ever be able to conceive, much less produce. A key element of economic progress, underscored by the evolutionary theorists, is having an economic system that generates the maximum number of trials or experiments that lead to the discovery of economically valuable new ideas. Limiting the production of new ideas to just a small fraction of a company’s employees necessarily limits the amount of experimentation and knowledge creation that can occur.

One result of this observation is that many private companies are explicitly restructuring their management systems to give all workers, including front-line workers a broader array of responsibility, including responsibility for the development of new ideas. Case studies of the automobile industry underscored the importance of worker led teams and continuous innovation and quality improvement, practices pioneered in Japan and now emulated by the best North American manufacturers (Womack, et al. 1990). Careful quantitative studies of new forms of

work organization tend to confirm the role of high performance work organization in raising productivity (Black and Lynch 2000).

E. Macroeconomic Policies Can Trigger Increasing Returns Growth

Much of the debate about New Growth Theory deals with the long-term growth potential of the economy. Some argue, however, that New Growth Theory has important implications for short run macroeconomic policy decisions. Has the shift to a knowledge-based economy fundamentally changed the rules that should guide the Federal Reserve Board and other policymakers in deciding how fast the economy can grow without inflation?

The excellent economic performance of the U.S. economy during the 1990s has led to a considerable amount of speculation as to whether computers and information technology have fundamentally changed the economy. Only a few years ago most economists believed that an economy that grew fast enough to produce unemployment rates lower than six percent would trigger increasing inflation.

In addition to enjoying a sustained period with unemployment rates below six percent and very low levels of inflation, the U.S. economy has continued to grow robustly years into an economic expansion. GDP growth has averaged four percent annually in 1997, 1998 and 1999. A leading cause of the continuing increase in economic growth has been the growing productivity of U.S. workers. Productivity growth which average about 3 percent annually in the period 1948 to 1973, slowed to about 1 percent per year between 1973 and 1989 (Bluestone and Harrison 2000). During the 1990s, average productivity growth in the has rebounded sharply, growing to more than 2.5 percent annually between 1995 and 1998, and more than 3 percent in the year ending in the third quarter of 1999 (Bureau of Labor Statistics 2000).

Some take this as evidence that we are in a new economy, and that it is possible to enjoy higher levels of growth with low inflation, both due to the integration of the global economy (in which domestic firms price increases are held in check by the threat of loss of market share to foreign rivals) and due to the development of much more productive enterprises, thanks to computerization and information technology. Some experts have argued that the New Growth Theory provides a basis for believing that sustained growth can continue almost indefinitely (Kelly 1997).

A major reason for the success of the U.S. economy during the 1990s has been the Federal Reserve Board's willingness to keep interest rates low even in the face of low unemployment rates that many economists believed would trigger inflation. Indeed, even Chairman Alan Greenspan has alluded to the important role that technology, and the creation of new ideas plays in enabling continued economic growth with modest inflation (Greenspan 1997).

For a long time economists have been skeptical of claims that the economy can grow much faster. The consensus view has been that the "speed limit" for the U.S. economy is about 2.3 percent or 2.5 percent per year, and that at best we might be able to change that amount by a quarter of a percent or so (Blinder 1997). Recently some skeptics have conceded that productivity growth has accelerated, although they still maintain that it is too soon to label this a permanent change (Blinder 2000). The long-accepted "Phillips Curve" tradeoff between

employment and inflation has fallen from favor. While most economists don't believe in possibilities for unlimited growth, the experience of the 1990s is leading economists to become more optimistic. Some macroeconomic forecasters have increased their long-term estimates of the rate of U.S. economic growth (Karl 2000).

Paul Romer and two colleagues have developed a macroeconomic model that incorporates New Growth Theory. In particular, they argue that given the complementarity of investments, particularly in new technology, and the cyclical character of spending in research and development, business expectations about growth are likely to be self-fulfilling: So, for example, if businesses expect growth, they spend more on research and development and invest more, which triggers and sustains growth; the increasing returns associated with new technology can help make this process self-sustaining. On the other hand, if businesses are pessimistic, they may cut research and development spending and invest less, contributing to or aggravating an economic slowdown (Evans, et al. 1996).

The connection between increasing returns, expectations and the prospects for sustained growth have lead two economists, Barry Bluestone and the late Bennett Harrison to argue that macroeconomic policies should explicitly aim to achieve and sustain higher levels of growth. A high growth strategy, they reason, will encourage businesses to make further investments in research and development, and to make greater investments in productive new capital, increasing the rate of productivity growth in the economy, and raising incomes, wages and living standards in the process. Even a modest improvement in growth rates, from 2.3% per year to 3.0% would produce more than $3 trillion in additional economic output in a decade (Bluestone and Harrison 2000).

The recent economic evidence, while consistent with the argument that we can grow faster is far from conclusive. It may well be, however, that the advent of new technology may create the opportunity for much greater economic growth in the next few decades than we have experienced during most of the period after 1973.

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