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Faculté des arts et des sciences
Département de sciences économiques

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COMMUNICATIONS AND ECONOMIC GROWTH

Leonard DUDLEY

Département de sciences économiques and Centre de recherche et développement en économique (C.R.D.E.), Université de Montréal

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C.P. 6128, succursale Centre-ville
Montréal (Québec) H3C 3J7

Télécopieur (FAX) : (514) 343-7221
Courrier électronique (E-Mail) : econo@ere.umontreal.ca

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RÉSUMÉ

Au cours du dernier millénaire, chacun des trois siècles de croissance démographique rapide dans l'Ouest a coïncidé avec la diffusion d'une nouvelle technologie de communications. Ici, nous étudions l'hypothèse de Harold Innis (1894-1952) qu'il y a du feed-back à double sens entre de telles innovations et la croissance économique. Premièrement, nous étudions l'évidence historique. Deuxièmement, nous résumons les idées de Innis à l'aide d'un modèle formel. Enfin, nous simulons ce modèle et comparons ses prévisions avec l'évidence historique européenne. Les résultats suggèrent une explication technologique pour les longs cycles de la période 1000-1975 ainsi que pour le ralentissement économique mystérieux aux pays industrialisés après 1975.

Mots clés : croissance économique, communications, Europe, technologie

ABSTRACT

Over the past millennium, each of the three centuries of most rapid demographic growth in the West coincided with the diffusion of a new communications technology. This paper examines the hypothesis of Harold Innis (1894-1952) that there is two-way feedback between such innovations and economic growth. First, detailed historical evidence is studied. Second, Innis's ideas are translated into a formal model. Finally, the model is simulated and its predictions compared with European historical data. The results suggest a technological explanation for the long cycles of the 1000-1975 period and for the puzzling productivity growth slowdown in industrialized countries after 1975.

Key words : economic growth, communications, Europe, technology

I. Introduction

Visitors to Paris are generally taken to see Notre Dame Cathedral, the Louvre, and the Eiffel Tower; those who go to London usually do not miss Westminster Abbey, Hampton Court, and Big Ben. These buildings belong to Western Europe's legacy from three centuries of exceptionally rapid growth compared to the rest of the past millennium.[1] Unfortunately, neoclassical growth theory has no satisfactory explanation for the very long cycles that such evidence implies.

Some fifty years ago, the Canadian economic historian Harold Innis argued that these cycles are generated by dynamic feedback between a society's communications technology and its production system. Innis's writings on possible links between communications and economic growth have lain dormant since his death in 1952 (Dudley, 1995). Why might they be worth dusting off for a contemporary audience? A compelling reason is that they offer a possible explanation for prolonged periods of decelerating growth, such as the puzzling slowdown in productivity gains that occurred in industrialized countries during the 1970s and 1980s. In his writings, however, Innis failed to present detailed historical evidence to support the hypothesis of causal links between information technology and economic growth. In addition, he chose not to develop an internally consistent formal model. Moreover, he made no effort to generate quantitative predictions that could be compared with the historical record. The object of this paper is to make a first attempt at completing these three tasks.

The neoclassical theory of economic growth developed in the 1950s and 1960s predicted the gradual convergence of an economy to a steady-state rate of growth determined by the exogenous rate of technological change. Beginning in the early 1970s, however, all of the major industrialized economies experienced a sudden sharp slowdown in rates of total factor productivity growth compared to the immediately preceding decades. In the case of the United States, for example, average annual GDP growth declined from 3.72 percent between 1950 and 1973 to 2.32 percent between 1973 and 1984. Well over half of this decline remains

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[1] The exceptional centuries are the years 1150-1250, 1500-1600, and 1800-1900 respectively.

unexplained by neoclassical growth accounting, even when structural changes, crime rates, energy prices and factor-augmenting technical progress are taken into account (Maddison 1987, 679). Nor do recent models of endogenous growth offer much help in explaining the slowdown. They predict a *rise* in the growth rate over time due to the accumulation of knowledge and the widening of the market (Lucas 1988; Romer 1990).

A paradoxical feature of the productivity-growth slowdown of the 1970s and 1980s is that it coincided with very rapid innovation in information technology. Throughout this period, the integrated circuit, first developed in 1959, was reducing the cost of information storage by about 30 percent annually (Forester, 1987, 27). Was it simply a coincidence that a high rate of innovation in a communications technology was accompanied by a fall in productivity growth rates?

A look at other long periods of decelerating growth might provide a clue to a possible relationship between communications and growth. For the years prior to 1750, there are no reliable estimates of aggregate production for most western countries. However, more recent data from the nineteenth and twentieth centuries shown in Figure 1 indicate that growth of output tends to follow approximately the same cycle as population.[2]

[Insert Figure 1 about here.]

Accordingly, the data for demographic growth in Western Europe over the last one thousand years shown in Figure 2 may be considered an approximate indicator of swings in the rate of output expansion. From this very long-term perspective, a number of features stand out. First, it is evident that there have been three cycles, one from the beginning of the millennium to the mid-fourteenth century, another running from the renaissance until the mid-

[2] A possible explanation for the observed correlation is that a society will develop a long-term rule for dividing additional output between higher per-capita income and additional population. Jones (1987, 226) has suggested that because the frequency of natural disasters is lower in Europe than in Asia, European societies have tended to devote a smaller share of output gains to producing more children than their Asian counterparts.

eighteenth century, and yet another from then until the third quarter of the present century. Moreover, each cycle appears to have had three phases, an initial period of relatively slow growth, a second of acceleration and deceleration, and a final phase of very slow growth if not actual decline. Finally, the cycles differ from one another. Not only does their length decrease over time, from about 450 years to 300 years to about 225 years; but also the underlying rate of progress accelerates, from a barely perceptible rate of one-twentieth of one percent to three-tenths of one percent to about six-tenths of one percent.

[Insert Figure 2 about here.]

