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INFORMATION TECHNOLOGY AND THE FUTURE OF CITIES

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ABSTRACT

Will improvements in information technology eliminate face-to-face interactions and make cities obsolete? In this paper, we present a model where individuals make contacts and choose whether to use electronic or face-to-face meetings in their interactions. Cities are modeled as a means of reducing the fixed travel costs involved in face-to-face interactions. When telecommunications technology improves, there are two opposing effects on cities and face-to-face interactions: some relationships that used to be face-to-face will be done electronically (an intuitive substitution effect), and some individuals will choose to make more contacts, many of which result in face-to-face interactions. Our empirical work suggests that telecommunications may be a complement, or at least not a strong substitute for cities and face-to-face interactions. We also present simple models of learning in person, from a written source, or over the phone, and find that interactive communication dominates other forms of learning when ideas are complicated.

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I. Introduction

Will improved telecommunications technology make cities, and indeed space itself, obsolete? Alvin Toffler (1980), Roger Naisbitt (1995), Nicholas Negroponte (1995) and William Knoke (1996) are among the many prognosticators who have weighed in on this topic and generally forecast the end of the need for cities. The general idea, which appears in various guises, is that the ongoing improvements in telecommunications are creating a "spaceless world" (Knoke's phrase) in which we will all inhabit "electronic cottages" (Toffler's phrase) and teleconference or telecommute. These seers assert that electronics will eliminate the need for face-to-face interactions and the cities which facilitate those interactions.

Indeed, these arguments are not *a priori* unreasonable. We can already communicate large quantities of written information over long distances at almost no cost by using information technologies such as e-mail, fax machines, the internet and the world wide web. Already, the technologies exist so that we can hold "virtual meetings," where people can look at each other and talk to each other over long distances. If telecommunications are a substitute for face-to-face interactions, then these face-to-face interactions will decline as telecommunications improves.[1] As face-to-face interactions vanish, cities will lose their role as a physical center that allow people to meet and communicate easily.[2] The informational city, according to the futurists, will disappear once the technology gets good enough.[3]

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[1]The traditional urban response to the idea that telecommunications will make face-to-face meetings, and cities obsolete, is to argue that there are some types of information that cannot be electronically communicated (as in Mills, 1992). Ihlanfeldt (1993) provides a fine review of this literature.

[2]The basic idea that lower communication costs should reduce the role of cities is analogous to the result of economic geography, as in Krugman, (1991), that lower transportation costs may lower the degree of urban concentration. In Krugman (1991), as in this paper, it is possible that higher transportation costs may lower, as well as increase the degree of agglomeration.

[3]There are also economic models that formalize some of these arguments. Henderson and Mitra (1993) argue that the internal structure of a city will decentralize as information technologies enable non-central business areas to communicate with the downtown area. Their work is inspired by Garreau (1991) who suggested that Edge Cities are increasing in relevance, in part because of improvements in information technology. Ota and Fujita (1993) present a model where spatial decentralization of firm activities is a function of communication technology.

The questionable lynchpin of this argument is whether or not telecommunications are indeed a substitute for face-to-face interactions. Some might claim that many types of interactions will always require real meetings, and that telecommunications will never eliminate all face-to-face contacts. More interestingly, it is also possible that telecommunications are not a substitute for face-to-face interactions, but in fact these two forms of information transmission are complements.[4] If they are complements, then we should expect cities and space to get more important as information technology improves.

Improved telecommunications may increase face-to-face interactions because one effect of improved telecommunications is that people will start more relationships and make more contacts. Some of these contacts start with phones, but eventually lead to face-to-face meetings. On the other hand, if face-to-face contact is needed early in a relationship, but after establishing an initial relationship phones and e-mail can be used, then people will try to meet a broader range of contacts to take advantage of the improvements in phone technology. Coauthorship is a form of relationship that usually involves both face-to-face and electronic meetings.

When relationships involve both electronic and face-to-face meetings, then as electronic meetings become cheaper, there is a rise in the overall level of interaction in the economy, and face-to-face meetings should increase in number as well. The massive rise in coauthorship in economics since the 1960s may be in part due to improved telecommunications, and this rise has led to both electronic interactions and face-to-face meetings. Cities are particularly linked to face-to-face meetings since a common urban location drives down the costs of face-to-face meetings. If face-to-face meetings rise in importance, then more people will try to group together in areas that are easily accessible to their many contacts, and cities will still have an economic role to play in the informational economy.[5]

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[4] Tofflemire (1992) argues that cities are centers of information technology because of the urban advantages in communication generally. This article can be seen as suggesting a complementarity between cities and telecommunications.

[5] There is a large literature on the role that cities play in supporting informational exchanges because of physical proximity. Two of the most important members of this literature are Marshall (1890) and Jacobs (1968). Jaffe, Trajtenberg and Henderson (1993) present evidence supporting the localization of information flows.

This effect hinges only on the fixed costs of face-to-face contact being lower in cities, presumably because of lower reducing travel costs. If cities are also centers of telecommunications technology, as suggested by Sassen (1991) or Huber (1995), then for obvious reasons improvements in information technology will help cities even more. In addition, if the return to interaction or if the average complexity of informational contacts are rising independently of improved telecommunications then face-to-face interactions will increase for those reasons as well.[6] For example, an increase in the division of labor should lead to an increase in the need for contact holding telecommunications quality constant. The rise of the New York multimedia industry may be a sign of big cities' comparative advantage is facilitating the difficult information flows involved in cutting edge industries.

One telling piece of evidence on this topic is that the past fifteen years has seen a dramatic rise in the number of business trips in the U.S. despite the improvement in information technology. Business travel is a convenient measure because it shows the demand for face-to-face contact, and changes in business travel appear much more quickly than changes in urban form. The futurists' view on travel is given by Naisbitt (1995) who writes that "situations that might once have required an overseas flight will now be resolved in cyberspace."

While on some level that statement must be true, since the late 1980s as we have watched telecommunications improve, there has been a contemporaneous, dramatic rise in business travel. Airfare prices have fallen over this period, but the drop in airline prices occurred primarily over the pre-1985 and since that time airline prices have not fallen enough to account for the rise in travel. The rise in business travel may be the result of an increased demand for intense interaction in business or possibly the direct result of improved telecommunications. Telecommunications could be a complement with business travel, because telecommunications facilitates those trips (faxes to make reservations, telneting home, etc.) and helps to initiate business relationships that ultimately result in people traveling so that they could be somewhere in person.

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[6]Glaeser and Maré (1994) show evidence suggesting that benefits of cities for the most educated worked seemed to be rising between the 1970s and 1990. That paper also focuses on the role of cities as conduits for information transmission.

This paper has two theoretical sections. In the first section, we explicitly model how changes in telecommunications technology will effect the use of face-to-face interactions and the size of cities. This section essentially assume that telephone interactions will be more efficient for less intensive interactions, but for more intensive interactions face-to-face meetings will be more efficient. The second theoretical section of the paper gives this assumption some microfoundations, based on the economics of simple communications technologies.

The basic structure of the first model is that individuals make a decision about initiating "relationships" with other individuals. These relationships are unspecified and might be business or social in character. Individuals who choose to initiate relationships do so without knowing *ex ante* how advantageous a particular relationship will be. After an initial contact period, the individual learns the quality of the particular match and chooses how intense he or she wants the relationship to be.[7] The choice of intensity is accompanied by a choice of communications technology: telephone or face-to-face.

Given our assumption about the two technologies, telephones will be used for the initial contact that is used to determine the quality of the match and for later relationships that are not particularly intense. Face-to-face interactions will only be used for later relationships that are particularly rewarding. An improvement in the telephone technology (e.g. videophones) will increase the usage of the telephone technology and will increase the number of new contacts generally. It will have two effects on the number of face-to-face interactions. First, some relationships that had occurred in a face-to-face setting will occur over the phone. This is the futurists' substitution effect. Second, there will be more new contacts and as society becomes more interactive there will be more use of both the telephone and the face-to-face technology as a result. If the new contact effect outweighs the substitution effect, then an improvement in the quality of telephones may in fact increase the number of face-to-face interactions.

We imbed this model in an urban framework. The city is modeled as a costly place that has an advantage in facilitating face-to-face contacts. The same

[7]We are assuming that the initiator has all the bargaining power and receives all the benefits from the relationship. Relaxing this assumption would add little except for inefficiency in the number of new relationships.

conditions that determine whether or not face-to-face contacts will rise with quality of telecommunications determine whether or not as telecommunications improve, individuals will have an added desire to live in the city.

Our primary result is that improvements in telecommunications technology may increase the relevance of face-to-face interactions and the relevance of cities, and we are able to show when we would expect cities and telecommunications to be complements. If at the same time that telecommunications is improving, interactions, and particularly intense interactions, become more important (perhaps because information becomes more complicated), then cities will rise due to these factors as well. A useful and simple result of the model is that an improvement in telecommunications will make cities more appealing in the future, if at a particular point in time urban residents use more telecommunications than rural residents.[8]

The second section of the paper deals with the microeconomics of communications technologies. We try to explain the costs and advantages of face-to-face communication vs. communication either over the phone or by memo. In particular, we first deal with the decision about when to communicate using "transcribed" information (memos, taped lectures or books) and when to communicate interactively (whether by phone or in person).[9] The section is written in the context of a teacher-student relationship but the model applies to any learning situation where one person is trying to transmit knowledge to another.

In the model, we avoid the extensive psychological and educational work on the relative benefits of interactive vs. transcribed teaching and focus on a simple economic model where the advantage of interactive teaching is that the teacher can learn what the students need to know as he teaches.[10] In the case of transcribed teaching, the teacher must either answer all of the questions that the

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[8]This result is dependent upon at least one important assumption of the model. Nevertheless it is a useful benchmark to take to the data.

[9]In some sense the distinguishing characteristic of transcribed communication is that it is asynchronous in the sense of Negroponte (1995), and we assume that the information receivers cannot communicate back or can communicate back only at a significant cost.

[10]Our decision to avoid these issues is not because we don't think they are important. Indeed, we think that they are probably more important than the issues that we ourselves discuss. However, we have little to add to the psychology of learning.

student might have or be prepared that the student might not learn something the he wants to know. With interactive teaching, the teacher can respond to each student's ignorance appropriately and not bother teaching subjects that students already know.

The primary results of that model are that transcribed learning is more useful when (1) the heterogeneity among teachers is high (because transcribed teaching can let us use the talents of "superstars" as in Rosen, 1981), (2) transcriptions can be reused often, and (3) students are likely to miss points in lectures. Interactive learning is most valuable when there is a large gap between the expected ignorance of students and their maximum possible level of ignorance. This gap should be larger for very complicated topics or where there are few students. Interactive teaching is also more efficient when students can leave after they have learned what they need to know, and when student time is cheap relative to teachers' time.

The second model in this section compares face-to-face learning with learning over a telephone (or in principle a videophone). The primary advantage of face-to-face learning is that the teacher and the student can perform the task together to make sure that the student has actually understood the teacher's instructions.[11] The advantages of face-to-face learning will be higher when the topic is complex and contains many subtasks.

The fourth section of the paper presents some suggestive evidence on the observed connection between telephones and cities. We find that the introduction of the telephone, a revolutionary innovation in telecommunications, seems to have had a small influence on the path of urbanization in the U.S. We find that across countries urbanization and telephone use move together. The cross-national correlation holds when controlling for income. Within the U.S., we find that residents of big cities spend less on telephones than residents of tiny cities (less than 75,000 residents), but slightly more than residents of medium cities (between 75,000 and 4 million residents). Overall, it appears that telephone use does not decline in cities, and our model argued that such a connection was

[11]Our focus on actually performing the task together, as opposed to the student simply hearing the information and learning as he hears, brings us close to the educational viewpoint of constructionism (see Papert (1991)).

necessary for us to believe that improved telecommunications would hurt cities. Finally, we present data on business travel between 1972 and 1993 and document the large rise in business trips over that period.

A further piece of evidence suggesting that face-to-face contact and telecommunications contact are complements is that most telephone calls are made to individuals who are quite close physically. In mid-1970s data, more than 40% of phone calls are made to places within a two mile radius, and more than 75% are made to places within a six mile radius (Mayer, 1977). The basic tendency to call people who are physically close has been confirmed with modern Japanese data as well.[12] Unfortunately, these results tend not to control for the price of phone calls and are biased by the endogenous location problem. Nevertheless, the strong tendency to call people who are easy to physically visit, is additional evidence suggesting the phone calls and face-to-face meetings are complements.

The fifth section of the paper concludes and completes our argument that while it is possible that telecommunications improvements may lesson the relevance of urban density, it is also possible (and we think just as likely) that telecommunications improvements may increase the desire for urban living.[13]

Section II. Telecommunications and Cities

This section models interactions using face-to-face and telephone based interactions. The key assumption is that telephones are better for less intense relationships and face-to-face interactions have a comparative advantage for more complicated relationships. The first subsection gives conditions under which an improvement in telephone technology will increase the number of face-to-face interactions. The second subsection embeds this technology in a simple urban framework.

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[12]Private communications between the authors and Takuo Imagawa of the Japanese Ministry of Post and Telecommunications confirms this fact.

[13]In a related paper, Wheaton (1996) argues that "the demise of tradition real estate is much exaggerated and far too premature." Wheaton presents strong evidence arguing that traditional offices are not obsolete and that there is still a substantial demand for face-to-face interaction in the workplace.

In this model, individuals choose whether to contact another person to create a potential relationship. After they learn the characteristics of the new contact (the "match quality"), they choose the intensity of the relationship. Relationships are assumed to generate positive profits or utility, at least if the match level is sufficiently high. More intense relationship yield greater profits, but at a time cost. The model is meant to capture situations ranging from firms trying to connect to a new client or a new partner, to people trying to make new social acquaintances.

If an individual decides to try and create a new relationship, he draws from the pool of possible contacts. After a certain initial contact period, they learn the quality of the match. The returns from the match to the initiator are denoted $\alpha g(i)$, where α is a stochastic variable capturing the uncertain qualities of the match, $g(.)$ is a continuously differentiable, concave function and i is the intensity of the relationship. These returns are meant to include all possible gains to a relationship from information that is learned to financial gains from a explicit transaction. The density function of α is $\phi(\alpha)$, its cumulative distribution function is $\Phi(\alpha)$, and we assume that α is nonnegative.

In each period, there is a continuum of agents, all of whom are considering whether to undertake a new contact or a private project. They cannot do both. New contacts should perhaps be seen as joint projects and they should be contrasted with private projects. Agents are homogeneous except for their returns to the other project, which will change for each agent each period (each period, agents will draw a new private project). Technically, each agent will be assigned a number on the unit interval, j. The returns to the private project will by $R(j)$, with $R'(j)>0$, and $R(j)$ invariant over time. The measure of agents undertaking the project will be denoted j^* and it will be found by equating $R(j^*)$ with the expected returns from the interaction technology.

