Did the Death of Distance Hurt Detroit and Help New York?*

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Abstract

Urban proximity can reduce the costs of shipping goods and speed the flow of ideas. Improvements in communication technology might erode these advantages and allow people and firms to decentralize. However, improvements in transportation and communication technology can also increase the returns to new ideas, by allowing those ideas to be used throughout the world. This paper presents a model that illustrates these two rival effects that technological progress can have on cities. We then present some evidence suggesting that the model can help us to understand why the past thirty-five years have been kind to idea-producing places, like New York and Boston, and devastating to goods-producing cities, like Cleveland and Detroit.

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1 Introduction

Thirty years ago, every major Northeastern and Midwestern city looked troubled. America had twenty cities with more than 450,000 people in 1950. Every one of them lost population between 1950 and 1980, except for Los Angeles, Houston and Seattle. The primary source of economic decline for these places was a decline of manufacturing, which first suburbanized, as in the case of Henry Ford's River Rouge Plant, and then left metropolitan areas altogether. Improvements in information technology had made it quite easy for corporate leaders, who often remained in the older cities, to manage production in cheaper locales.

But since 1980 a number of older cities, which had been declining, started once again to grow both in population and often more strikingly in incomes. Places like New York, San Francisco, Boston and Minneapolis have all thrived since the 1970s, generally in idea-intensive industries, like finance, professional services and new technology. Urban density that once served to connect manufacturers with railroads and boats now serves to facilitate contact of smart people in idea-producing sectors. The idea-producing advantages of geographic concentration are not a new phenomenon. After all, Alfred Marshall wrote in 1890 that in dense agglomerations "the mysteries of the trade become no mystery, but are, as it were, in the air." However, these idea-producing advantages appear to be more and more critical to the success of older, high density cities.

This paper advances the hypothesis that improvements in transportation and communication technology can explain both the decline of Detroit and the reinvigoration of Manhattan. While we present some suggestive evidence, the main contribution of this paper is a model that illustrates how reductions in the costs of communication can cause manufacturing cities to decline and innovative cities to grow. Reductions in transport costs reduce the advantages associated with making goods in the Midwest, but they increase the returns to producing new ideas in New York.

In the model individuals choose between three activities: (1) innovating, which creates more varieties of advanced products, (2) manufacturing those advanced goods, and (3) producing in a traditional sector which we think of as agriculture. Firms can also choose whether to locate in a city or in the hinterland. Urban location is associated with the scarcity of real estate, but also with the availability of shared infrastructure and with knowledge spillovers that depend on the direct interaction between individuals, and therefore thrive on density.

We assume that the traditional sector needs land the most and suffers the least from poor communication, while the innovative sector needs land the least and loses the most from communication difficulties. Since the city has a comparative advantage in speeding communication and limited, and hence expensive, land, the traditional sector locates entirely in the hinterland, while the innovative sector locates entirely in the city. The manufacturing sector is generally split between the city and the hinterland. These predictions of the model roughly describe modern America, where high human capital industries tend to be centralized within metropolitan areas, manufacturing is in medium-density areas and natural resource-based industries are generally non-urban (Glaeser and Kahn, 2001).

All individuals have the same level of productivity in the manufacturing or traditional sectors, but we assume that there is heterogeneous ability to innovate. As a result, the most able people end up in the innovative sector. Heterogeneity of ability determines decreasing returns to the size of the innovative sector, and it also predicts that the economy will become more unequal if it becomes more innovative.

The model allows us to consider the impact of improvements in information technology. We model these improvements as a reduction in the disadvantage that people working in the hinterland suffer due to the local nature of knowledge spillovers and the inability to share urban infrastructure. This may affect both the manufacturing and innovative sectors; however, as long as the innovative sector stays entirely in the city, what matters at the margin is the cost associated with advanced manufacturing in the hinterland. In our view, the comparative statics are meant to reflect the increasing ability of corporate leaders or idea producers, who remain in urban areas, to communicate with far-flung production facilities.

When the costs of distance fall, manufacturing firms leave the city, which causes a decline in urban income and property values. The economy as a whole is getting more productive as the city's advantage in production is disappearing. This effect captures the decline in erstwhile manufacturing powerhouses like Cleveland and Detroit.

But the decline in communication costs also has two other impacts which are more benign for the city. Most importantly, reducing these communication costs increases the returns to innovation. Since the city has a comparative advantage in producing new ideas, this effect increases incomes in the urban area. The exodus of manufacturing and the decline in the costs of urban land also increase the total size of the innovative sector in the city, which in turn further bolsters urban success through the increasing returns to new idea production that are a key element in models like ours (Grossman and Helpman 1991, Romer 1990).