Neoclassical growth theory has no convincing explanation of such very long cycles; however, economic historians have tended to interpret them as the effects of innovation clusters in production and transportation technology. In the high middle ages, the iron plow, the horse-collar and the three-field system permitted a steady rise in agricultural productivity. In the fifteenth and sixteenth centuries, the compass and the lateen sail enabled ships for the first time to cross broad stretches of water at any time of year, thereby opening the world economy to western navigators. And finally, in the nineteenth century, the steam engine and new techniques for producing steel, textiles and chemicals generated a long rise in output (Mokyr, 1990; Cameron, 1993, 51-4, 99-103, 197-210). The principal difficulty with this explanation is that for almost a millennium this growth was confined to western Europe and regions settled by Europeans (Jones, 1987). Indeed, two centuries after the beginning of the industrial revolution, modern economic growth remained limited to a fifth of the world's population (Kuznets, 1966, 469). This simple fact suggests that there must be some other conditions that are necessary, and perhaps also sufficient, to generate accelerated growth.

Although neoclassical growth theory has difficulty explaining alternating phases of accelerating and decelerating growth, this phenomenon is an integral part of the theory of historical change developed by Harold Innis during the last years of his career. In *Empire and Communications* and the initial essays of *The Bias of Communication*, he developed a three-phase theory of the impact of a new communications technology on social institutions.[3] Nathan Rosenberg has set out the conditions that a theory of long cycles must satisfy. 'A technological theory of long cycles needs to demonstrate that [inventions, innovations, diffusion paths and investment activity] interact in a manner that is compatible with the peculiar timing requirements of such cycles' (Rosenberg, 1994, 68). Does Innis's theory fulfil these conditions?

To understand Innis's ideas on communications, consider a moment at which a single medium has come to dominate the communications system of a society. Innis argued that since the group that controls this medium will tend to charge a monopoly price for access to it, the high cost of information will encourage innovative activity. For example, in western Europe in the first centuries of the second millennium, the Church and its monasteries were able to monopolize access to the dominant medium of parchment, quill and Latin. As a result, in the late middle ages, paper, printing, and standardized vernacular languages were developed as components of an alternative, less costly medium (Innis 1951, 49-53). Despite the intense innovation of this initial phase, the economic impact of the new medium is likely to be limited because of the dominant group's efforts to block its diffusion (Innis 1951, 53-55).

Second, Innis proposed, if these attempts to innovate are successful, there will be a subsequent phase during which the new technology is diffused widely. Initial success will occur in marginal areas where the power of the controling group is weak. In the fifteenth century, for example, printing spread most widely in Germany, where political division made control over technology difficult (Innis 1951, 53). Subsequently, however, the new technique will challenge the previously dominant medium. It is during the phase of balance where two or more media coexist, that welfare will be highest.[4]

[3] Neill (1972) assessed Innis's writings on communications, evaluating them with respect to Innis's earlier historical research on the staple theory.

[4] Recently, De Long and Shleifer (1993) have found a positive correlation between the degree of political competition and the rate of population growth in European cities over

In the third and final phase of the cycle, the successful new medium attains a monopoly position. Innis suggested that each medium will have its own characteristics or 'bias' (Innis, 1951, 33). Parchment, with its weight and durability, produced a bias in terms of conserving information over time (Innis 1950, 7). However, paper being lighter, more easily transportable, and more perishable resulted in an 'obsession with space' (Innis 1951, 60). If the new technology is better adapted than the old to existing conditions, it will tend to be selected. Once the new medium has displaced the old, a new monopoly will be created and the cycle will begin once again (Innis 1951, 34).

In short, Innis's writings on communications seem to contain the essential elements for modeling very long growth cycles. But do these ideas constitute a theory -- a set of consistent statements that lead to falsifiable predictions? Previous attempts to assess Innis's final works have concluded that they contain no consistent causal structure (Neill 1972, 96; Christian 1977, 29). The remainder of this paper reexamines this question. The following section studies the historical evidence for a possible causal link from communications technology to economic growth with the help of a simple theoretical framework based on Innis's writings. Section III then confronts one of the major problems with Innis's theory of communications; namely, the role he assigns to monopoly in creating the incentives for innovation. An alternative mechanism is proposed in which one or more seminal innovations lead to overshooting by channeling subsequent technological change in a specific direction. Finally, section IV simulates this model over the very long run and compares its results with observed population growth rates for western Europe.

the period prior to 1800. Innis's theory of communications offers an explanation for this phenomenon: both rapid population growth and institutional competition are characteristic features of the second or diffusion phase of Innis's hypothesis.

II. THREE TYPES OF COMMUNICATIONS MEDIUM

This section compares the dates of major transformations in Europe's communications techniques with those of its periods of most rapid growth. In any society, the communications structure must accomplish several different tasks. One of Harold Innis's important contributions to communications theory was to note that each medium tends to be biased, able to do some of these tasks well and others less adequately. Innis contrasted two polar types of communications medium, one biased toward time and the other toward space.

A. Time, Space and Number

Innis argued that a heavy, durable medium was appropriate for the dissemination of information over *time*. Parchment, the medium of choice of the Church during the middle ages, is an example of such a medium. When he referred to dissemination over time, Innis was in effect saying that the cost of *storing* information is low, so that it can be transferred accurately from any moment to a later one. Parchment, Innis noted, did not perform very well in another important communications task; namely, the transmission of information over distance. Because of its high cost and weight, it was not appropriate for the routine administrative tasks of a large political unit.

An alternative type of communications structure described by Innis is based on a light but perishable medium. Such a medium, Innis argued, is biased toward dissemination over *space*. Papyrus, the medium of later antiquity, and paper, used in the West from the end of the middle ages, are examples of this type of bias (Innis 1951, 48). Here, it is evident that Innis was referring to the cost of *transmitting* information from the center of an administrative unit to its periphery.