Everyone who chooses the interaction technology must achieve a level of interaction, denoted $\underline{i}$, to learn the worth of this potential interaction.[14] Since this time represents a sunk cost that is common to all individuals, for simplicity we will define a new function $f(i)=g(i-\underline{i})$, and assume that $f(0)=0$, so when we discuss the level of intensity we will only be discussing the level of intensity beyond this initial level. Once an individual learns the worth of the new contact, the person then chooses the actual quantity of interaction desired. The level of intensity will be reached by one of two technologies: the telephone or face-to-face meetings.

In our model individuals will choose to use the telephone to determine the initial match quality, even in cases where face-to-face meetings are eventually used. The common use of telephones and face-to-face meetings in some relationships drives our results, but the actual use of telephones at preliminary stages is simply one reason for some relationships to use both telephones and face-to-face meetings. For example, if face-to-face meetings were used first (to meet people) and email was used later, the results would still hold. If individuals regularly used both, alternating from one to the other as the alternative value of time rose and fell, our results would still hold. The Appendix shows a less structured model, and in some senses a more general model, where our basic results still hold.

Both technologies use only time which is available at cost c.[15] The telephone technology produces interactions at the level $\beta_P t$; the parameter β_P is meant to capture the efficacy of the phone technology. Our choice of the word telephone is meant for convenience. This technology is meant to include all electronic technologies with small set-up costs for the user, for example e-mail, videophones, etc.. Improvements in telecommunications (i.e. teleconferencing) are meant to be thought of as increases in β_P.

The second, or face-to-face, technology produces interaction at the level $\beta_F(t-t_F)$. The t_F parameter represents the fixed time component needed to set up face to face interactions, i.e. time spent traveling to a meeting. Our crucial assumption

[14]In principle, we could allow a more complicated process where match quality was revealed in a more interesting manner, as in Jovanovic (1979). This type of change would add significant complication and little further insight.
[15]Allowing cash costs would add little to the analysis.

will be $\beta_F > \beta_P$, which means that face-to-face interactions will have a comparative advantage for high intensity interactions. The experimental literature on telephones and face-to-face meetings has difficulty documenting any major differences in the effectiveness of communicating over the phone or in person (Reid, 1977). However, the empirical literature documents a powerful preference for people to use telephones for short contacts and face-to-face meetings for long contacts (Thorngren, 1977). We believe that the evidence on what people actually choose to do is somewhat more convincing than laboratory work involving invented problem-solving experiments.

In this model, we will simply assume this feature of the two technologies. In section 3, model 2, we will explicitly model the differences between face-to-face and telephone interactions and show why face-to-face interactions seem to work better for complicated exchanges of information, but telephones are fine for simple, brief exchanges. Figure 1 shows the mapping between time spent and relationship intensity using the two different technologies.

After the initial contact that determines match quality, optimal match intensity for each communications technology will be found by setting $\alpha f'(i)$ equal to the marginal costs of intensity, which is the marginal cost of the time required to produce that level of intensity. We denote $i_P^*(\alpha)$, as the optimal level of interaction given that the phone is being used. More precisely $i_P^*(\alpha) = f'^{-1}(c/\beta_P\alpha)$. Likewise, $i_F^*(\alpha)$ represents the optimal level of interaction when using the face to face technology, and $i_F^*(\alpha) = f'^{-1}(c/\beta_F\alpha)$. It must be true that $i_F^*(\alpha) > i_P^*(\alpha)$, and that both functions are increasing in α. For notational ease, we also define variables for the optimal time spent using either technology, $T_P^*(\alpha) = i_P^*(\alpha)/\beta_P$, and $T_F^*(\alpha) = i_F^*(\alpha)/\beta_F + t_F$.

There are three important cutoff points for α. First, given that phone technology has been used for the initial contact, $\underline{\alpha}$ denotes the minimum level of match quality for which any further contact is sensible. The level is found so that:

(1) $$0 = \text{Max}\left[\underline{\alpha} f\left(i_F^*(\underline{\alpha})\right) - c\frac{i_F^*(\underline{\alpha})}{\beta_F} - ct_F, \underline{\alpha} f\left(i_P^*(\underline{\alpha})\right) - c\frac{i_P^*(\underline{\alpha})}{\beta_P}\right],$$

Second, given that face-to-face interactions have been used initially, we define a lower cutoff, $\underline{\underline{\alpha}}$, defined by $0 = \underline{\underline{\alpha}} f\left(i_F^*(\underline{\underline{\alpha}})\right) - c\, i_F^*(\underline{\underline{\alpha}})/\beta_F$. The term, $\underline{\underline{\alpha}}$, is the lowest minimum match quality for continuing contact when face-to-face interactions are used in the initial contact. The cutoff is lower because the fixed costs of face-to-face contact have already been paid in this case.

The final cutoff point α^* denotes the minimum level at which face-to-face contact is preferable to telephone interaction, if the telephone was used initially. This level is determined by the point where the telephone and face-to-face meetings yield equal returns:

$$(2) \qquad \alpha^* f\left(i_F^*(\alpha^*)\right) - c\frac{i_F^*(\alpha^*)}{\beta_F} - ct_F = \alpha^* f\left(i_P^*(\alpha^*)\right) - c\frac{i_P^*(\alpha^*)}{\beta_P}$$

We are going to assume parameter values so that individuals always use the telephone for their first contact, when they ascertain their match quality. When $\alpha^* > \underline{\alpha}$, the condition for the telephone to be a preferable first technology is:

$$(3) \qquad \begin{aligned} &-\frac{c\underline{i}}{\beta_F} - ct_F + \int_{\alpha=\underline{\underline{\alpha}}}^{\infty}\left(\alpha f\left(i_F^*(\alpha)\right) - c\frac{i_F^*(\alpha)}{\beta_F}\right)\phi(\alpha)d\alpha < -\frac{c\underline{i}}{\beta_P} + \\ &\int_{\alpha=\underline{\alpha}}^{\alpha^*}\left(\alpha f\left(i_P^*(\alpha)\right) - c\frac{i_P^*(\alpha)}{\beta_P}\right)\phi(\alpha)d\alpha + \int_{\alpha=\alpha^*}^{\infty}\left(\alpha f\left(i_F^*(\alpha)\right) - c\frac{i_F^*(\alpha)}{\beta_F} - ct_F\right)\phi(\alpha)d\alpha \end{aligned}$$

which can be rewritten as:

$$(3') \qquad \begin{aligned} ct_F\Phi(\alpha^*) > c\underline{i}\left(\frac{1}{\beta_P} - \frac{1}{\beta_F}\right) - \int_{\alpha=\underline{\alpha}}^{\alpha^*}\left(\alpha f\left(i_P^*(\alpha)\right) - c\frac{i_P^*(\alpha)}{\beta_P}\right)\phi(\alpha)d\alpha \\ + \int_{\alpha=\underline{\underline{\alpha}}}^{\alpha^*}\left(\alpha f\left(i_F^*(\alpha)\right) - c\frac{i_F^*(\alpha)}{\beta_F}\right)\phi(\alpha)d\alpha \end{aligned}$$

This inequality will hold as long as the fixed costs of face-to-face interactions are sufficiently high. These fixed costs need to be high enough so that it is very unlikely that face-to-face interactions will be optimal once the individual has learned match quality. We assume that (3') holds.[16]

There are now two cases to consider. The first case occur when face-to-face contact always dominates telephone contact whenever further contact is desirable, i.e $\underline{\alpha} > \alpha*$.[17] In this case, the equilibrium condition equates the opportunity cost for the marginal agent, with the returns from trying out a new contact:

$$(4) \qquad -\frac{c\underline{i}}{\beta_P} + \int_{\alpha=\underline{\alpha}}^{\infty} \left(\alpha f\left(i_F^*(\alpha)\right) - c\frac{i_F^*(\alpha)}{\beta_F} - ct_F \right) \phi(\alpha) d\alpha = R(j^*).$$

Simple differentiation shows that $\frac{\partial j^*}{\partial \beta_P} = \frac{c\underline{i}}{R'(j^*)\beta_P^2} > 0$, which means that more people undertake new contacts when telephone costs decline. As j* rises there will be more face-to-face contacts in society as well, since the total number of interactions are $j^*\Phi(\alpha*)$ and $\alpha*$ does not change as telecommunications improves. This result is fairly obvious and uninteresting. If all successful contacts involve face to face contacts, more efficient phone conversations leads to more contacts which inevitably leads to more face-to-face meetings.

In the second and more interesting possible scenario, where $\underline{\alpha} < \alpha*$, face to face interactions may indeed by a substitute for telecommunications. In this case the equilibrium condition will be:

$$(5) \qquad -\frac{c\underline{i}}{\beta_P} + \int_{\alpha=\underline{\alpha}}^{\alpha*} \left(\alpha f\left(i_P^*(\alpha)\right) - c\frac{i_P^*(\alpha)}{\beta_P} \right) \phi(\alpha) d\alpha + \int_{\alpha=\alpha*}^{\infty} \left(\alpha f\left(i_F^*(\alpha)\right) - c\frac{i_F^*(\alpha)}{\beta_F} - ct_F \right) \phi(\alpha) d\alpha = R(j^*)$$

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[16]If (3') doesn't hold, then no telephone interactions will be used and there will be no marginal effect of improved telecommunications on the number of face-to-face interactions.

[17]This case is still compatible with telephones being used in the initial contact. Equation (3') becomes $t_F\Phi(\underline{\alpha}) > \underline{i}(1/\beta_P - 1/\beta_F)$.

Differentiation gives the connection between the number of individuals who initiate contacts (j*) and the quality of telecommunications:

(6) $$\frac{\partial j^*}{\partial \beta_P} = \frac{c\underline{i}}{R'(j^*)\beta_P^2} + \int_{\alpha=\underline{\alpha}}^{\alpha^*} \frac{c i_P^*(\alpha)}{R'(j^*)\beta_P^2}\phi(\alpha)d\alpha > 0,$$

so the total number of interactions rises as telecommunications technology improves. The important questions are whether $j^*(1-\Phi(\alpha^*))$ (the number of face-to-face relationships) or $j^* \int_{\alpha=\alpha^*}^{\infty} T_F^*(\alpha)\phi(\alpha)d\alpha$ (the total amount of time spent in face-to-face contact) rise with β_P. The effect on the number of face-to-face contacts is:

(7) $$\frac{\partial\left(j^*(1-\Phi(\alpha^*))\right)}{\partial \beta_P} = \frac{\partial j^*}{\partial \beta_P}(1-\Phi(\alpha^*)) - \frac{\partial \alpha^*}{\partial \beta_P} j^* \phi(\alpha^*)$$

There are two terms involved in equation (7). The rise in the number of interactions raises the number of face-to-face interactions (i.e. j* rises). However, since differentiation of equation (5) shows that:

(8) $$\frac{\partial \alpha^*}{\partial \beta_P} = \frac{\alpha^* T_P^*(\alpha^*)}{\left(T_F^*(\alpha^*) - T_P^*(\alpha^*)\right)\beta_P} > 0,$$

some matches that would have been handled face-to-face are now handled over the telephone as α^* rises. Substituting in from (6) and (8), the condition for $\partial\left(j^*(1-\Phi(\alpha^*))\right)/\partial \beta_P$ to be positive is:

(9) $$\frac{R(j^*)}{R'(j^*)j^*} \frac{c\underline{i}/\beta_P + \int_{\alpha=\underline{\alpha}}^{\alpha^*} c T_P^*(\alpha)\phi(\alpha)d\alpha}{R(j^*)} > \frac{\alpha^* \phi(\alpha^*)}{1-\Phi(\alpha^*)} \frac{T_P^*(\alpha^*)}{T_F^*(\alpha^*) - T_P^*(\alpha^*)}$$

Equation (9) has four terms. The first term is the elasticity of j* with respect to the profits from making a new contact. When this term is high, then the increase in phone efficiency will have a large influence on the number of new interactions.

The second term is the ratio of total phone costs to total net gains from interaction. When this term is high, it means that the increase in phone efficiency will have a large effect on the overall returns to making contacts, and there will be a large increase in the number of new interactions as phones become more efficient. The third term (the first term after the inequality) is the absolute value of the elasticity of the proportion of face-to-face meetings (relative to all attempted contacts) with respect to $\alpha*$. The final term is one over the percentage increase in the amount of time spent in total contact when an individual switches from phone to face-to-face contact-- this term determines how much $\alpha*$ moves when phone technology improves.

The equivalent expression, which determines whether the total amount of time spent in face-to-face contact rises as phone technology improves is:

$$(10) \qquad \frac{R(j^*)}{R'(j^*)j^*}\,\frac{c\underline{i}/\beta_P + \int_{\alpha=\underline{\alpha}}^{\alpha^*} cT_P^*(\alpha)\phi(\alpha)d\alpha}{R(j^*)} > \frac{\alpha^*\phi(\alpha^*)T_F^*(\alpha^*)}{\int_{\alpha=\alpha^*}^{\infty} T_F^*(\alpha)\phi(\alpha)d\alpha}\,\frac{T_P^*(\alpha^*)}{T_F^*(\alpha^*)-T_P^*(\alpha^*)}$$

The only change between equations (9) and (10), is that in equation (9) the third term was the elasticity of the number of face-to-face contacts with respect to $\alpha*$. In equation (10), the third term is the elasticity of the time spent in face to face contacts with respect to $\alpha*$. Equation (9) is a more stringent requirement than equation (10), because the elasticity of number of contacts will always be bigger than the elasticity of the amount of time. This point follows from the fact that the marginal face-to-face contact spends less time in face-to-face interactions than the average face-to-face contact. When we are counting the total number of face-to-face contacts, the marginal contacts counts just as much as the average contact. The ratio of the right hand side of the inequality in (10) to the right side of the inequality in (9) is the ratio of the time spent by marginal face-to-face interaction to the time spent by the average face-to-face interaction.

Figures 2A and 2B show the two effects of improved telecommunications graphically. Figure 2A, which is based on a simulation described in the figure, shows that as telecommunications improves more initiated contacts will lead to more exclusively telephone relationships. Figure 2B shows that as telecommunications improves there will be more initiated contacts. If the effect shown in 2B is bigger than the effect shown in 2A then face-to-face interactions will become more important as telecommunications improve.

Conditions (9) and (10) may both hold and fail to hold for nonnegligible ranges of parameter values, so it is possible that telecommunications will either be a substitute or a complement for face-to-face contact. Both equations are more likely to hold when telephone costs are large relative to net revenues, or when j* moves quickly as the profitability of interactions increases. Also, when the number of face-to-face interactions responds slowly to changes in $\alpha*$, either condition is more likely to hold. When the marginal face-to-face interaction involves little time spent relative to the average face-to-face interaction, then condition (10) is more likely to hold, even when (9) does not hold. Finally, when face-to-face interaction are much more intensive than telephone interactions, then increases in telecommunications are likely to increase the prevalence of face-to-face interactions. It should be stressed however, that as telecommunications become equivalent to face-to-face interactions (which perhaps is the futurists' ultimate vision), both (9) and (10) will fail to hold and face-to-face interactions will be eliminated.