As communication costs decline and the size of the innovative sector increases, within-city inequality increases. This increase in inequality does not represent a welfare loss, for improvements in communication technology improve the real wages for all workers even though nominal wages for workers in the city decline. City population will rise as city manufacturing declines, because the innovative sector is less land-intensive than the manufacturing sector.

As long as manufacturing is the industry on the margin between the city and the hinterland, then decreasing the productivity costs of locating in the hinterland will reduce city property values. However, once all manufacturing has left the city, then further decreases in communication costs impact the city mainly by increasing the returns to innovation through a reduction of the costs of production. In this case, further improvement in information technology causes urban land values to rise. We think of the first case as capturing cities like New York and Boston in the 1970s, when the exodus of manufacturing first caused property values to plummet, while the extension reflects these cities in more recent years, when booming innovative sectors have been associated with rising real-estate costs.

We also extend the model to consider a second city. The agglomeration externality implied by local knowledge spillovers makes it efficient for the innovative sector to cluster completely in one of the two cities. Manufacturing instead locates in both. In this case, an improvement in communication technology causes the more innovative city to increase its population and real income relative to the manufacturing city. When improvements in transportation technology reduce manufacturers' dependence on urban infrastructure, property values in the two cities also diverge. This model is meant to show how technological progress can strengthen idea-oriented cities and hurt production-oriented cities.

After discussing the model, we turn to a little suggestive evidence. First, we document the connection between urban success and specialization in innovation, measured, as the model suggests, by employment in primarily non-governmental occupations that are high-education. Specialization in these high-education, and presumably more innovative sectors, is positively correlated with income growth between 1980 and 2000 and with employment growth over the same time period in the Northeast and Midwest. We also find that successful places increased their specialization in these activities, just as the model suggests.

Second, we turn to the model's predictions about urban inequality. We find that inequality within cities rose more in cities that had faster income growth and in cities with more initial specialization in skilled occupations initially. These effects are, however, modest.

2 Urban Diversity and Improvements in Communication Technology

Before proceeding to the model, we first review four facts that motivate the model: (1) the past forty years have seen spectacular improvements in communication and transportation technology, (2) those improvements have made separation between idea-producers and manufacturers increasingly common, (3) there has been a remarkable heterogeneity in the growth of both income and population among many older cities since 1980, and (4) while all of the older cities suffered a significant decline in manufacturing jobs, the successful older cities have increasingly specialized in idea-intensive sectors.

Thousands of pages have been written about the improvements in transportation and telecommunication that have made it easier to ship goods and communicate ideas over long distances. Glaeser and Kohlhase (2004) summarize some of the evidence on the decline in moving goods over space; the real cost of moving a ton a mile by rail has declined by more than 90 percent over the last 120 years. The improvements in other transport modes have been at least as striking and the improvements in communications technology are, if anything, even more miraculous. Figure 1 shows the decline in the real cost of a three-minute phone call between New York and London from 1930 to 2000. The decline has been more than ninety-nine percent.

The substantial improvement in information and transportation technology has at least two separate sources. First, there has been a proliferation of new technologies that facilitate communication across space. Among the communication technologies that were not generally available in 1975 but are commonplace today are fax machines, cellular phones, e-mail, the internet, wi-fi, and personal digital assistants. Many of these technologies, like cellular phones, existed before 1975, but they only became widely affordable after that date.

Increased competition in key communication sectors, like telephones, air travel and cargo shipping, has also improved the ability to exchange information, goods and services over long distances. For example, in 1973, Federal Express began challenging the U.S. Postal Service in providing speedy delivery of packages. In 1982, as part of a settlement of an anti-trust case, ATT divested its local exchanges. After this divestment there was a considerable increase in long-distance phone companies, such as MCI and Sprint, that made long-distance communication cheaper. In the late 1970s, the airline industry was also deregulated, which increased competition and reduced prices in that sector.

These technological improvements have been accompanied by an "increasing separation of the management and production facilities of individual firms" (Duranton and Puga, 2005). Duranton and Puga (2005) connect this separation to the increasing specialization of cities on the basis of function (i.e. management or production) rather than industrial sector. Kim (1999) is among the empirical sources cited by those authors, and he found that the share of manufacturing workers in the U.S. working in multi-unit firms increased from 51 percent in 1937 to 73 percent in 1977. There is also an increase in the number of corporate headquarters that are separate from their production facilities (Kim, 1999), which is also seen in the work of Henderson and Ono (2007). The rise in multinational firms, which has been extensively documented and discussed (Markusen, 1995), represents a particularly extreme example of increasing geographic distance between firm leadership and production.