Consider how these ideas might be expressed more formally. Assume a simple Ricardian production structure in which knowledge and fixed resources are combined to produce a homogeneous good. Output, y, under a particular medium, I, is equal to the resources

allocated under that medium, ℓ_I, divided by the number of resource units required per unit of output with that communications technology. If s represents the resource cost per unit of output when the communications system is based upon decentralized storage, we have

$$y_s = \ell_s / s. \qquad (1)$$

Consider now a competing medium whose costs are entirely transmission costs. Let t represent the resource cost of a unit of output under such a transmission-based medium. This type of centralized system is likely to have substantial fixed costs. Let α equal one plus the markup rate over variable costs that is required to finance the overhead of the medium. Since this fixed-cost markup per individual will decline as population, m, grows, output under such a centralized system is

$$y_t = \ell_t / [\alpha(m)t], \qquad \alpha(m) \geq 1, \ \alpha'(m) < 0. \qquad (2)$$

Although Innis devoted most of his attention to these two types of communications technology, based on storage and transmission respectively, he was well aware that this simple time-space dichotomy could not account for all of the major changes in social institutions in western history. In the introduction to one of his last essays, 'The problem of space,' he briefly mentioned an additional concept that he placed on the same level as time and space; namely, *number*.[5]

Might number be considered the basis of a third type of communications technology? If so, how would this concept fit into the structure that Innis designed to model space and time? At issue, Innis realized, is the complexity of the communication system. 'A complex system of writing becomes the possession of a special class and tends to support aristocracies. A simple flexible system of writing admits of adaptation to the vernacular but slowness of

[5] 'Gauss held that whereas number was a product of the mind, space had a reality outside the mind whose laws cannot be described a priori. In the history of thought, especially of mathematics, Cassirer remarked, "at times, the concept of space, at other times, the concept of numbers, took the lead"' (Innis: 1951, 92).

adaptation facilitates monopolies of knowledge and hierarchies' (Innis: 1951, 4). Thus when a complex system of communication is replaced by a simpler one, there is deeper penetration into the society. What was formerly reserved for an elite becomes accessible to a much wider segment of the population. The key issue is the cost of atomistic *reproduction* of information which must be sufficiently low to allow any two individuals to communicate with each other.

Consider, then, a third type of communications medium -- one that permits the reproduction of information among numerous pairs of comparably trained or equipped individuals. Let r represent knowledge costs per unit of output under this medium based upon atomistic reproduction. Assume further that there is a network effect of e for each possible bilateral link between a given individual and the m-1 other people in the society (see Katz and Shapiro, 1985, 1994). This network effect reduces unit knowledge costs per unit of output in the exchange network by $(m-1)e$. Then output under atomistic reproduction is

$$y_r = \ell_r \,/\, [r - (m-1)e]\ . \qquad (3)$$

B. Institutional Change in Western Europe

Within any given society, these three types of communications medium will tend to coexist, although their relative importance may vary considerably over time. Under what circumstances will large numbers of people abandon one system of communication and adopt another? Suppose that initially most of the people in a society are living under a system whose principal costs are transmission costs. For example, under the Carolingian Empire and the kingdoms that immediately followed it, the principal communications costs were those involved in the transmission of decisions from higher to lower levels in a hierarchy of mounted warriors, few of whom could read or write. The essential contacts were oral, between lords and their dependents. The emperor, for example, spent much of his time on a circuit that brought him periodically into personal contact with his principal vassals in each region of the empire (Ganshof 1971, 257-8; Reuter 1991, 86). As McKitterick (1989, 13) has

explained, in the Carolingian court of the eight and ninth centuries, Latin appears to have been used as both a spoken and a written language. However, until the eleventh century, it was the oral command of the ruler that took precedence, with written notes serving as a reminder for later recall of the content of the spoken language (Stock, 1983, 13).

From equations (1) and (2), people will be willing to give up such a system in order to adopt one based on decentralized storage if and only if

$$s/t < \alpha. \qquad (4)$$

In Figure 3, the ratio of storage to transmission costs per unit of output, s/t, is plotted on the vertical axis (the ratio of reproduction to transmission costs, r/t, is shown on the horizontal axis). The horizontal line EG represents the threshold between the transmission ('space') and storage ('time') systems. Technological change in the form of a downward movement across the line (at point a) leads to a movement from a transmission- to a storage-based information medium.

[Insert Figure 3 about here.]

A fundamental change of this sort appears to have occurred in western Europe during the eleventh century. From the year 1000 onward, there occurred in European society what Brian Stock (1983, 3) has described as the 'rebirth of literacy' as society passed from a mode of interaction in which oral communication took precedence to one in which written texts structured social interaction. About 1020 the papacy switched from papyrus to more durable parchment. From about 1050, it began to keep permanent registers of its activities. From the early eleventh century, nobles in both France and Germany began to use surnames, usually taken from their family's principal estate (Gies and Gies, 1987, 126; Reuter, 1991, 227). In civil administration, the Normans took the lead. Between 1085 and 1087, William the Conqueror undertook the first detailed survey of fiscal resources of a European state, a set of records that became known as the Domesday Book (Hallam, 1986, 19). By 1100, England under the Norman dynasty had acquired a permanent administrative structure based on written records, the administration of the fiscal and justice systems being placed in the hands of lay scribes (Stock, 1983, 38). Between the eleventh and thirteenth centuries, written forms of the vernacular languages began to be used with increasing frequency (Stock, 1983, 25). For the first time in centuries, cursive writing began to be used once more in order to accelerate the recording of information.

Consider next a second type of institutional change, in which individuals reject a communications system based on this type of decentralized storage biased towards 'time' in favor of a system based on atomistic exchange relationships biased towards 'number'. From equations (1) and (3), the necessary condition is

$$r - (m-1)e < s.$$

After division by t we have

$$r/t - \phi(m) < s/t, \tag{5}$$

where $\phi(m) = (m-1)e/t$ captures the importance of network externalities generated by increases in the number of users under a system of exchange.[6] In Figure 3, a movement from right to left across the threshold HE leads to this type of change in mechanism (see the point b).