The City and the Hinterland

Before modeling our simple locational framework, we will just show the simple logic of our argument. We will model cities as mechanisms that reduce t_F, the fixed cost of face-to-face interactions. If agents choose their location before they observe j (and j is distributed uniformly on the unit interval), then we can calculate their willingness to pay for a slightly lower value of t_F and interpret this as agents' willingness to pay for the urban amenity of lower fixed costs of meeting face-to-face.

Agents willingness to pay for a particular location is found by setting the expected utility in an area with attributes X (these attributes are assumed only to effect the interaction technology) minus the willingness to pay for attributes (denoted W(X)) equal to reservation utility (denoted $\underline{U}$):

(11) $$\int_{j=0}^{j^*(X)} R(j^*(X))dj + \int_{j=j^*(X)}^{1} R(j)dj - W(X) = \underline{U}$$

Throughout this section, we assume that we are in the case where $\underline{\alpha} < \alpha^*$, which is the more interesting case where both face to face interactions and telephone interactions are used beyond the initial contact. The relationship between willingness to pay and the fixed time costs involved in face-to-face meetings is found by differentiating (11):

(12) $$\frac{\partial W}{\partial(-t_F)} = j^* R'(j^*)\frac{\partial j^*}{\partial(-t_F)} = cj^*\left(1 - \Phi(\alpha^*)\right)$$

This equation captures the willingness to pay for an urban location. The connection between the willingness to pay and lowered fixed costs of face-to-face meetings can be found by differentiating (12) with respect to β_P. This derivative equals c times the derivative of the total number of face-to-face interactions with respect β_P. The condition for the term $\partial^2 W/\partial\beta_P\partial(-t_F)$ to be positive is equation (9). Using the arguments of that section, it again holds that the willingness to pay for urban proximity may either rise or fall with improvements in telephone technology.

Now we actually introduce our simple spatial structure. We assume that there are two locations. The first location is a city, with per period locational costs denoted H(N), where N is the total population in the city, and H'(N)>0, for N large. The function H(N) is increasing in N because there is congestion in the city. There is also a hinterland with location costs denoted h-- the hinterland is assumed to be low density and has no congestion costs.

Beyond these cost differences, the two locations are exactly the same except for a difference in the fixed cost component of face-to-face interactions. Specifically the fixed time cost component for face-to-face interactions in the city is t_F^C. The fixed time cost component for face-to-face interactions in the hinterland is t_F^H, and t_F^C is lower than t_F^H.

Individuals do not know the opportunity cost of their time (their draw of j) when they make their location decision each period. They can only form an expectation over their possible outcomes and their possible usage of interactions technology. In the case where individuals do know j, then those individuals who are particularly likely to interact (have a low value of R(j)) will select into the city. This suggests that any attempts to connect city living with amount of interactions will be biased because of self-selection of highly interactive people into the city.

The city and the hinterland will not differ in the optimal interaction level conditional upon α, once the technology has been chosen, i.e $i_P^*(\alpha)$, and $i_P^*(\alpha)$ will be constant over space. The lower bound, $\underline{\alpha}$, will likewise be constant over space since it is determined exclusively by the telephone technology. The cutoff point between telephones and face-to-face interactions, $\alpha*$, will differ over space because the cost of starting face-to-face contact is lower in the city. We will denote the cutoff in the city as $\alpha^C *$, and the cutoff in the hinterland as $\alpha^H *$. If we differentiate (2), we find that $\partial\alpha */\partial t_F = \alpha */\left(T_F^*(\alpha*) - T_P^*(\alpha*)\right) > 0$, so $\alpha^C *$ is lower than $\alpha^H *$, and people are more likely to use telephones conditional upon contact being initiated in the hinterland.

The number of individuals who initiate contacts will also differ between the city and the hinterland. We will denote the highest level of j for which interactions are attempted as $j^C *$ in the city , and similarly use $j^H *$ to denote the marginal level of j in the hinterland. As $\partial j */\partial t_F = -c(1-\Phi(\alpha))/R'(j*) < 0$, we know that $j^C *$ is higher than $j^H *$ so more total interactions are attempted in the city. The spatial equilibrium is found by equating the expected utility levels, before observing j, in the two communities:

(13) $$\int_{j=0}^{j^{C}*} R(j^C *)dj + \int_{j=j^{C}*}^{1} R(j)dj - H(N) = \int_{j=0}^{j^{H}*} R(j^H *)dj + \int_{j=j^{H}*}^{1} R(j)dj - h, \text{ or}$$

(13') $$N = H^{-1}\left(h + j^H *(R(j^C *) - R(j^H *)) + \int_{j=j^{H}*}^{j^{C}*} (R(j^C *) - R(j))dj \right).$$

From (13') it is easy to show that for any variable X (other than h-- it is trivially true that city size rises with h, the cost of living in the hinterland):

$$(14) \qquad \frac{\partial N}{\partial X} = \frac{1}{H'(N)}\left(\frac{\partial j^{C}*}{\partial X} j^{c} * R'(j^{C}*) - \frac{\partial j^{H}*}{\partial X} j^{H} * R'(j^{H}*) \right)$$

Thus we can calculate the response of city size to all of the technology variables. First, as telecommunications becomes more effective, i.e. as β_P rises, we find that:

$$(15) \quad \frac{\partial N}{\partial \beta_P} = \frac{1}{H'(N)}\left(j^{c} * \left(\frac{c\underline{i}}{\beta_P^2} + \int_{\alpha=\underline{\alpha}}^{\alpha^{c}*} c\frac{i_P^*(\alpha)}{\beta_P^2}\phi(\alpha)d\alpha \right) - j^{H} * \left(\frac{c\underline{i}}{\beta_P^2} + \int_{\alpha=\underline{\alpha}}^{\alpha^{H}*} c\frac{i_P^*(\alpha)}{\beta_P^2}\phi(\alpha)d\alpha \right)\right)$$

The condition for (15) to be positive, and for cities to rise with telecommunications technology, is:

$$(16) \qquad j^{c} * \left(\frac{c\underline{i}}{\beta_P} + \int_{\alpha=\underline{\alpha}}^{\alpha^{c}*} c\frac{i_P^*(\alpha)}{\beta_P}\phi(\alpha)d\alpha \right) > j^{H} * \left(\frac{c\underline{i}}{\beta_P} + \int_{\alpha=\underline{\alpha}}^{\alpha^{H}*} c\frac{i_P^*(\alpha)}{\beta_P}\phi(\alpha)d\alpha \right), \text{ or}$$

$$(16') \qquad \frac{j^{C}* - j^{H}*}{j^{H}*}\left(\underline{i} + \int_{\alpha=\underline{\alpha}}^{\alpha^{c}*} i_P^*(\alpha)\phi(\alpha)d\alpha \right) > \int_{\alpha=\alpha^{c}*}^{\alpha^{H}*} i_P^*(\alpha)\phi(\alpha)d\alpha$$

Essentially (16') has the same tradeoffs as equations (9) and (10). The first term is the gap between the number of contacts in the city and the hinterland. If this gap is large, then an increase in the telephone technology is likely to increase city size. The second term refers to expected intensity of phone interactions in the city. The change in the phone technology decreases average total contact costs by this amount in the city, and the difference in the number of interactions over space (i.e. the first term) is multiplied by this effect. The relevance of decreasing phone costs needs to be multiplied by the increased number of interactions in the city.

The term after the inequality represents the difference in phone usage, conditional upon contact being initiated between the city and hinterland. This term is important because it captures the fact that lowering phone costs may have more of an effect on the hinterland because phones are used more in hinterland, conditional upon a contact being initiated. As this gap widens, phone improvements are more likely to increase hinterland size. As before, the inequality can both hold and fail to hold for non-trivial parameter spaces.

While these terms may seem difficult to interpret empirically, equation (16) is quite simple. That equation says that if telephones are used more in the city then an increase in phone technology will increase the number of people in the city. Section IV will discuss whether cities do feature more telephone usage. If individuals who are prone to have contacts have selected to move into the city, then examining relative phone usage in the two areas may no longer be a valid means of determining whether or not telecommunications improvements will expand cities. Selection of high interaction people into cities will lead to an overestimate of the degree to which phones and face-to-face meetings are complements.

We can also show that city size falls as t_F^C rises and rises as t_F^H rises. As the city becomes a better place for face to face interactions, or the hinterland becomes a worse place for face to face interactions city size should contract. As $\underline{i}$ falls, city population rises, so if it becomes easier to establish the initial contact, cities become more appealing places. As β_F rises, city size unambiguously rises. Finally, we can consider an improvement in the importance of interactions, so f(.)=zf(.) and we consider an increase in z. In that case, when interactions become more profitable city size also increases.

The overall message of this model is that increases in telecommunications technology may either increase or decrease city size and face-to-face interactions. A simple rule of thumb for determining whether increases in telecommunications will increase city size is whether telecommunications are used more in urban areas or in the countryside. Furthermore, if we are experiencing a period when interactions become more valuable or complicated then city size will rise on its own, even if the improvement in telecommunications ends up shrinking city size.

Section III. The Technology of Communication

This section leaves our major theme of cities and telecommunications to attempt to present some basic economics of communications technology. The previous section assumed that the telephone were preferable for less intense interactions, and face-to-face interactions were preferable for intense interactions. While it is certainly possible to come up with a large number of stories for this assumption, and it certainly seems plausible to at least our own introspection, we will here try to model these technologies more thoroughly.

This section models two specific technological choices: (1) books (or taped lectures) vs. interactive lectures and (2) telephone vs. face-to-face teaching. Since face-to-face communication must dominate both telephone and transcribed teaching, it seems valuable to address both of these technology choices. For simplicity, we will be considering the choice of technologies separately and assuming the simplest communication structure. A teacher (who is not necessarily a professional teacher, but may simply be a knowledgeable coworker) must communicate a complete body of knowledge to a student (who again may be a coworker or even a superior). We have assumed away any flexibility in the amount of information to be transmitted-- the teacher must completely inform the student.[18] The key question is what technology allows this communication at the cheapest price. This type of analysis is particularly close to Marschak and Radner (1972) and to work done in the computer science literature.

Books vs. Lectures

In this model, there are N students all of whom must learn a "body of knowledge" completely. We mean the term body of knowledge in its broadest sense. It could represent working knowledge of German, the fact that GDP is $ 5 trillion and what that fact means, or how to get to someone's home.

[18]This assumption is, of course, important and limiting. None of our results hinge in any way on this assumption but the nature of the equations would change somewhat if there was flexibility in how much to teach. In particular, inefficient teaching would show up both in higher costs and less information transmission while now inefficient teaching shows up only in higher costs.

The teacher has access to two teaching technologies, and we assume that these technologies are mutually exclusive.[19] In the first technology, the teacher either writes down his lecture or tapes himself and the audience views this tape or reads the lecture in the book. This technology includes memos, books, articles, letters, tapes and any technology (including some lectures) where students cannot respond to the teacher and ask questions.[20] In the second technology, the teacher stands in front of the audience and communicates the information directly to them. The hallmark of this technology is that students are able to respond immediately and this technology includes classes, phone calls, conversations, seminars and meetings.

We assume that the technologies are the same in certain basic aspects. For example, it takes the teacher the same amount of time to communicate a fixed quantity of information (denoted Q) on the tape in written form or in the classroom. We also assume that there are no "psychological" advantages to teaching interactively, despite the fact that a wide range of educational research seems to suggest that involvement in a class is extremely important to students' utility levels and comprehension.

Teaching the total body of knowledge is assumed to require $\overline{T}$ minutes for all students. While we will introduce heterogeneity among teachers, students will be assumed to be identical in their capacity to learn. Students will differ only in their stock of initial knowledge. For example, when explaining that GDP is $ 5 trillion, these $\overline{T}$ minutes would include at least a thorough discussion of GDP, the failings of this measure, and some comparative information on what GDP is in other countries, what it has been in the past and what is GDP per capita. However, most if not all students know some of this information (especially if the audience is a set of economics Ph.D.s), and communicating the information can be done in less than $\overline{T}$ minutes.

Teaching involves gauging the students' ignorance so after an initial amount of knowledge transfer students are encouraged to reveal how much they don't

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[19]In reality, communicators frequently make use of two or more communications technologies. Such an addition would complicate things significantly.

[20]In fact, email and some letter writing can be seen as interactive technologies but with a higher cost of interaction than face-to-face interactive teaching. These forms of teaching really occupy a middle ground.

know and how much more they need to be taught. Students either reveal the extent of their knowledge through questions or facial expressions. Since students may have some information, teachers need not spend the entire $\overline{T}$ minutes teaching, when the teacher is communicating with the students interactively. If the teacher is communicating via transcription, the teacher must include the entire $\overline{T}$ minutes of knowledge or accept that some students might not learn everything they need to learn. Since we have assumed that teachers must generate complete knowledge, transcribed teaching must contain all $\overline{T}$ minutes.

The primary benefit of interactive teaching in this model is that teachers can tailor their teaching to the students' ignorance and need not include unnecessary facts when they know what their students already know. This benefit is commonly thought of as "the students can ask questions." The ability of students to ask questions, and thereby reveal their ignorance, enables the teacher to tailor and avoid teaching everything (or more likely in the real world, teaching incompletely).

There may well be other benefits of interactive teaching that are not captured in this model. We will not discuss agency problems that can occur when teachers are trying to generate a higher level of attention and effort than students want to deliver. Agency effects might further support the benefits of interactive teaching where teachers are able to directly monitor their students. Furthermore, there may be psychological effects (usually thought to be positive) associated with live teaching that we cannot possible capture with a simple model.

In the first version of the model, information is ordered. By ordered, we mean that if a student knows the kth piece of information, he must also know the k-1th piece of information. Made more precise in the framework of this model, each student requires T_i minutes of teaching, before he has learned all he needs to know about the topic. The sense of ordered information is that if student i requires T_i minutes, and student j requires T_j minutes, where $T_i > T_j$ then student i knows strictly less than student j and must learn all of the things that student j needs to know. The distribution of T_i has a cumulative distribution function F(T), an expectation $\hat{T}$, and an upper bound $\overline{T}$.

With transcribed knowledge, students themselves can stop reading or listening when they have learned completely what they need to know. We assume a probability δ, that each student misses any particular piece of information and needs to have it repeated. Students are assumed not to miss a piece of information twice. If students didn't miss anything, each student i must spend exactly T_i minutes viewing the tape or reading the book. Since students miss information, they are actually required to spend $(1+\delta)T_i$ minutes learning. The cost of each students' time is denoted C_S.