A transformation in favor of a reproduction-based communications system occurred in the fifteenth and early sixteenth centuries. Around 1430 experiments with movable wooden characters were being carried out at Haarlem by a Dutchman named Laurens Janszoon Coster

[6] This distinction between individual access to decentralized stocks of knowledge and exchange between symmetrically trained individuals is perhaps the key to explaining the difference between the individualism of medieval Genoese merchants and the collectivism of contemporary Maghribi traders modeled by Greif (1994). If the Genoese merchants were among the few lay people in their society able to read and write, the cost of acquiring accurate information on other traders would be high, particularly if the latter were in distant cities. Among the Jewish traders with a long tradition of literacy, however, such information could circulate at a low cost even when distances were considerable.

(Chappell, 1970, 5). In 1455 Gutenberg and his associates used movable metal characters to produce a 42-line Bible. The effect of this discovery was to reduce the marginal cost of reproducing information on paper dropped to one three-hundredth of its former level (Eisenstein, 1980, 46).[7] For the first fifty years after the invention of the printing press, the diffusion of the new technology remained limited to those who could read and write in Latin.[8] By 1515, however, the appearance of texts in standardized printed versions of the spoken word had become sufficiently important for the papacy to impose censorship on all works translated from Latin into the vernacular (Hirsch, 1974, 90). In 1522, Luther began to translate the Bible from Latin into the high-German dialect spoken in the Saxon court. His insistence that his followers learn to read the scriptures printed in their native tongue served as a model for other Protestant leaders.[9]

The third type of change is from a communications medium based on atomistic reproduction to one based on transmission from a centralized point. From equations (2) and (3), the necessary condition for this change is

$$\alpha t < r - (m-1)e. \tag{6}$$

This condition is satisfied when the technology point of Figure 3 crosses EF at the point c.

Prior to the nineteenth century it was virtually impossible to reach large numbers of people simultaneously with a common message. Since hand-operated presses could produce only about 150 sheets printed recto-verso an hour, the circulation of periodicals had an upper limit in the low thousands. As a result, information tended to circulate slowly and within

[7] In the place of parchment, the new printing industry used paper, production of which had been introduced into Europe from China in the fourteenth century.

[8] It has been estimated that three-quarters of all texts printed in Europe before 1500 were written in Latin (Steinberg, 1955, 81).

[9] By the end of the sixteenth century, a majority of works were being published in languages other than Latin (Hirsch, 1974, 132).

sharply circumscribed circles.[10] The situation changed substantially in the first few decades of the nineteenth century. In 1814 *The Times* of London installed a steam-operated press developed by Friedrich Koenig capable of printing 500 sheets an hour; its circulation reached 5,000. In the following decades, there were numerous other improvements in mechanized printing.[11] Over the following century, further decreases in the cost of transmitting information rapidly to large numbers of people occurred with the invention of the telegraph, the telephone, and radio (Mokyr, 1990, ch. 6).

It may be seen, then, that over the past millennium there have been three major transformations in western Europe's communications system, each occurring at the beginning of a new cycle of economic growth. The diffusion of literacy in classical Latin written with a standardized script that began in the eleventh century was followed by rapid economic expansion in the twelfth and early thirteenth centuries. In the fifteenth century, the diffusion of printing with movable type began about a half century before Europe's population began to push beyond the level it had attained prior to the Black Death. In the case of the third logistic, it is less evident that the change in technology preceded the acceleration in growth. In Britain, industrialization began in the last half of the eighteenth century -- *before* the developments in communications described above. However, as Figure 1 shows, it was not until the first third of the nineteenth century that average annual growth rates of industrial production exceeded one percent in western Europe as a whole. It might therefore be argued that the change in communications was coincidental with the acceleration in output. When individual countries are examined separately, yet another pattern emerges: there is a rough

[10] At the time of the French Revolution, for example, there were no broadly based political parties; rather there were political clubs such as the *Jacobins* and the *Cordeliers* whose members were sufficiently few that they generally knew one another and were able to meet periodically.

[11] By the time of the July 1830 Revolution, the liberal daily, *Le Constitutionnel* had a circulation of 18,600, and the total circulation of the Paris newspapers exceeded 60,000 (Bellanger, 1969, 100). Protests by the liberal press against repressive decrees issued by the government of Charles X sparked a two-day insurrection that forced him to abdicate. Leaders of the press played a major role in the founding of two new political parties with broad support, the *parti du Mouvement* on the left and the *parti de la Résistance* on the right. Subsequent to 1840, the French state began to finance primary education (Cameron, 1993, 221).

correlation between literacy levels in 1850 and *subsequent* production growth in Europe (Cameron 1993, 219). By permitting a rise in literacy in the first half of the nineteenth century, the new media seem to have supplied a necessary input for the systematic application of knowledge to production that was to characterize the industrialized world after 1850.[12]

[12] North (1981, 172-173) also emphasizes the role of human capital in the 'Second Economic Revolution' of the later nineteenth and twentieth centuries (the first having occurred with the introduction of agriculture).

III. THE DYNAMICS OF INNOVATION

As soon as one attempts to understand *why* changes in communications technology might tend to precede long periods of accelerated growth, several gaps in the writings of Harold Innis become readily apparent. First, Innis did not detail clearly the process by which innovations are generated from an existing body of knowledge. Second, although the patterns of social change Innis described do appear to coincide with changes in techniques of communications, he failed to explain why innovations in this sector should be given any more attention than those in other areas such as agriculture, transport, or energy production. Finally, Innis's theory of monopoly does not provide a convincing explanation for the mechanism that triggers a new burst of innovation in the final phase of the life cycle of a communications medium. Each of these three issues must be addressed if Innis's ideas on communications are to be translated into a consistent theory of economic growth.

A. Innovation as a Directed Search Process

Turn first to the details of the innovation process. It is evident that for Innis innovation is triggered by a signal from the price system. What is not clear in Innis's writings is the process by which innovations emerge. He of course understood that new ideas generally require inputs from existing knowledge. For example, he described how the development of printing required the combination of four different techniques: the metal punch, an alloy with a low melting point, oil-based paint, and the screw press (Innis 1950, 173-174). To understand the process by which the existing concepts to be combined are identified, however, we must look elsewhere. Perhaps the most convincing account of how inventions arise was proposed over a decade after Innis's death by the Hungarian writer Arthur Koestler. In *The Act of Creation*, Koestler (1964) argued that innovations arise when existing ideas are combined in hitherto untried ways. Weitzman (1995) has recently formalized this process as a model of 'recombinant' growth. Economic growth occurs when the techniques resulting from successful crosses of old ideas replace existing ways of doing things.