The teacher must transcribe information equal to the maximum T_i that might exist in the student population to make sure that all students learn everything, i.e. $\overline{T}$. The price of the teacher's time is denoted C_T. The total expected cost of teaching these students using the transcription method is $\overline{T}C_T + N(1+\delta)\hat{T}C_S$. To expand this model slightly, we will assume that the transcription may be reused in subsequent classes. In this case, we divide the cost to the teacher of transcribing the information by R, where R denotes the number of times that the transcription will be repeated, and the teacher's time costs should be interpreted as the cost per class. The total cost of the transcription method is $\overline{T}C_T/R + N(1+\delta)\hat{T}C_S$.

If the teacher is teaching face-to-face we can consider two possible scenarios: (1) students can leave after they have learned all that they need to know, and (2) students are forced to stay through all of the teaching (presumably because there will be subsequent topics addressed in the same class). In the first scenario, each student spends only as much time as he or she needs to learn the topic. We denote $Max[T_i, N]$ as the expected maximum level of T_i realized over N students. Again, students may miss certain points and require repetition. For simplicity, we assume that students all miss the same points, so the students will require $(1+\delta)Max[T_i, N]$ minutes of instruction.

When students are allowed to leave after they have learned what they need to, the expected total cost of interactively teaching all the students is $(1+\delta)Max[T_i,N]C_T + (1+\delta)N\hat{T}C_S$, The costs of face-to-face teaching represents a lower cost than transcribed teaching when:

(17) $$\frac{\overline{T}}{R} > (1+\delta)\text{Max}[T_i, N].$$

The fundamental tradeoff is that with face-to-face teaching, the teacher must revisit the topics that the students miss and that with transcribed teaching the teacher must answer all of the possible questions students might ask. If students miss more, then transcribed teaching makes more sense.

When there is a large gulf between what the students probably will need and what they possibly could need, then face-to-face teaching makes more sense. This gulf would be expected to be higher when the subject area is complicated, and there is a huge stock of knowledge that the student might potentially need. This gulf will rise with N because $Max[T_i, N]$ rises with N. As N goes to infinity, the benefits of using face-to-face teaching falls for the teacher because there will likely be one student who needs almost the complete range of teaching. When R=1, N gets sufficiently large, and $\delta>0$, transcribed teaching will always be preferable even for a one time usage.

Figure 3 shows that for simple or complex topics, as the class size rises the costs of teaching in person rise while the cost of transcribed teaching remain constant. This effect of class size would diminish if students abilities were correlated in the class. If the points that students miss were not perfectly correlated across students then face-to-face teaching becomes less appealing. As R rises, then again transcribed teaching makes more sense.

When topics gets more complicated (which we model as a shift in the distribution of T), the costs of both forms of teaching rise. If we assume that increasing complexity means that $\overline{T}$ rises faster than $Max[T_i, N]$, personal teaching becomes more appealing as complexity rises. For example, consider a simple topic where T is uniformly distributed on the interval [a, b]. The values of $Max[T_i, N]$ will be a+(b-a)N/(N+1), $\overline{T}$ will be b. and c respectively. As long as a>0 (so that everyone needs to learn something), an increase in b (the complexity of the topic) will lead to an increase in the ratio of $\overline{T}$ to $Max[T_i, N]$, and increase in the desirability of face to face teaching.

Somewhat more interesting is the comparison between having R teachers teach independently or having one teacher transcribe lectures for all R teachers. In this case, we may think that teachers differ in their quality of teaching. To capture this we denote a parameter, α, where a teacher of ability α, requires T/α "minutes" to teach T "minutes" of the subject to his students. We assume that the expectation of $1/\alpha$ across teachers equals 1, and that the best teacher has ability level $\alpha^*>1$. In that case, the cost of having R teachers teach R classes independently is still R times $(1+\delta)\text{Max}[T_i,N]C_T + N(1+\delta)\hat{T}C_S$. The cost of having the best teacher transcribe a lecture for all R classes is $\left(\bar{T}C_T + R(1+\delta)N\hat{T}C_S\right)/\alpha^*$. The comparison between optimal transcription by the best teacher and teaching by R independent teachers is:

$$(17') \qquad \frac{\bar{T}C_T}{R} > (1+\delta)\alpha^*\,\text{Max}[T_i,N]C_T + (\alpha^*-1)N(1+\delta)\hat{T}C_S$$

The basic comparative statics still hold, but now transcribed teaching will be more prevalent when α^* goes up, which means that the best teacher has gotten better relative to the average teacher. Transcribed teaching will also be better when students' time is more valuable relative to teachers' time, because students save time by having access to the best teacher.

When students are not allowed to leave the lecture hall, the benefits of face-to-face teaching contract further. The expected total cost of teaching the students face-to-face is $\text{Max}[T_i,N](1+\delta)(C_T + NC_S)$. This quantity will be less than the cost of transmitting the information by transcription if:

$$(17'') \qquad \frac{\bar{T}C_T}{R\alpha^*} > (1+\delta)\text{Max}[T_i,N]C_T + N(1+\delta)\text{Max}[T_i,N]C_S - \frac{N(1+\delta)\hat{T}C_S}{\alpha^*}$$

The costs of face-to-face teaching have increased because students now have to sit through the transmission of information that they already possess. There are no changes in the comparative statics, except that the cost of students time becomes more important, and as students' time becomes more expensive, relative to teachers' time, face-to-face lectures become less advantageous. Increases in class size will also always act to make face-to-face teaching more expensive relative to transcribed classes since more students will end up wasting their time in class, since the worst student in the class gets worse as class size rises. Segregation by knowledge would mitigate this problem substantially.

The savings of face-to-face teaching is that the teacher does not necessarily have to teach the student everything. The cost is that students who know everything have to sit through class time devoted to teaching their less knowledgeable peers. So face-to-face teaching will be more efficient when the teachers' time is expensive or when the students' time is cheap.

When using face-to-face teaching, there may be a natural optimum class size, depending on whether the problem is sufficiently concave (which will depend on the shape of F(.)), found by minimizing the average cost of educating each student or $(1+\delta)\mathrm{Max}[T_i, N](C_T/N + C_S)$. The problem we are solving is how many teachers to hire for a given number of students, which is equivalent to asking what level of N minimizes costs per student.

Increases in N allow the teachers to spread their time over a wider range of students, but they increase the length of time for teachers in a given class and higher levels of N increase the probability that students may have to listen to information that they already know. (The optimal class size is unbounded when students can leave the room.) The first order condition is:

$$\text{(18)} \qquad \frac{N}{Max[T_i, N]} \frac{\partial Max[T_i, N]}{\partial N} = \frac{C_T}{C_T + NC_S},$$

which means that the elasticity of maximum time spent with respect to N is equal to the share of class time costs that are born by the teacher.[21] The optimal class size rises as teachers become more expensive, or students time becomes less valuable. If students become more heterogeneous so $Max[T_i, N]$ rises, for a given $\frac{\partial Max[T_i, N]}{\partial N}$, then optimal class size will shrink as well.

[21]For this condition to be meaningful, second order conditions must hold as well.

Books vs. Lectures without correlated ignorance

If we now assume that information is not ordered, the advantages of face-to-face teaching diminish further. Here we will address this problem using a reduced form approach. We will also assume that students do not miss any points and that all teachers are homogenous. Furthermore, we will assume that transcribed information is organized or indexed so that students can readily identify only those things that they don't know.

Given a class of size N there will be an optimal order to teach the information (although perhaps not a unique ordering), even though individuals' ignorance are not perfect correlated. In general this will mean that for any individual who lacks T minutes worth of information, the individual will require more than T minutes worth of information if the class size is greater than 1. If the class size is exactly one, we assume that the class can be exactly tailored to this individual and he will be taught in exactly T minutes. As the class size grows, even given optimal structuring of teaching, the individual will need more and more total time spent in class because the class is less and less tailored to this particular individual.

In the case where students are not allowed to leave the classroom the situation is not very different from the previous case, there is just a slight alteration in the relevant variable. We define a new variable $\phi(N)$, which represents the total amount of information, that N students need. When information is completely ordered, of course, $\phi(N) = Max[T_i, N]$. It always must be true that $\phi(N) \leq \overline{T}$. As the correlation across students stocks of knowledge fall $\phi(N)$ must rise. In addition, $\phi'(N) > 0$. The cost of face-to-face teaching when students are not allowed to leave is $\phi(N)(C_T + NC_S)$. Teaching by transcription is dominated by face-to-face teaching wh$\left(n\overline{T}/R - \phi(N)\right)C_T > \left(\phi(N) - \hat{T}\right)NC_S$. The intuition for this inequality is unchanged from the intuition for equation (17). The only change is that now as the level of correlation in the type of ignorance across students rises, the cost of teaching interactively falls. Face-to-face teaching is much more likely to be optimal when students need to learn the same thing, even if they need different quantities of that same thing.

When students can leave after they have learned all of the information that they need, the problem gets somewhat more difficult. The order in which the teacher presents the information becomes important. We denote $T_i + \tau(i,\Theta)$, as the amount of time person i needs to gain complete knowledge given that the teacher has chosen an order of teaching, denoted Θ. The term $\tau(i,\Theta)$ represents the wasted time each student spends listening to information the he or she already knows. We assume that the teacher quickly understands the nature of the students' ignorance and can choose Θ, to minimize $\sum_{i=1}^{N} \tau(i,\Theta)$. We denote this optimal ordering as $\tilde{\Theta}$; this optimal ordering is properly thought of as a function mapping the knowledge requirements of students into a single order of teaching. The teacher will always need to spend $\phi(N)$ units of time teaching, so the teacher's time costs need not be considered in finding the optimal ordering of information.

The total cost of this form of teaching will be $\phi(N)C_T + N\hat{T}C_S + NE\left(\tau(i,\tilde{\Theta})C_S\right)$, where E(.) denotes the expectations operator. The comparison between face-to-face teaching and transcribed teaching then becomes:

(19) $$\left(\overline{T}/R - \phi(N)\right)C_T < NC_S E\left(\tau(i,\tilde{\Theta})\right)$$

As we increase the number of students, transcribed teaching will be more efficient, for three separate reasons. First, $\phi(N)$ rises. Second, more students spend wasted time. Third, the expected value of $\tau(i,\Theta)$ also rises with the number of students-- there is more need for wasted time as the number of students with differing educational needs rises.

Telephones and Meetings

The previous section focused on the difference between transcribed information (books or taped lectures) and information being transferred in person. In the previous section the hallmark of personal interaction was that the individual could stop teaching when he knew that the students had learned enough. Since both telephone and face-to-face contact occur in real time and feature instant responses, this cannot be the difference between telephone and face-to-face contact.

There are several possible primary differences between using the telephone and face-to-face contact. The first difference is simply visual cues. We use our faces, hands, bodies, etc., to transfer added information. There is more information that can be transferred when those cues are used than when they are not used. Obviously, this may suggest that telephones should be desirable when individuals want to protect certain types of information. This disadvantage of telephone conversation should be eliminated as phones include screen contact, although today this is still a substantial part of the advantages of telephone contact.

A second potential cost of using telephones rather than face-to-face speaking is that there may simply be positive utility generated by face-to-face speaking. This is somewhat ad hoc, but it seems to be true, at least based on our own introspection. While we suspect that this aspect of positive utility is important, we will not focus on it in this model.

Instead, the aspect of telephone communications that distinguishes it from face-to-face interactions is that individuals can do things together when they meet face to face. Doing things together can include looking at the same document, performing some simple task, watching television, or going for a walk. The advantages of face-to-face interaction that we shall stress stem ultimately from the fact that verbal information transmission can be joined with actions that others take. We will also include a parameter that capture the utility gained from interpersonal contact, but our primary results are basically independent of that effect.

The basic intuition for this is that it is almost impossible to teach someone to play the piano over the phone. The entire learning process depends on the teacher watching what the students do and then informing them of the mistakes that they make. Frequently the teacher will then play the piano himself and show the student how it is done. Even if the teacher could watch the student (by means of visual links to the phone), the teacher would not be able to play together with the student, adjust the students' hands, or in any way participate in the piano playing process himself.

This type of process exists any time two individuals are trying to get a task done together and are trying to share information. In principle the teacher could set out the complete set of information ahead of time, or try to verbally describe the problem to the student, but since verbal instruction is surely an imperfect substitute for performing the task yourself, there will be costs to telephone communication.

We assume that the task involves K sequentially performed subtasks. As in Kremer (1993), if one of the subtasks is performed incorrectly the entire project suffers severely. We will consider two possibilities: first the outcome of the subtasks are not apparent until the entire task is completed, and second, the outcome of the subtasks will be apparent as soon as the subtask itself is completed. There are many examples of the former types of technology. Computer subroutines or parts of cooking are sometimes difficult to evaluate until the entire routine has been run or until the meal is completed. Many tasks also fall into the latter category, learning how to type or learning to speak a foreign language reveal the learners problems on each subtask immediately.

We first consider the case where outcomes are readily observable. In many cases of learning, repetition is needed to instill a skill in memory. Face-to-face learning will have a total time cost, which is equal to the total time of performing and repeating the task, describing the subtasks, and coming back and forth to the lessons. We assume that each task must be learned sequentially, and that the student must learn each task (which requires R repetitions) before he or she can move on to the next task. The teaching will then optimally take the form of K lessons, and in each lesson either the teacher or the student must travel (in general, we will be assuming that the student's time is cheaper so he travels). The teacher must describe the task and the student and teacher must perform the task once together. Then the student goes home and repeats the task R times and then returns for his or her next lesson. Each subtask is assumed to be homogenous. Thus the time involved in each lesson is d(the time spent describing) plus t (the time spent performing the task), which is paid by both teacher and student. The student in addition pays 2*v (where v is the time spent getting to the teacher).

The time spent performing the tasks is equal to K*R*t; the time spent describing is K*d. The total cost of learning a task through face-to-face interactions is:

(20) $$K\left(C_T(t+d)+C_S(t+d+2v+Rt)\right)$$

This method of teaching is assumed to be completely accurate. The telephone/videophone method of teaching avoids the costs of traveling to the teacher. Instead the learning portion is simply done over the phone. The teacher need not perform the task with the student. The cost of this form of learning is that the student may not get the knowledge properly unless he actually does the task with the teacher. There will be some probability that the student has misunderstood the teachers instructions (denoted M).

If the teacher can actually evaluate the subtask separately, the student can perform the subtask for the teacher after Q repetitions (the minimum necessary for the subtask to be interpretable by the teacher-- we assume that the teacher only hears the Qth repetition). After the student listens or watches or reads the students performance (which again has time cost t), the teacher can correct the student's mistakes (if any). If the student has made a mistake the Q repetitions are wasted, but the teacher can correct the task perfectly (still over the phone, at a time cost d_2) and the student then performs the R repetitions necessary to get the task correctly. The price of learning each subtask is then:

(21) $$C_T(t+d+Md_2)+C_S((1-M)(Rt+d)+M(d+d_2+(Q+R)t),$$

and the cost of learning the entire task is K times that amount. Using (20) and (21), teaching over the telephone dominates teaching face to face when:

(22) $$2v>\frac{C_T}{C_S}Md_2+Md_2+(MQ-1)t.$$

Face-to-face learning becomes more appealing when the price of coming to the teacher's house (v) is low or when the student's time is not very expensive, or when M (the probability of being misunderstood is high) or when d_2 is high, or when C_T is high, or when Q or t is high. While many of these comparative statics are fairly obvious, there are some points which may be more subtle. An overall increase in everyone's value of time will not effect the decision between face-to-face and telephone interactions, but as the ratio of teacher's time cost to student's time cost rises, we expect to see more face-to-face meetings, since they minimize the time costs of the individual with the more valuable time. Perhaps this explains why children are taught face-to-face so often.

The more complicated the task (so that the probability of misunderstanding is high, the number of repetitions necessary before the subtask can be evaluated is larger or the amount of time needed to explain any mistakes is longer), the more likely individuals are going to use face-to-face meetings.

When each subtask cannot be separately evaluated, then only the entire task can be evaluated after the student has tried to learn everything. In this case, the individual learns all K tasks and then repeats the tasks Q times. If the individual has misunderstood an instruction, the teacher will not know which instruction to repeat and thus must repeat all the instructions.. Repeating all instructions will take Kd units of both the teacher's and the student's time. In the case that the student has messed up his trial run (after Q units of practicing all subtasks), and has heard all K tasks repeated (and is then assumed to have learned the task entirely), he must perform R new repetitions for all tasks that he misunderstood In this case, the total costs of teaching the student are:

$$(23)\quad C_T(Kt + Kd + (1-(1-M)^K)Kd) + C_S(KRt + Kd + (1-(1-M)^K)Kd + KMQt)$$

The cost of learning over the phone will always be higher than the cost when you can check after each subtask. This cost will be higher than the cost of learning face-to-face when:

$$(24)\quad 2v > \frac{C_T}{C_S} d(1-(1-M)^K) + (1-(1-M)^K)d + (MQ-1)t$$

Figure 4 shows our basic results. As the distance to the teacher rises, the cost of learning in person rises and the cost of learning over the phone stays constant. Eventually teaching over the phone dominates teaching in person. As the number of subtasks (K) rises, the expected cost of learning over the phone rises, while the expected cost of learning in person is constant.

Face to face interactions are likely to be more costly if v is high, or if student time is more valuable relative to teacher time, or if d is low, or if M or Q is low, or if t is low (when $MQ<1$ then face-to-face teaching becomes more appealing when t is high). Now it is also true that as K grows, it becomes more likely that face to face teaching will dominate learning over long distance. Again it seems as if telephones are less appealing and effective when the tasks are more complicated. Furthermore, the conditions for face-to-face teaching to dominate are more likely to hold when students check their mistakes for each subtask separately instead of only being able to check correctness when the whole task is done.

Section IV. Suggestive Evidence

Ideal evidence on whether cities and information technology are complements or substitutes would be an exogenous shock to the quality of telecommunications and an investigation of the response of urbanization to this shock. Ideally, all other forces effecting urbanization would be held constant. Some evidence on this topic can be gained from the introduction of the telephone, but there were a large number of additional factors driving urbanization in the late 19th century, so we cannot claim that we have isolated any effect of the telephone.

The model suggested that it was sufficient to look at the relevant use of telephones in urban and non-urban areas, and such information is available but problematic. The model's conclusions assumed that any concentration of telephone usage in the city would be the result of cities, not the selection of people prone to communicate into cities. This selection bias makes interpretation difficult, but we nevertheless look at the connection between urbanization and telephone usage across countries, across prefectures in Japan and across consumers in the U.S.. Finally, we look at how business trips (one measure of face-to-face interactions) have changed in the past 20 years as telecommunications quality has improved.

All of this evidence should be seen as suggestive and highly preliminary. Our main conclusion is not that it is obvious that face-to-face contacts and telephone contacts are complements. Rather, we can only say with confidence that there is no evidence whatsoever that suggests that telephone and face-to-face contacts are substitutes.

The City and The Telephone-- Historical Evidence

Perhaps the most relevant piece of evidence on how current telecommunications changes will effect cities is the historical connection between urbanization and telephones in the late 19th and 20th centuries. The telephone was invented in 1876, but telephone usage in the United States did not become significant until after 1894 (when Bell's patents expired). Contemporary observers immediately believed that telephones would "exert a powerful influence on the problems of country life." (Kingsbury, 1895 cited in Moyer, 1977), but it is not obvious that telephones either greatly expanded or contracted the role of cities. Pierce (1977) also suggests that telephones do not seem to have had a particularly negative effect on any of the alternative communication media (the post, books).

Moyer (1977) connects telephones with the rise of urban decentralization in Boston over the late 19th and early 20th centuries. The evidence Moyer presents is mixed. Decentralization began before the telephone, and the best evidence showing the connection between telephones and urban decentralization is anecdotal and suggests a complex relationship. In addition, urban decentralization may mean that highly urban activities are now done in the suburbs (which would be seen as a decline in the relevance of cities) or that rural areas have now become cities (which would be seen as an increase in the relevance of cities). Certainly, the period of urban decentralization that Moyer discusses is one in which Boston's relevance as a metropolis grew significantly. Perhaps the most striking, if not the most convincing, piece of Moyer's evidence is a quote from F. Rice, Jr. who wrote in 1906 that "the telephone is in short about the greatest urbanizer on record."

The overall record on the time series connection between urbanization and telephones can be seen in Figures 5 and 6. Figure 5 shows the path of urbanization and telephones in the U.S. from 1840 to 1980. The urbanization measure is persons living in urban places, and the telephone measure is phones per 100 citizens, which is a worse but more available measure than number of households with access to phones. The growth of urbanization seems to fairly oblivious to the introduction of the telephone and its growth. There is no trend break at 1900 for urbanization and the leveling off in urbanization since 1960 is best seen as the result of reflecting diminishing returns to urbanization, not telephone growth.

Figure 6 shows the connection between telephone growth and urban growth decade by decade since 1840. The basic point is that there is no connection whatsoever. This result does not change if we eliminate the pre-telephone observations from the regression. We certainly cannot claim that the historical evidence shows a tight connection between urban growth and telephones, but it does seem to be true that the telephone did not eliminate or mitigate in a major the rise of urban centers. We are left relying on anecdotal reports such as Gottman (1977) who writes "the telephone has been used in the evolution of settlement in diverse ways but mainly as a help in the development of larger metropolitan systems with a more diversified and complex structure."

Cities and Telephones-- Japanese Evidence[22]

Thus far, we have only used data on the presence of telephone lines. In Japan, we have data available on a prefect-by-prefect basis of both numbers of telephone calls and time spent making telephone calls. With this data, we can show the connection between the urbanization of the prefecture and its tendency to use telephones, holding income constant. Unfortunately, we cannot correct for the fact that individuals who are more prone to interact may select to live in cities.

Our data on telephones was provided by the Japanese Ministry of Post and Telecommunications. Our data on income comes from the Economic Planning Agency and our urbanization data comes from the Management and Coordination Agency. The definition of urbanization in this data is living in cities with more than 100,000 people (which differs from the standard definitions of urbanization). Our phone call data combines long distance and local calls. Our basic result is the following regression (standard errors are in parentheses):

[22]Takuo Imagawa provided us with the evidence and the regression for this section.

(25) Total Minutes of Calls = -.7+.37*Log(Income)+.10*Urban, R-Squared=.58, N=47
(.10) (.03)

Similar results show up if we use the total number of calls instead of the total minutes spent calling. The connection between urbanization and phone calling is quite strong in this data and is significant at more than the 1% level.

This is our strongest evidence that people who live in cities are more prone to use telephones. As we showed earlier, this condition (if there is no selection of individuals into cities) is sufficient to show that cities and telecommunications are complements. If this results survives controlling for selection, then it suggests that in Japan at least improvements in telecommunications will increase the size of cities.

Cities and Telephones-- International Evidence

Our next evidence on the connection between cities and telephones comes from the World Development Report 1994, which presents evidence on the number of telephone mainlines per household and the amount of urbanization. This evidence shows whether more urbanized countries make more or less use of telephones. Of course, urbanized countries differ along many dimensions from non-urbanized countries, even beyond GDP per capita, so any interpretations of this data must be tentative at best. Our urbanization and GDP numbers also come from the World Bank.[23]

Figure 7 shows the relationship between the log of GDP per capita and both telephones and urbanization. The two figures both move together with GDP strongly. The slope on telephones starts lower and is somewhat less steep. Both methods of increasing communication seem to rise similarly as development proceeds.

Figure 8 shows the nonlinear connection between phones and income. At relatively low levels of GDP there are almost no phones in most countries.

[23]Our choice of using World Bank GDP numbers instead of Summers and Heston figures is fairly arbitrary. We do not believe that our result would change significantly moving to alternative measures of national wealth.

However after a certain point (a GDP level of about $ 4,000 per capita in 1994 dollars) there is a jump and there are a large number of phone lines per household. This might be evidence for a multiple equilibria type view of phones created by the strategic complementarity across phone users. The value of having a phone is almost nil when none of your neighbors have phones, so either everyone gets access to phones or no one has access to phones. Alternatively, this might reflect substantial fixed involved in telephone infrastructure. We used a fifth order polynomial to fit this highly non-linear relationship.

Figure 9 shows the raw relationship between phones and urbanization. The two variables are correlated at above the 70% level. Figure 10 shows the much weaker relationship once we have controlled for GDP per capita. This figure shows the relationship of the residuals from two regressions of phones and urbanization on the fifth order polynomial shown in Figure 7. There is still a positive and significant correlation, but it is much weaker than in Figure 9.

We interpret these results as suggesting that phones and cities tend to go together, but that this connection is primarily the result of development driving both of these variables. Holding income constant, there is still a connection between phones and urbanization but not a terribly strong one.

Cities and Telephones-- Evidence from the Consumer Expenditure Survey

In order to get some evidence on telephone usage in the United States, we used the Consumer Expenditure Survey to connect telephone expenditures with city size of residence for the years 1989-1991. Unfortunately this survey told us nothing about the prices people face so it is difficult to interpret these results as telling us about quantities of phone time actually consumed. In general, it is true that long distance companies are not allowed to price discriminate geographically, so in some sense price may be constant over space. A particular problem is that in small towns, a much smaller number of people will be accessible through local phone service, so relying on long distance phones may underestimate the true usage in large cities relative to small towns.

Because almost all individuals in the survey had local service and local service expenditures reflect basically the fixed price of the monthly local fees we excluded local service from the regressions. Our independent variable is the natural logarithm of one plus long distance telephone expenditures. We have excluded agents with multiple properties and business expenditures.

In regression (1), we control for real income and real income squared. We also control for midwest and south dummies. The east is the omitted area and our data does not include the west coast (city identifiers were not given for the west). We have four city variables (these definitions are the only ones available): major city (which refers to living in a "primary statistical unit," with more than 4 million people), big city (which refers to living in area with less than 4 but more than 1.2 million people), average city (an area with less than 1.2 but more than .33 million people), a small city (less than .33 million and more than 75 thousand) and other (which means areas with less than 75 thousand people-- rural areas are not in the data set).

The results show that the largest telephone expenditures occur in the omitted tiny city areas and the second largest expenditures are in the major cities. The big city and the average cities have somewhat less expenditures than the major cities. The tiny city has the least expenditures, and these are significantly less than the expenditures in the major city. In regression (2), we control for the age of the reference person (usually the head of household) and the family size. These basic results are unchanged.

We are not sure how much of these results refer to prices and how much refer to quantities. If we interpret these results as quantities, then they imply that improvements in telecommunications should help the least urban areas and the most urban areas. The areas that will be hit are the medium and small sized cities. Of course, these results are tentative at best.

Telephones and Business Travel

Early in the use of telephone it was obvious that phones were a complement to travel. Aronson (1977) relates that the hundred largest hotels in New York city had 21,000 telephones in 1909, which was more than Spain and almost as many as the continent of Africa. The Waldorf-Astoria had the largest number of telephones under one roof in the world. To this day, telephones, email, and faxes continue to be useful for organizing trips and for calling home while away.

Our next evidence on the connection between telecommunications and face-to-face interactions is the change in the number of the business trips since 1972. The period since 1972 has seen the growth of faxes, e-mail, cellular phones and a steady improvement in the quality of telecommunications. Unfortunately, there have also been changes in the features of business travel, most importantly a major airline deregulation.[24]

Instead of trying to adequately control for these myriad features, we have simply presented two figures showing the change in the number of business trips since 1972. This data has been culled from the various copies of the Statistical Abstract of the United States and the ultimate source of this information is the National Travel Survey. Figure 11 shows the raw number of business trips divided to real GDP and shows the significant rise in those trips. Our decision to normalize by dividing by real GDP seems logical, and alternatively choices of normalization (such as dividing by the total size of the labor force) show a much more striking rise in business travel.

The second set of data in Figure 11 shows the real cost of airline travel on a per mile basis. These costs were originally in cents per mile, but we have normalized them so that our graphed measure takes on a value of 100 in 1973. These costs are calculated and described by Morrison and Winston (1995).[25] Airline costs, particularly during the era of deregulation fell sharply in this period.

Figure 12 shows the path of business travel "controlling" for airline prices. This graph is found by first regressing business trips divided by real GDP on real airline costs. Our cost controlled measure is just the residuals from that time series regression. The graph shows a substantial decline in air travel from the early 1970s to the early 1980s. This decline reflect the fact that even though real air prices substantially fell, business travel divided by GDP did not rise substantially at all. While one explanation of this fact is a substantial decline in

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[24] It is worthwhile stressing, though, that the changes since deregulation have improved prices for flexible vacationers more than for business travelers.

[25] The data were kindly provided for us by Steven Morrison.

the demand for air travel over that period, a second explanation is that our time series regressions have substantially overestimated the price elasticity of demand for travel.

Since the 1980s, Figure 12 shows a substantial (and statistically significant) rise in the level of business travel/GDP, controlling for airline prices. The rise is capturing the sharp rise in real travel/GDP shown in Figure 11 and the relatively small movements in the cost of air travel over that period. Since the mid 1980s, when faxes and then email became ubiquitous, business travel has risen more than 50%.

It would be impossible to prove that this change is directly the result of improved communications technology. Increasing role of industries like consulting or other relatively travel intensive fields might well explain this change. Nevertheless, most travelers must be aware the improved telecommunications have made much travel easier and more effective. Faxes and e-mail make it easier to set up meetings and to communicate home when the meetings are going on. Furthermore, as suggested by the model, it is possible that improved telecommunications have increased our overall number of contacts which eventually lead to more travel.

While, this evidence (like all of our evidence) is only suggestive, business trips are important because they give us a direct measure of face-to-face interactions. Certainly this measure suggests that the informational changes since the 1970s have increased the importance of face-to-face interactions. We have yet to see if these changes result in urban growth or urban decline.