In Weitzman's theory, innovation is modeled as a search process.[13] New ideas are discovered through the combination of existing concepts in ways that have not yet been tried. As an example, think of the combination of the goldsmith's punch and the wine press described by Innis. Only a fraction of such crosses, however, will be successful.[14] Moreover, the results of this search process are affected by randomly occurring events.[15] Accordingly, the rate of growth will depend on the success rate of new crosses that are attempted and on the number of spontaneously occurring random events.

All crosses are equally probable in Weitzman's formulation. There is therefore no direction to technological change in his model. In reality, however, some crosses are more likely to be tried than others. People may have explicit objectives in mind when they combine ideas, choosing those combinations that their experience suggests may most fruitful. Equally, they may use search routines or habits that arbitrarily exclude certain combinations. Let us suppose, following Innis, that research resources tend to be directed toward products or processes whose relative cost is high.[16] But suppose also that there is a lag between the appearance of a price discrepancy and a change in the way that search resources are allocated.

The resulting hypothesis of *directed search* provides a possible answer to the second question that has long troubled readers of Innis. Why should technological change in a particular sector, communications, be singled out for special attention? In criticism of Innis's approach, it might be argued that other types of innovations, for example, in food production,

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[13] Nelson and Winter (1982) were among the first to suggest that innovation should be thought of as a search process.

[14] For example, the cross between the steam engine and the horse-drawn cart failed because of the lower weight and greater convenience of the competing internal combustion engine.

[15] A famous example is the accidental contamination of Alexander Fleming's culture by a mold that, he discovered, yielded the antibiotic penicillin.

[16] For example, in the fifteenth century, as described above, there was a conscious redirection of research in information processing away from storage technology to reproduction technology in order to overcome the high cost of reproducing information.

in transportation, or in energy production, have been at least as important as those in communications for the progress of humanity.[17]

But if technical progress comes from the combination of old ideas in new ways, the crucial factor in determining the rate of productivity growth may well be the cost of bringing existing concepts together. If so, then language may well have been a precondition for agriculture, writing for the expansion of commercial activities, and printing in the vernacular for the development and diffusion of industrial techniques. In short, communications media are arguably the most fundamental of 'enabling' technologies in that they determine how other, secondary techniques are developed and applied?[18]

There is a third aspect of Innis's theory that has puzzled those who have studied his communications papers. There seems no strong evidence to support Innis's argument that the price changes which trigger innovative activity are due to monopoly of existing media.[19] However, the direct-search hypothesis described above provides an alternative and more plausible explanation for such price signals. As mentioned above, a society's communications structure must perform three essential tasks; namely, the storage, transmission, and atomistic reproduction of information. If the costs of any single dimension get seriously out of line with those of the other two, bottlenecks will occur. Resources will then be devoted to the development of a new medium capable of relieving the bottlenecks.

[17] Think, for example of the discovery of agriculture, of the sailing ship, or of the steam engine. Each had an impact that was arguably as profound as the discovery of writing, printing, or newsprint that attracted the attention of Innis.

[18] Lipsey and Bekar (1995) define innovations in 'enabling' technologies as those having economy-wide applications that lead to the development of other technologies.

[19] Innis argued that at the end of the middle ages, 'monopolies of knowledge controlled by monasteries were followed by monopolies of knowledge controlled by copyist guilds in the larger cities. The high price for large books led to attempts to develop a system of reproduction by machine and to the invention of printing' (Innis 1951, 53). While there might well have been some monopoly rents in the price of manuscripts in certain towns in the late middle ages, the high price of such documents would seem to be attributable primarily to the scarcity of skilled labor for reproduction by hand (Cardwell, 1972, 20). As for the next phase of innovation, in the early nineteenth century, there was clearly no general monopoly of the existing medium, craft printing.

Once an innovation that relieves the existing bottleneck has been developed, the new idea may subsequently be crossed with existing ideas at moderate additional cost to generate further innovations. Thus one should expect a burst of innovation following the introduction of a new communications medium. Thereafter, however, as the number of economically feasible untried crosses falls, the rate of innovation will decline. Since the direction of these subsequent innovations will be channeled by the initial breakthrough, there will tend to be *overshooting* of cost reduction in the dimension determined at the outset.[20] Other directions of innovation will not immediately be profitable because the seminal innovation will be missing. Only late in the cycle, when new strains on relative prices have appeared will research be channeled in a different direction.

B. A Model of Biased Growth

How might this concept of recombinant growth be incorporated into Innis's model of communications? Assume that there are three possible ways in which funds for research on information processing may be spent; namely, to reduce reproduction costs, r, to cut storage costs, s, or to lower transmission costs, t. As suggested above, the key innovations at the beginning of each cycle will tend to channel subsequent technological change in a particular direction. It is as though at the start of such a cycle, a switch corresponding to one of these

[20] An example of the channeling effect of a seminal innovation and the overshooting that can result is the Carolingian minuscule, developed in the eighth century for writing in Latin on parchment and subsequently applied to a limited range of religious and administrative purposes (Graff, 1991, 47). Once the new idea began to be widely diffused (with a concomitant rise in literacy in Latin) from the eleventh century on, it was gradually crossed with existing ideas from the stock of classical manuscripts in history, philosophy and literature. The combined concepts were then crossed with the idea of paper, borrowed from China. By the early fourteenth century the demand for books had outstripped the capacity of medieval copyists (Cardwell, 1972, 20). In short, a sequence of innovations in information storage had led to a bottleneck in information reproduction. A second example is printing, which was originally developed for religious and educational documents in Latin. Once it began to be applied to political and commercial information in the vernacular, there arose a demand for rapid diffusion in large volume could not be met by existing information gathering and distribution methods. By the early nineteenth, these successive innovations in reproduction methods had created great pressure on the transmission system (Dudley, 1991, 198-199).

directions of research were activated while the other two were closed.[21] Let δ_i represent the switch for process i, $i = r, s, t$. When the switch is on, it takes the value one; otherwise it has the value zero.