Coauthorship in Economics

Our final piece of highly suggestive evidence looks at the rise of coauthorship in economics journals. We assembled data on the percentage of articles published in four top journals (the *American Economic Review*, *Econometrica*, the *Journal of Political Economy* and the *Quarterly Journal of Economics*) over three years at decadal intervals (i.e. 1960-1962, 1970-1972, 1980-1982 and 1990-1992). Our goal was to look at the patterns in coauthorship and the geographic dispersion of coauthorship. These results are presented in Table 2.

The second column shows the overall rise in coauthorship. Between the 1960s and the 1990s, coauthored articles grew from being a relative rarity (12.1% of published articles) to a majority phenomenon (55.7% of published articles). There are many possible explanations for this rise (increased complexity of topics, changing social norms in the profession, and so on), but there is no question that it is an indication of increased interactivity in the production process, and a greater number of productive relationships.

The most striking increases occurs for out-of-state and out-of-country coauthorships. These two groups together grew from representing 4.6% of all papers in the 1960s to 27.6% of all papers in the 1990s. We counted papers as out-of-state or out-of-country if at least one of the coauthors was from out-of-state or out-of-country, so perhaps this figure is biased upwards, still it represents a significant growth in interregional and international coauthorship that is good evidence for the increasing globalization of the economy.

However, this increased globalization has not caused a decrease in the number of articles coauthored locally. Indeed, the percentage of articles coauthored with someone from the same school or in the same metropolitan area has risen from 5.7% of all articles in the 1960s to 18.3% in the 1990s. If we include articles coauthored with someone from the same state the growth if from 7.5% in the 1960s to 28.1% in the 1990-1992 period. This growth represents 20.6% of the 43.6% growth of coauthorship.

Yet growth in the 1980-1990 decade was particularly skewed towards relationships that occurred beyond state and local boundaries. The notable fact for this decade is not that there wasn't disproportionate growth in the non-local joint papers, but rather that this growth did not seem to diminish the level of local contacts. This growth created an overall rise in the degree of interactivity, not a decline in the amount of local relationships. Further research would be needed to know whether increased coauthorship involved face-to-face contacts or just increased electronic communications. Anecdotal evidence seems to suggest that even long distance collaborations involve significant face-to-face contact, and thus the increase in non-local relationships also means an increase in face-to-face meetings and demand for greater localization.[26]

Section V. Conclusion

Information technology may indeed eventually cause a decline in the need for urban concentration. However, the case is much less clear than the futurists would have us believe. As telecommunications improve, the demand for interactions of all sort should rise and the role of cities as centers of interactions should also increase. After all, the most famous modern agglomeration of industry, Silicon Valley, has occurred in the industry with the most access to the latest and best information technology. This agglomeration probably occurs, as Saxenian (1993) and others suggest, because that industry relies so much on interactions and has so much knowledge to be transferred across firms and individuals.

Our work also suggests that the live lecture, the personal training session and the piano lesson are not dead either. While there are unquestionably gains related from using transcribed communication, or telephones, there are also dramatic advantages from communicating interactively and in person. These advantages seem to be most important when tasks are complicated and instructions can easily be misunderstood. Since none of the futurists seem to think that the world is getting any simpler, we must surmise that the advantages of face-to-face communications may in fact increase over time.

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[26]For example, this paper would classify as a long distance collaboration. Nevertheless, it involved significant face-to-face interactions initially (when Glaeser was at Hoover) and at least one trip after that period.

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Appendix

In this appendix, we present a somewhat more general form of the model in Section Two. In this case, we assume that conditional on choosing to initiate a contact the output of that contact will be $f(\beta_P t_1, \beta_F(t_2 - t_F)) - ct_1 - ct_2$, where t_1 refers to the time spent on the phone, t_2 refers to the time spent in face-to-face contact, and t_F is again the fixed costs involved in initiating face to face contact. We are eliminating any concerns with match quality and we assume that the agents are not at a corner in their use of the two technologies. Differentiation gives us the first order conditions:

(A1) $$\beta_P f_1(\beta_P t_1^*, \beta_F(t_2^* - t_F)) = c = \beta_F f_2(\beta_P t_1^*, \beta_F(t_2^* - t_F))$$

where the starred quantities refer to the optimal level of time spent in the two communications methods. We assume that second order conditions hold. We can further differentiate this condition to determine how much the time spent in face-to-face interactions changes as the telecommunications technology improves:

(A2) $$\frac{\partial t_2^*}{\partial \beta_P} = \frac{f_1 f_{12}}{\beta_F \beta_P (f_{11} f_{22} - f_{12}^2)}$$

where the f_i refers to the derivative of f(.,.) with respect to its ith argument. The sign of (A2) is going to be a function of the cross derivative between telephones and face-to-face communications. In the case that the marginal product of face-to-face communications declines with more phone calling, then this term will be negative.

We again assume measure one of agents who are indexed with j on the unit interval who can either pursue the non-interactive project with returns R(j) or the interactive project that has choice about telephone and communications usage. The equilibrium condition sets:

(A3) $$f(\beta_P t_1^*, \beta_F(t_2^* - t_F)) - ct_1^* - ct_2^* = R(j^*)$$

Simple differentiation yields $\partial j^*/\partial\beta_P = t_1^* f_1 / R'(j^*)$. We are interesting in differentiating $t_2^* j^*$ with respect to β_P to see how the total amount of time spent in face to face interactions changes with telephone technology:

$$\text{(A4)} \qquad \frac{\partial(t_2^* j^*)}{\partial\beta_P} = j^* \frac{\partial t_2^*}{\partial\beta_P} + t_2^* \frac{\partial j^*}{\partial\beta_P} = j^* \frac{f_1 f_{12}}{\beta_F\beta_P(f_{11}f_{22} - f_{12}^2)} + t_2^* \frac{t_1^* f_1}{R'(j^*)}$$

This term is positive if:

$$\text{(A5)} \qquad \frac{\beta_F\beta_P t_2^* t_1^*}{R'(j^*)j^*} > \frac{-f_{12}}{f_{11}f_{22} - f_{12}^2}$$

which again is true for ranges of parameter values. Again the critical issue is whether the substitution effect outweighs the new contact effect.

TABLE 1: CITIES AND TELEPHONES,
Evidence from the Consumer Expenditure Survey

Dependent Variable: Log of 1 + Long Distance Telephone Expenditures	(1)	(2)
Major City (>4 million)	-0.040 (.021)	-0.041 (.020)
Big City (<4 and >1.2 million)	-0.073 (.017)	-0.079 (.016)
Average City (<1.2 and >.33 million)	-0.068 (.021)	-0.076 (.021)
Small City (<.33 and >.075 million)	-0.109 (.02)	-0.106 (.020)
Real Income	0.031 (.006)	0.004 (.006)
Real Income Squared	0.001 (.001)	0.003 (.001)
Age of Reference Person		-0.003 (.000)
Family Size		0.035 (.0035)
Midwest	0.005 (.015)	0.000 (.015)
South	0.010 (.016)	0.099 (.016)
R-Squared	.0622	.110
Number of Observations	6145	6145

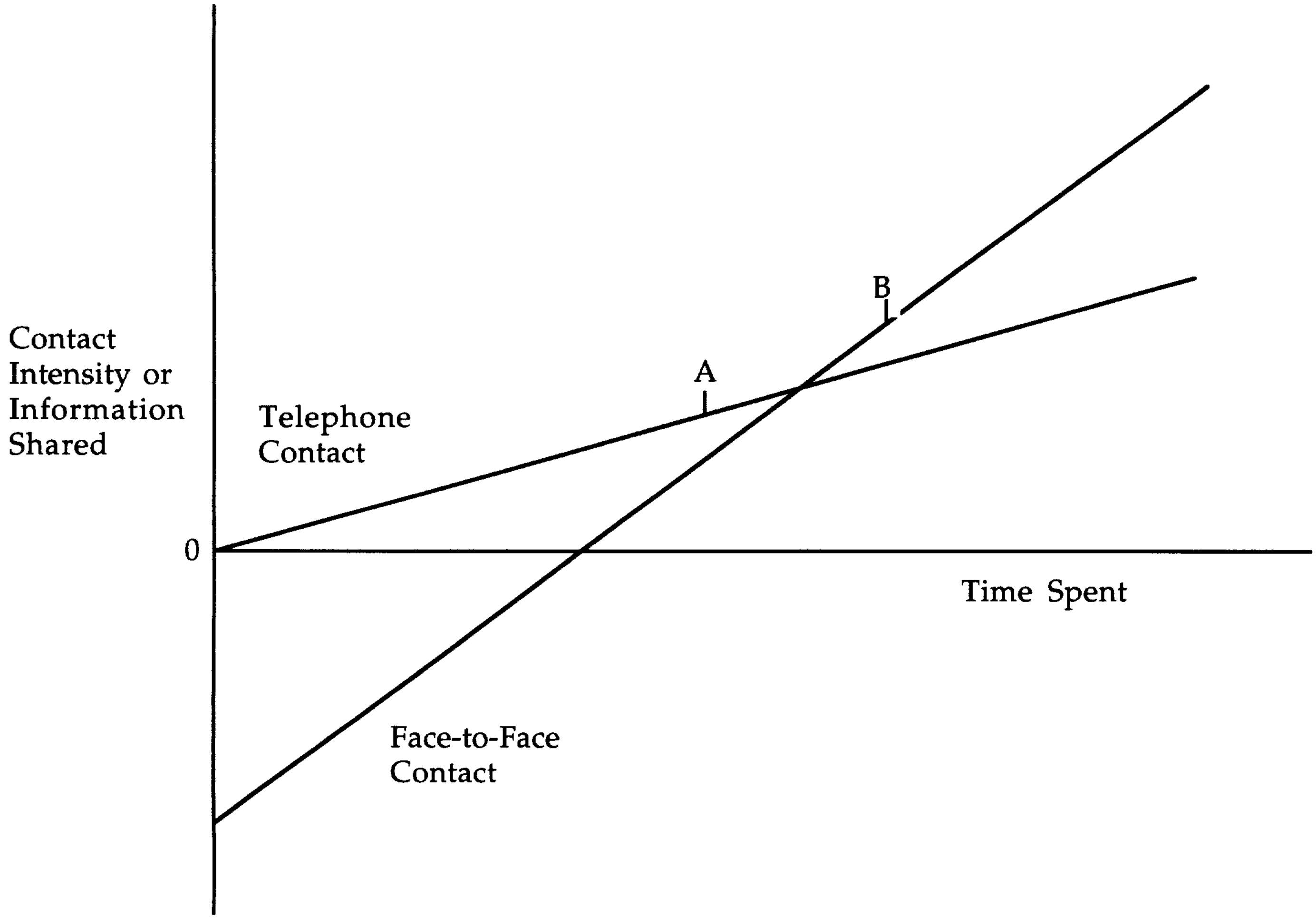
Note: Regression come from the 1989-1992 Consumer Expenditure Survey. Year dummies and an intercept are included in the regressions but not reported.

TABLE 2: COAUTHORSHIP IN ECONOMICS JOURNALS

Years (Total Articles)	Two or More Authors	Same School	Same City, Different School	Same State, Different City	Same Country, Different State	Different Country
1990-92 (812)	.557 (.009)	.135 (.004)	.048 (.002)	.098 (.002)	.179 (.005)	.097 (.003)
1980-82 (1081)	.359 (.007)	.141 (.004)	.040 (.001)	.063 (.001)	.060 (.002)	.055 (.002)
1970-72 (1077)	.225 (.005)	.084 (.002)	.013 (.0004)	.038 (.0004)	.054 (.002)	.034 (.001)
1960-62 (602)	.121 (.004)	.052 (.002)	.005 (.0002)	.018 (.0002)	.030 (.001)	.016 (.001)

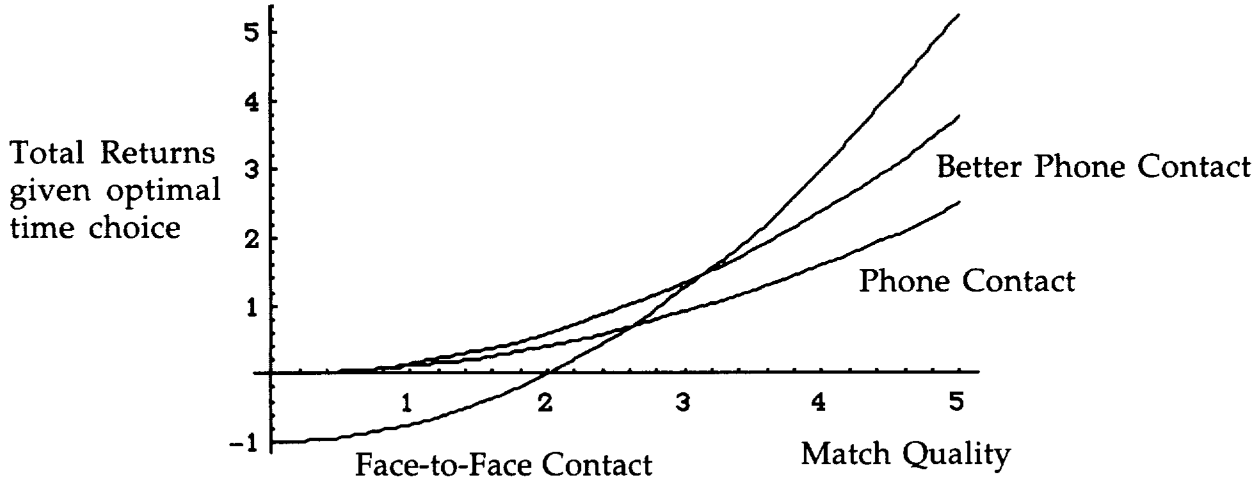
Notes: This data represents coauthorship information over twelve years, made up of four three year periods spread out over four decades. Information was gathered on articles in the *American Economic Review*, *Econometrica*, the *Journal of Political Economy* and the *Quarterly Journal of Economics*. Articles with multiple coauthors were classified by the most distant coauthor, so if the article had two coauthors from the same school and one coauthor from another country it was classified as a coauthored paper from two countries (i.e. it would be in the last column. Only research papers were included which includes shorter papers but excludes book review, and also articles that were tributes to the journal itself or to major economists. Standard errors are in parentheses.

Figure 1: Time and Knowledge Transfer



Point A denotes the point at which face-to-face contact becomes superior to telephone contact.

Figures 2A and 2B: Changes in the Quality of Telecommunications



This graph was created from a simulation of the model where f(x)=the square root of x, the cost of time is 1, the fixed time costs of face-to-face interactions is -1, the productivity of a unit of face time is 1, the productivity of a unit of old phone contact is .4, the productivity of better phone contact is .6.

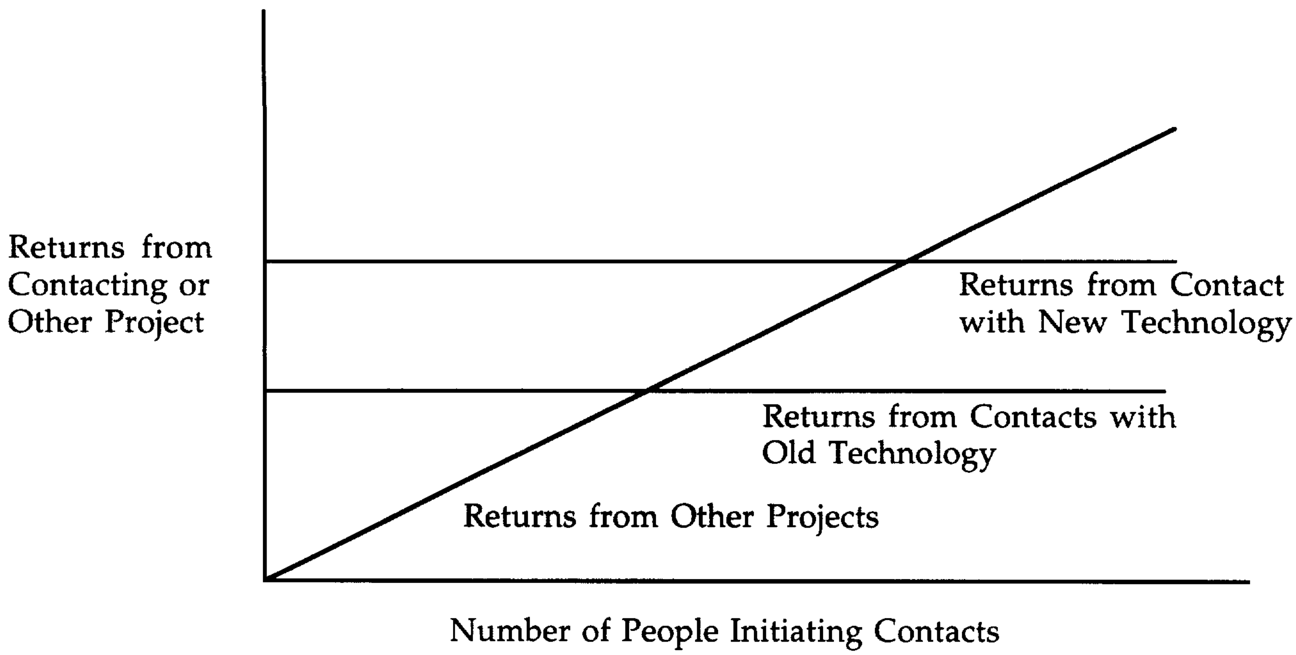


Figure 3: Personal vs. Transcribed Teaching

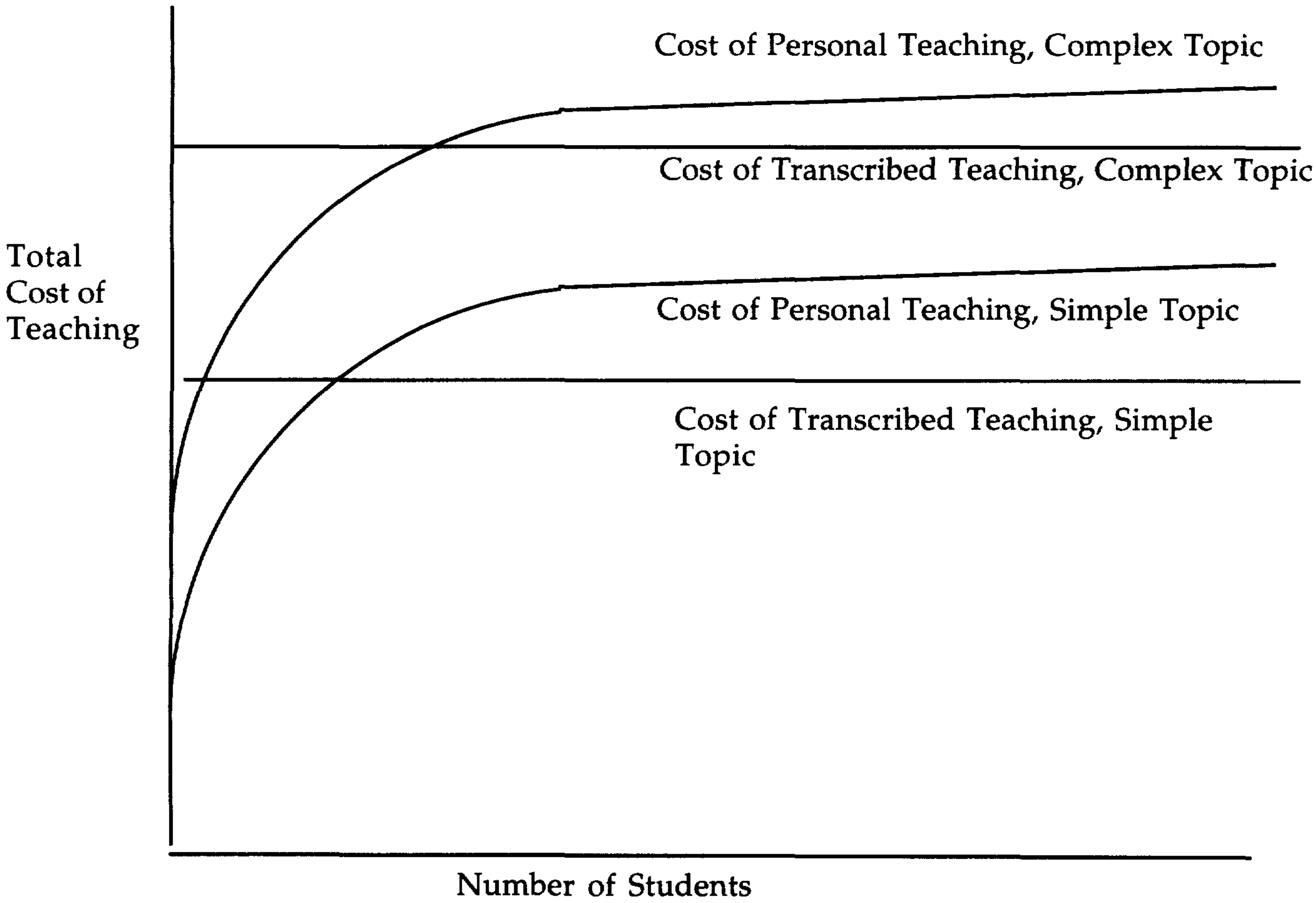


Figure 4: Personal Learning vs. Electronic Learning

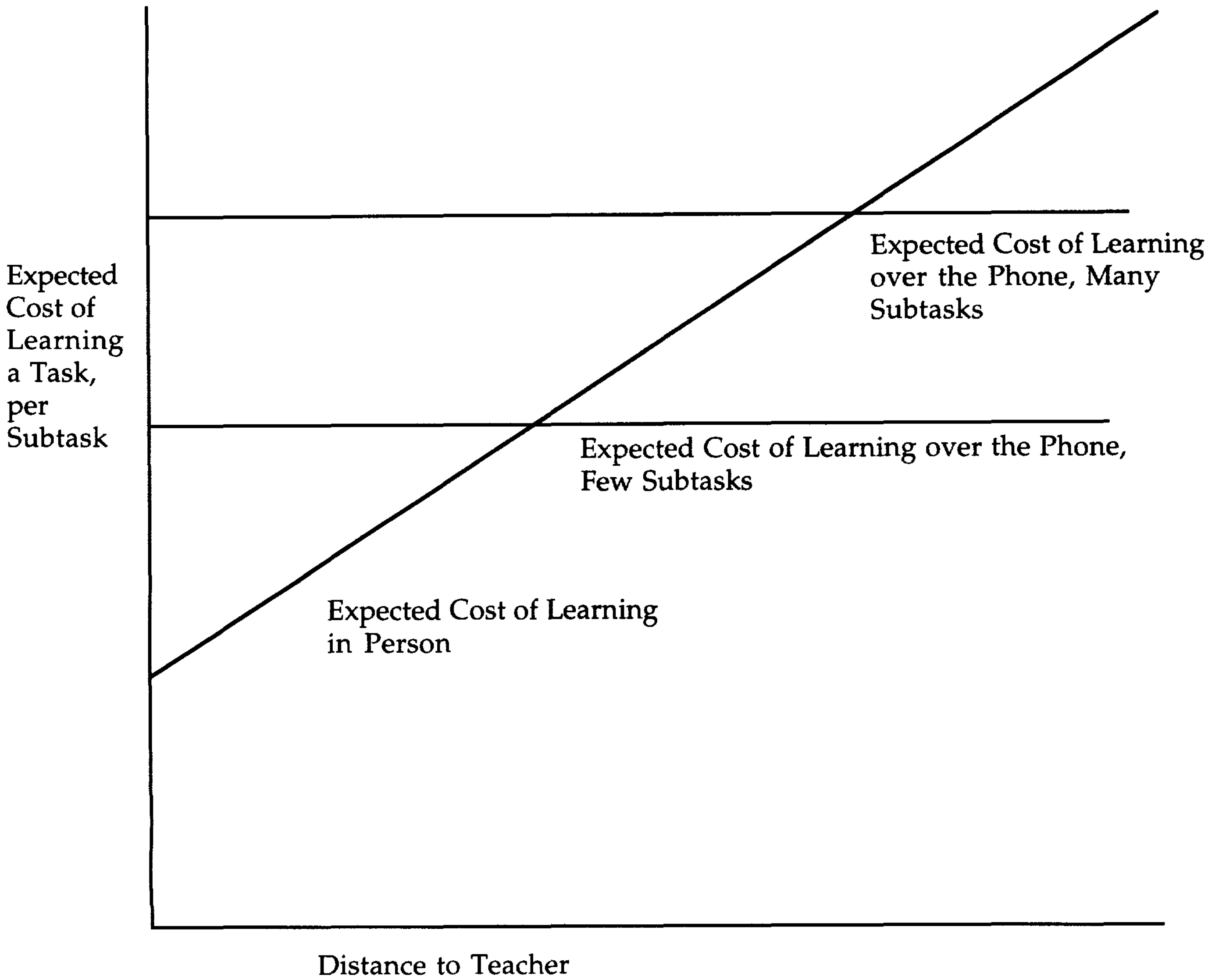


Figure 5: Urbanization and Phone Lines in the U.S., 1840-1980

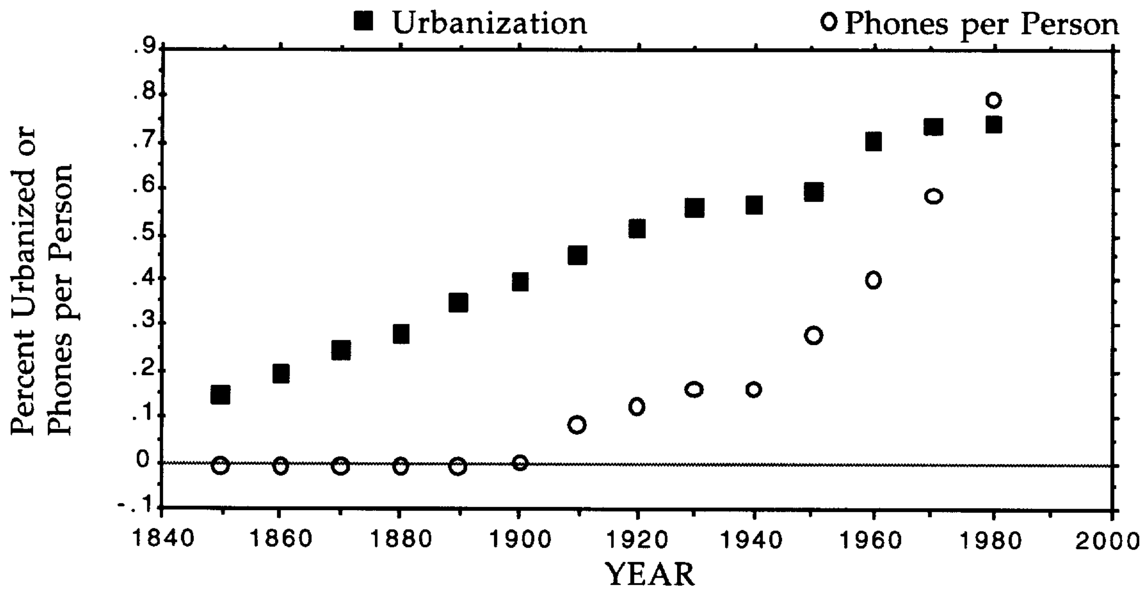
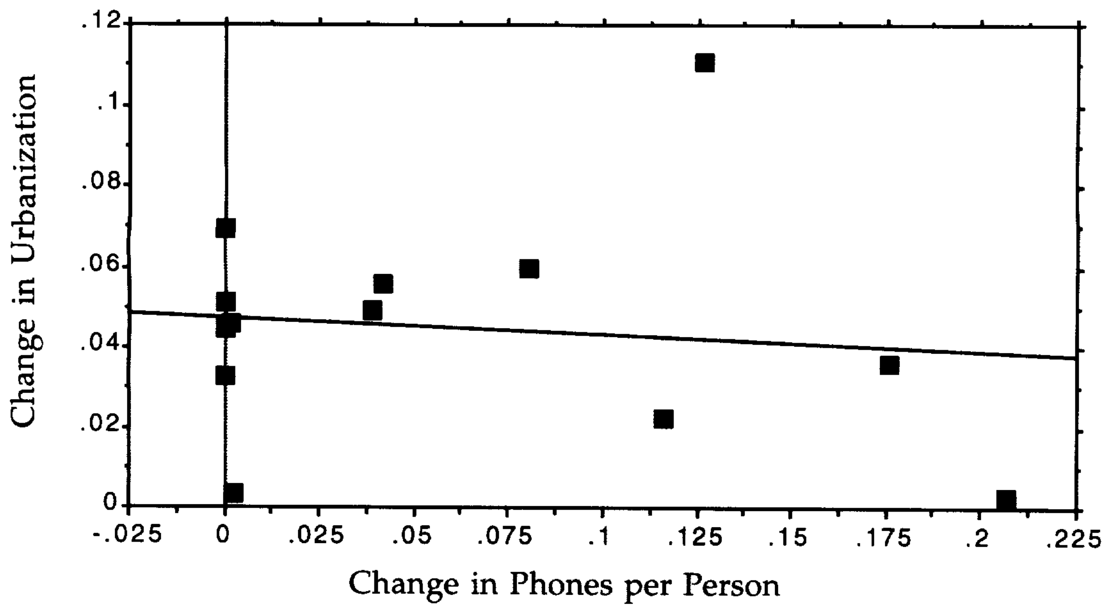