The *storage* research switch will be turned on when information storage costs become high relative to reproduction and transmission costs:

$$s > \sigma r + c_s t\ ,$$

where σ and c_s are positive parameters. Divide by t:

$$s/t > \sigma r/t + c_s. \qquad (7)$$

This inequality states that research to reduce storage costs will begin when the technology trajectory in Figure 3 is about to cross a line such as AB from below, as in the move from T to S.

Similarly, the *reproduction* research switch will be triggered when because of innovation elsewhere, information reproduction costs become too high relative to storage and transmission costs:

$$\rho r > s + c_r t\ ,$$

[21] The empirical relevance of this switching specification depends on the height of the thresholds necessary to activate the switches. If the thresholds are low, this model's implications are not very different from those of Weitzman's (1995) formulation. Historically, in communications technology, the thresholds do appear to have been quite important. Prior to the turn of the millennium, when the monasteries were attempting to standardize scripts and grammar for more efficient storage of information, few if any were working on lowering reproduction and transmission costs. Similarly, in the first half of the fifteenth century, when there was a burst of effort to lower reproduction costs, storage and transmission attracted little attention. Finally, in the first half of the nineteenth century, when the high costs of transmission captured the attention of inventors, there was little work to lower the costs of storage or low-volume reproduction. (Exceptions in the latter part of that century are the typewriter and the Hollerith punch-card machines, which lowered reproduction and storage costs respectively.)

where ρ and c_r are positive parameters. After division by t, this inequality becomes:

$$s/t < \rho r/t - c_r. \qquad (8)$$

In Figure 3, this condition is satisfied when the technology trajectory is about to cross the line BC from above, as in the move from S to R.

Finally, innovation that cuts storage and reproduction costs will eventually cause *transmission* costs to get out of line:

$$c_t t > s + \lambda r,$$

where c_t and λ are positive parameters. Divide by t:

$$s/t + \lambda r/t < c_t \qquad (9)$$

This inequality is the definition of points to the left of the threshold AC in Figure 3. Accordingly, the transmission-research switch will be triggered when the technology trajectory is about to cross this line from the right, as in the move from R to T.

Weitzman's hypothesis of recombinant growth suggests what happens when one of these triggers is set off. Let n be the number of ideas that exist at the beginning of a period. The number of possible binary combinations of these ideas, c, is $n(n-1)/2$. However, some of these combinations will already have been tried. If n' represents the number of ideas at the beginning of the *preceding* period, the number of new combinations that may be tried is:

$$c = [n(n-1) - n'(n'-1)]\ /2$$

Let γ be the success rate of these crosses. Then, with δ_i as the innovation switch defined above, the rate of productivity growth in process i is simply $g_i = \delta_i \gamma c\ /n$.

Now unless γ is relatively high, this process will peter out. To keep it from doing so, let us make use of the Weitzman's second hypothesis, allowing ε events that increase the stock of ideas to occur between periods. As an example, think of the impact of the prior discovery of electricity when attention began to be directed toward research on information transmission in the early nineteenth century. In addition, assume that at the moment when research is redirected from one information process improved access to existing knowledge allows ε' events occur.

Let θ_i be the fraction of the labor force that uses communications technology i, where $i = r, s, t$. By definition, the overall growth rate for the economy is

$$g = \Sigma_i \, \theta_i \, g_i$$

Under the above assumption of directed search, however, both productivity growth and the change in sectoral size will be zero in the two information sectors where research is not occurring. If research is taking place in process i, we have

$$dg = \theta_i \, dg_i + g_i \, d\theta_i \, . \qquad (10)$$

Allow the sector undergoing innovation to attract population from each of the other two sectors once the former's costs have fallen below those of the latter. Assume, however, that the two non-innovating sectors always retain a positive group of adherents, with the highest-cost sector being smaller than the intermediate-cost sector at the end of the cycle. Inspection of equation (10) then yields a growth cycle with three phases.

Between the start of the cycle and the moment at which the innovating system overtakes the less efficient of the other two systems, the rate of economic growth is low and possibly declining. Paradoxically, this is the *innovation* phase of the cycle, in which the rate of technological change is most rapid. All innovation resources have been withdrawn from the two most important sectors of the economy, which now stagnate. In the small innovating

sector, productivity growth is initially rapid, but slows thereafter, as the initial stock of new ideas is gradually run down. The first term in the right side of equation (10) may therefore be negative. However, as this sector's productivity still remains too low for it to be able to attract resources from the other two sectors, the second term is zero. In this initial phase, rapid innovation is occurring but its diffusion remains limited because relative costs in the innovating sector still remain high.

Once unit cost in the innovating sector falls below that of the intermediate-sized sector, the former begins to attract resources from the latter. This is the ***diffusion*** phase of the cycle, characterized by what Schumpeter (1942, ch. 7) described as "creative destruction." Although g_i continues to fall, this effect is more than offset by the increase in the relative size of the innovating sector, θ_i, as it grows at the expense of the other two sectors. Eventually, the progressive decline in costs then enables the innovating sector to overtake the leading sector, and θ_i continues to rise. Growth subsequently decelerates, however, since $d\theta_i$ falls with the slowing of diffusion once most of the economy's resources are in the innovating sector.

In the final *dominance* phase of the cycle, the innovating sector has absorbed all mobile resources and ceases to expand, the second term on the right side of (10) becoming nil. However, because of the mutations, ε, the rate of growth in the innovating sector remains positive. The growth rate will therefore be low. Each of the sides of the technology trajectory *SRT* in Figure 3 corresponds to a complete cycle of economic growth. A 'medieval' cycle from transmission to storage technology occurs along *SR*, a 'modern' cycle from storage to reproduction technology along *RT*, and a 'contemporary' cycle from reproduction to transmission along *TS*.