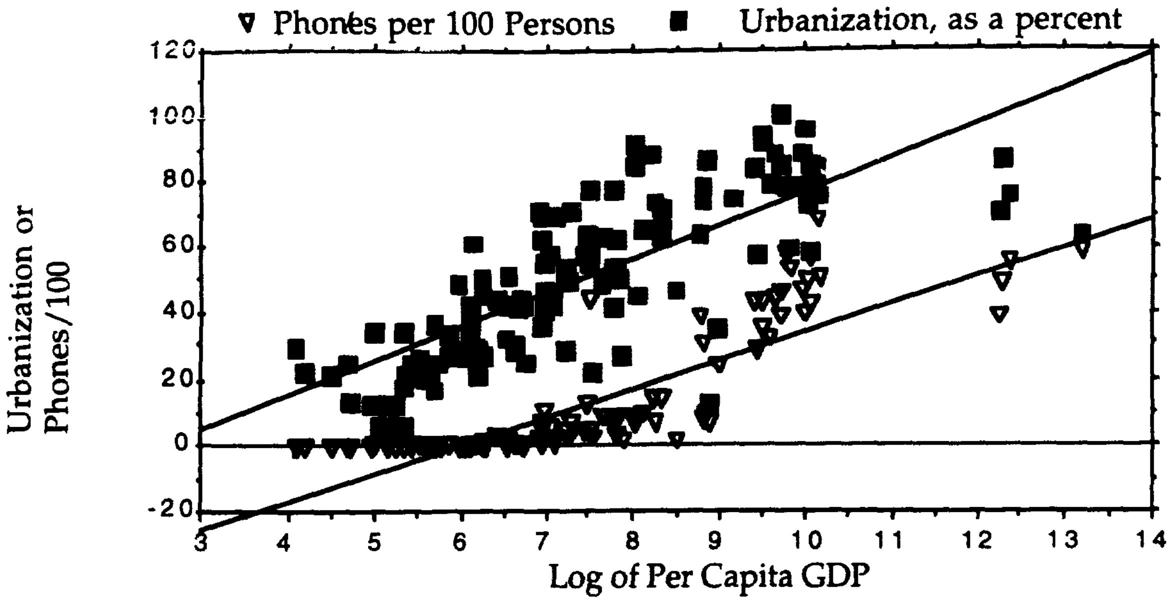
Figure 6: Change in Urbanization and Change in Phones



The regression estimated, with standard error in parentheses is:
Urban Change=.047-.041*Phone Change, Adj. R-Squared=-.07, 13 observations
(.11)

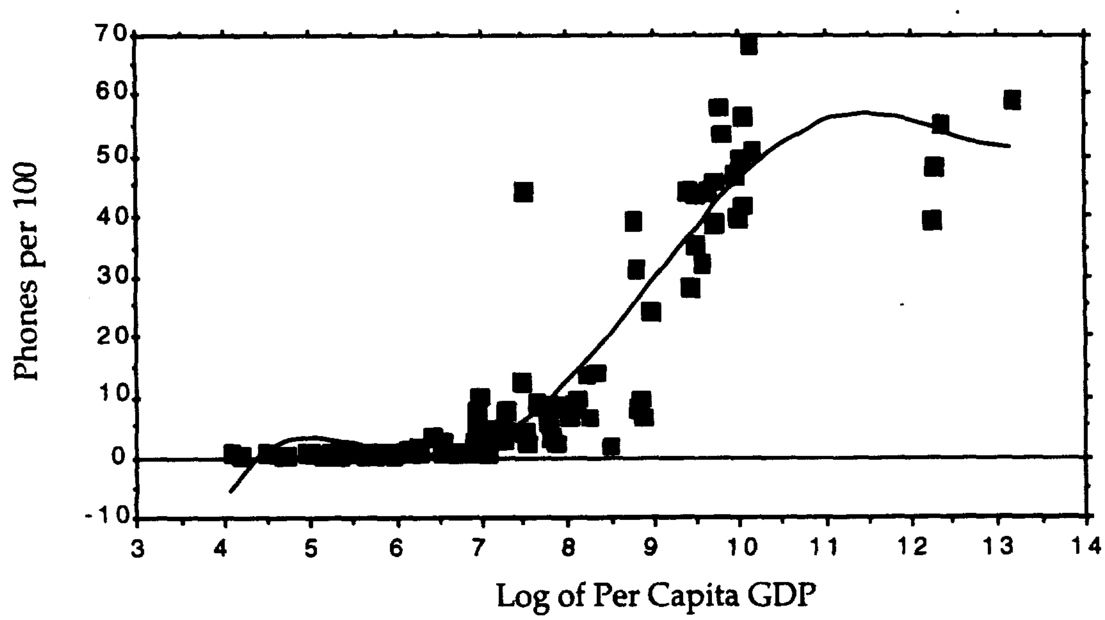
Source: These variables come from Historical Statistics of the United States 1790-1970 and issues of the Statistict Abstract of the U.S.

Figure 7: Urbanization, Telephones and Development



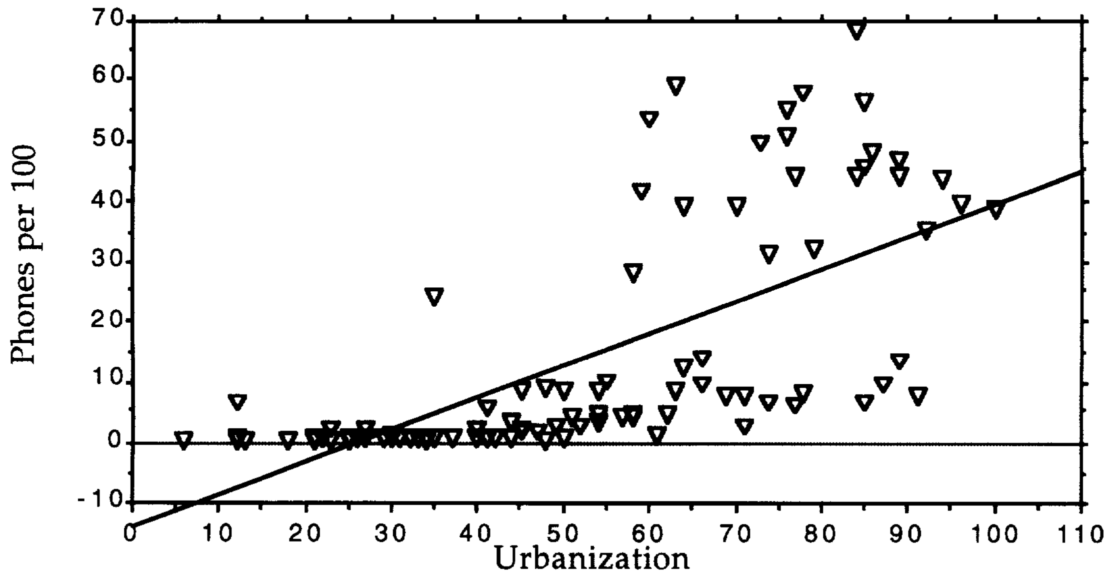
The two equations fit in this graph are (standard errors are in parentheses:
Urbanization=-26.3+10.29*Log(Per Capita GDP), R-Squared=.66, Observation=121
(.77)
Phones/100=-49.77+8.50*Log(Per Capita GDP), R-Squared=.71, Observations=101
(.54)

Figure 8: The Non-linear Relationship between Telephones and Income



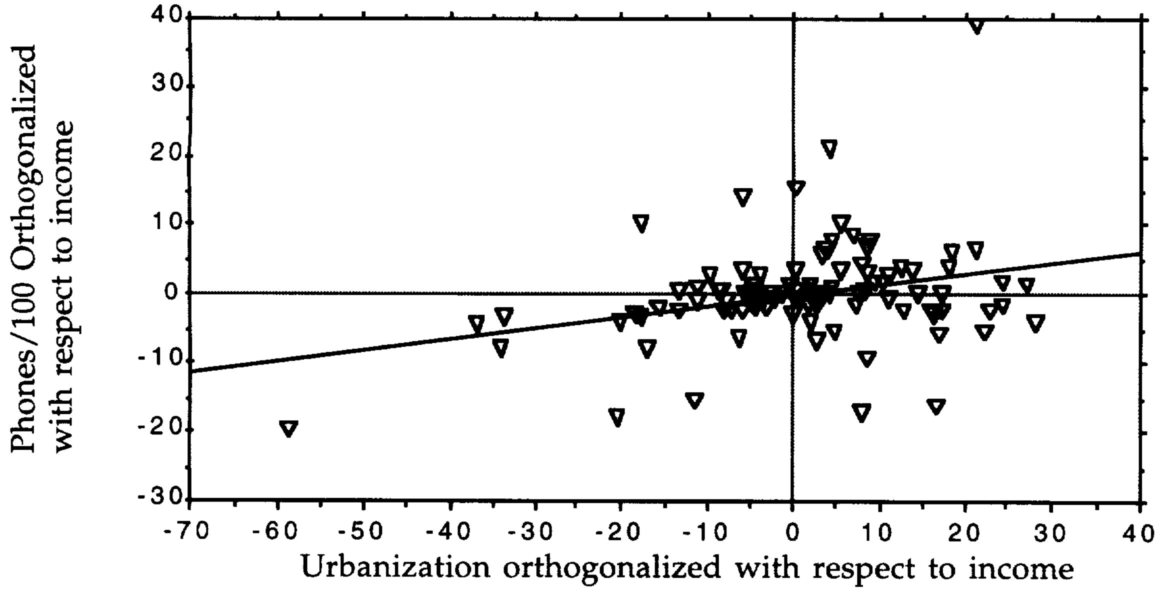
This figure shows the fit of a fifth order polynomial. All variables in this figures come from the 1994 World Development Report

Figure 9: Urbanization and Telephones across Countries



The equations fit in this graph are (standard errors are in parentheses:
Phones/100=-14.05+.533Urbanization, R-Squared=.47, Observations=100
(.057)

Figure 10: Urbanization and Telephones across Countries, Controlling for Income



Both phones and urbanization are the residuals from first stage regressions where they have been regressed on a fifth order polynomial of log gdp per capita.
The equations fit in this graph are (standard errors are in parentheses:
Phones/100=-.128+.159*Urbanization, R-Squared=.10, Observations=100
(.05)
All variables in these figures are taken from the 1994 World Development Report.

Figure 11: Business Travel in the U.S., 1972-1993

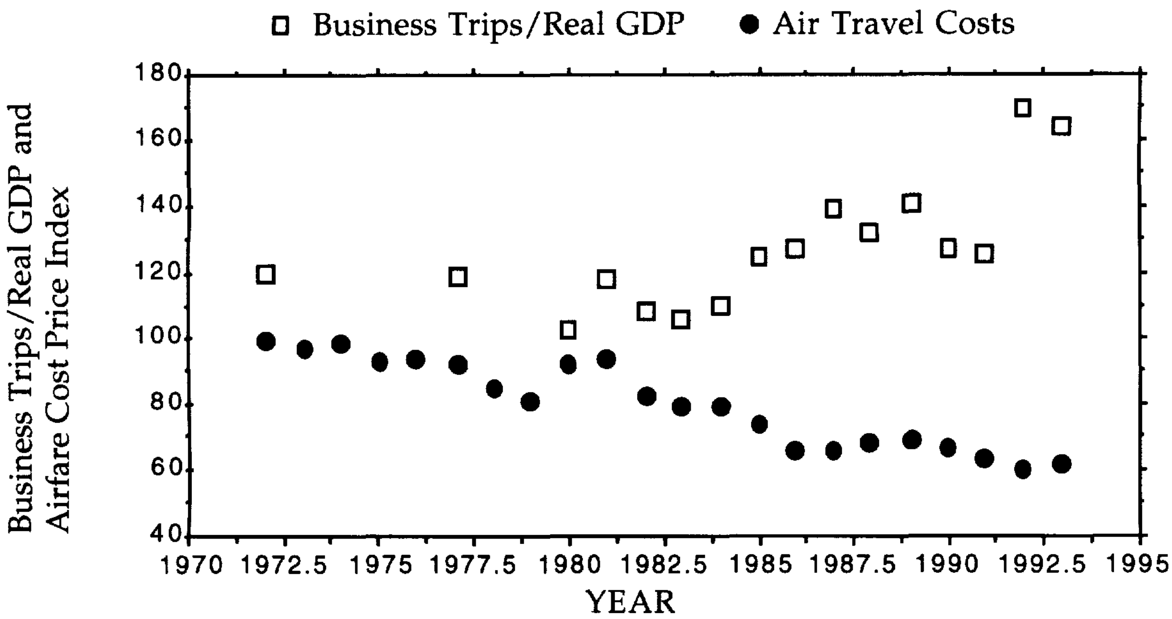
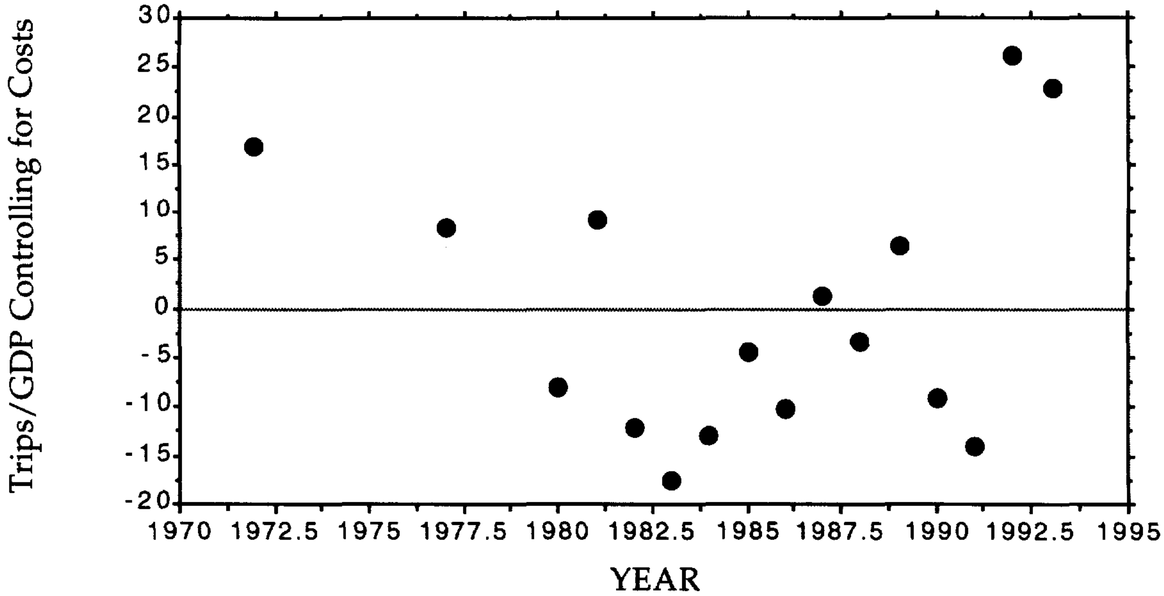


Figure 12: Business Travel and Costs , 1972-1993



In the top graph business trips in millions have been divided by real GDP in 1987 dollars and multiplied by 4 trillion. The air travel costs were provided by Steven Morrison. In the bottom graph, trips/real gdp were first regressed on air travel costs in a linear time series regression. Source: Business trips, GDP and prices are taken from various issues of the Statistical Abstract of the United States.