It may be seen, then, that Innis assigned too important a role to monopoly in causing the economic growth process to slow and in creating the price signal that sets off a new round of innovation. Even without the presence of monopoly rents, the recombinant approach proposed by Weitzman is able to generate the slowing down of the current cycle and the price distortions necessary to induce innovation in a new direction.

IV. A Numerical Simulation of Very Long-term Growth

A numerical example will illustrate the nature of economic growth in the theory proposed by Harold Innis. The first seven lines of Table 1 set out the assumptions made to carry out the simulation.[22] Parameter values were chosen such that the mean rate of growth within each period was identical to the historically observed population growth rate.[23]

[Insert Table 1 about here.]

Figure 4 portrays the overall rate of output growth, g, over time for the three successive cycles of Table 1. To compare this graph with the demographic data of Figure 2, note that each of the periods marked on the horizontal axis corresponds to roughly fifteen years. The resemblance of the simulated to the historical series is quite evident. Note first that there are three cycles. Second, each cycle can be divided into three phases. There is an initial *innovation* phase of slow growth followed by a *diffusion* phase of above-average growth and a *dominance* phase of slow but steady growth. Finally, over time the cycles decrease in length, since as the stock of previous ideas accumulates, the number of potential crosses for each *new* idea rises. It therefore takes less and less time to reach the threshold at which innovation resources are redirected.

[Insert Figure 4 about here.]

The principal discrepancy between the Figures 2 and 4 occurs at the end of the first

[22] Within each cycle, the combinatorial process was assumed to be continuous, applying not only to integers but also to fractions, fractions of ideas being interpreted in probabilistic terms. In addition, it was assumed that the success rate of new crosses, γ, declined between cycles. Finally, the weights, θ, for the three sectors were assumed to follow logistic functions of the form $\theta_\tau = c/[1 + \exp(-b\tau)]$, where τ is the number of periods after the point of inflection, c is the ceiling and b is the rate of approach of θ to the ceiling.

[23] For simplicity, it was assumed that all increases in output were devoted to population growth at a constant level of per-capita income. The same demographic profile could of course be consistent with higher productivity growth rates if some fraction of the additional output were reserved for improved living standards.

and second cycles. Historically, the fourteenth and seventeenth centuries were not merely periods of stagnation; as Figure 2 shows, they were times of actual population *decline*. These setbacks are sometimes explained by intervals of cooling of Europe's climate.[24] However, generalized warfare and a decline in population growth also appeared in the corresponding phase of the third logistic in the first half of the twentieth century, when no such climactic change occurred. A possible explanation is that as the payoffs to innovative efforts that increase the size of the pie decline, individuals become increasingly willing to invest in activities to redistribute the existing pie. If so, following Hirshleifer (1993), we would have to expand the model of production presented above to include the technology of destruction.

[24] It is argued that the resulting crop failures left the population vulnerable to epidemics and perhaps triggered the bloody conflicts over scarce resources that characterize these periods (Cameron, 1993; 74, 99).

V. Conclusion

Neither contemporary writing on the history of technology nor neoclassical growth theory provides a satisfactory explanation for the very long cycles of accelerating and decelerating growth that have characterized the economic development of the West over the past millennium. This paper has shown that a possible explanation for such phenomena may be found in the writings on communications of the Canadian economic historian Harold Innis. Once formalized in algebraic form and simulated by computer with the help of a probabilistic specification for the generation of innovations proposed by Weitzman (1995), Innis's theory proves to be surprisingly successful at replicating the main characteristics of observed long 'logistic' curves of demographic growth in Europe.

In rejecting any notion of enduring equilibrium and focusing of the generation of novelty, Innis was clearly taking an evolutionary approach to economics.[25] Indeed, his methodology was quite Darwinian, with his concepts of 'bias', 'balance,' and the 'margin' playing the roles of reproduction, selection, and mutation respectively in the biological evolutionary model.[26] The key to understanding Innis's ideas is to recognize that a particular communications medium will tend to be 'biased' in favor of one of three essential dimensions of information processing: it will tend to favor either storage over time, transmission over space, or atomistic reproduction among large numbers of individuals. Eventually, the high cost of one of the neglected dimensions will tend to induce a burst of innovation whose diffusion generates a period of accelerated growth. Any equilibrium or 'balance' between new and old technologies would be temporary, since the new medium would eventually dominate the old.

In recognizing the endogeneity of technological change, Innis was following an approach

[25] Nelson (1995) argues that in order to focus on long-term processes in economics, it is necessary to abandon the notions of static and dynamic equilibrium, since any stable situation will be upset by internally generated novelty.

[26] Witt (1991) discusses the relationship between biological models of evolution and those used in economics.

developed by his Austrian contemporary, Joseph Schumpeter (1939, 1942). However, Innis's focus on communications technology compelled him to broaden his analysis beyond Schumpeter's framework of firm and industry so as to include the society's underlying rules and the institutions set up to apply them. The cycles of change studied by Innis were therefore much longer than the 50-year cycles in price movements on which Schumpeter concentrated. Unlike Schumpeter, moreover, Innis viewed the large-scale enterprise as a reactionary force within a society rather than its principal source of innovation. New ideas, he felt, would come from the 'marginal' areas where the power of the dominant group was weakest.

How relevant are Innis's ideas to those trying to understand the nature of contemporary economic growth? To answer this question, one might consider how Innis would have analyzed the puzzling slowdown in productivity growth that characterized the industrialized world during the 1970s and 1980s despite very rapid innovation in the electronics sector. If he had lived to see this period, Innis would likely have recognized the characteristics of the first or *innovation* phase of his technological cycle. In this phase, despite rapid generation of new ideas, the new micro-electronics technologies were not yet sufficiently cost-effective to challenge the mass-transmission techniques that were left from the *dominance* phase of the preceding wave. As a result, the diffusion of the innovations remained limited and productivity growth was slow. It is only in the second or *diffusion* phase when the rate of innovation has slowed but the new technologies have become cost-effective that growth accelerates. The real test of the predictive power of Innis's theory of communications lies ahead of us.

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TABLE 1. THREE CYCLES OF BIASED INNOVATION

Parameter	Cycle 1	Cycle 2	Cycle 3	Cycle 4
Process undergoing innovation	Storage	Repro-duction	Transmis-sion	Storage
Number of ideas at end of last cycle	1	2.6	8.3	31.3
Number of ideas between cycles (ε')	1	2	4	6
Number of ideas between periods within cycle (ε)	0.015	0.02	0.06	0.06
Success rate of new combinations (γ)	0.15	0.12	0.05	0.03
Percent of population using technology at beginning of cycle:[a]				
- storage (θ_s)	2.5	80.0	17.5	2.5
- reproduction (θ_r)	17.5	2.5	80.0	17.5
- transmission (θ_t)	80.0	17.5	2.5	80.0
Logistic rate of approach				
- smallest sector	1.2	1.25	1.3	1.8
- intermediate sector	1.3	1.3	1.3	1.3
Number of periods in cycle[b]	30	20	15	
Average annual growth rate (%)	0.056	0.304	0.605	
Number of ideas at end of cycle	2.6	8.3	31.3	

[a] Over the course of each cycle, the sector undergoing innovation was assumed to capture 15 percent of total population from the intermediate sector and 62.5 percent from largest sector.
[b] Each period within a cycle corresponds to 15 years.

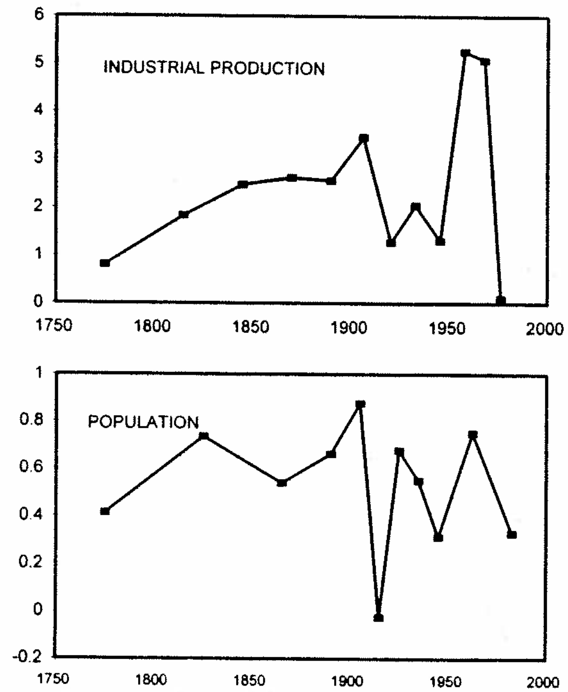

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Figure 1. Growth of industrial production and population and population, Western Europe, 1750 -1990, annual rates in percent

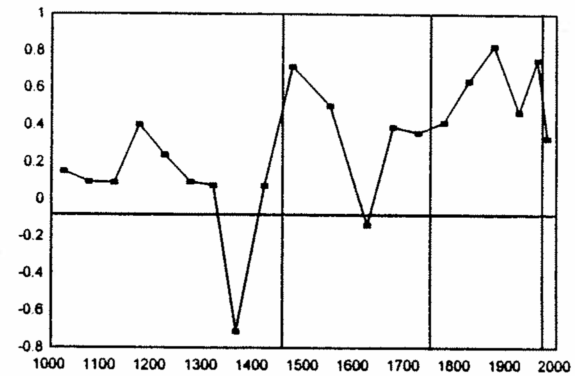

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Figure 2. Growth of population in Western Europe, 1000-1990, annual rates in percent

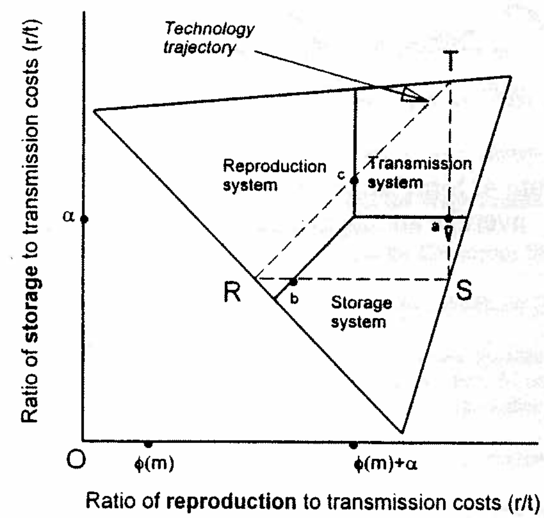

Figure 3. Technological change and the choice of communications system

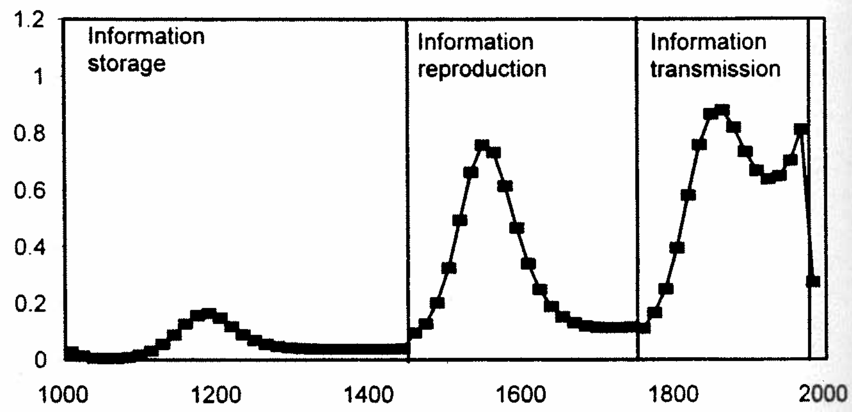

Figure 4. Simulation of three innovation cycles, average annual growth rates in percent

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