Our third motivating fact concerns the heterogeneity in urban success within the U.S. over the last forty years. Population and income give us two alternative measures of urban growth and Figure 2 shows the path of population for six major metropolitan areas. Since 1970, San Francisco has grown by more than 17 percent. Chicago has grown by 13 percent, while Detroit has lost more than 20 percent of its population. New York and Boston lost population in the 1970s, but have gained since then. Over the third decade, the population of New York increased by two percent while the population of Boston rose by eight percent. Cleveland has steadily lost population.

There has also been substantial divergence in income levels across metropolitan areas. Figure 3 shows the time path of earnings per worker in the largest county of each of these metropolitan areas. Since County Business Patterns is the natural source of firm-level data, this pushes us to look at the counties that surround the areas' economic centers. The earnings of New York and San Francisco soar over this time period. Wayne County (Detroit) begins with the highest payroll per worker and declines over the time period, starting out quite prosperous but losing substantially relative to the other two areas. In 1977, Wayne's payroll per worker was slightly higher than that of New York and today it is less than 60 percent of income in New York.

Figure 4 shows the distribution of median family income across metropolitan areas in 1980 and 2000. As the figure shows, the variance of incomes across metropolitan areas increased substantially over this twenty-year period. Almost all of the increase occurred in the 1980s.

Our final motivating fact is that the successful cities are specialized in idea-producing industries, while the less successful cities are in social services with some remaining manufacturing. Table 1 shows the top five industry groups measured by total payroll in the largest counties of the six metropolitan areas shown in 1977 and 2002. In 1977, manufacturing dominates four of the six cities, sometimes by a very substantial margin. In 1977, more than one half of Wayne County's payroll was in manufacturing. Even in New York, the payroll in Finance and Insurance only slightly nudged out manufacturing.

By 2002, manufacturing remains the dominant sector in Detroit and Cleveland, but it is now a much smaller share of the total payroll. In 2002, more than fifty-three percent of the payroll in New York is in finance and insurance and professional, scientific and technical services. More than forty percent of the payroll of San Francisco lies in these two areas. Chicago and Boston are more mixed and they do both idea-oriented production and manufacturing. In the next section, we present a model that attempts to explain the divergence of city economies as a result of improvements in the ability to communicate across space.

3 The Model

3.1 Basic setup

This model attempts to describe innovation and production in a closed economy where labor is mobile across space. We will address inter-urban inequalities in an extension that allows for a second city, but we begin with two locations: a city and the hinterland. Workers choose between three occupations: working in the traditional sector, working in the advanced sector, and innovating in a way that produces more varieties of differentiated goods for the advanced sector.

Individual utility is defined over the traditional good Z and measure n of advanced goods that are aggregated into a composite commodity Y in the manner of Dixit and Stiglitz (1977):

$$Y = \left[\int_0^n x(j)^{\alpha} \, dj \right]^{\frac{1}{\alpha}} \text{ with } \alpha \in (0,1) \tag{1}$$

The traditional good Z is produced with a fixed technology that has constant returns to scale. The market for Z is perfectly competitive, so its price equals unit cost: $p_Z = c_Z$. We treat Z as the numeraire, so that p_Z equals one.

Our focus is on demand for the advanced goods, and we will characterize aggregate demand by the homothetic preferences of a representative household, whose budget share for Y is

$$\beta(p_Y) = \frac{p_Y Y}{p_Y Y + Z} \tag{2}$$

For example, if the utility function has constant elasticity of substitution σ, so that $U(Y, Z) = (1-\varsigma)^{\frac{1}{\sigma}} Y^{\frac{\sigma-1}{\sigma}} + \varsigma^{\frac{1}{\sigma}} Z^{\frac{\sigma-1}{\sigma}}$, then the budget share is $\beta(p_Y) = \left[p_Y^{\sigma-1} \varsigma / (1-\zeta) + 1 \right]^{-1}$. We will assume that elasticity of substitution is never below one; equivalently, that demand for the advanced good has no less than unitary own-price elasticity; hence that $\beta'(p_Y) \leq 0$. Individuals will also need to consume exactly one unit of location-specific capital as a residence

Each differentiated advanced good is produced by a monopolistic competitor at a constant unit cost of c_x. As in Dixit and Stiglitz (1977), monopolistic competition with constant elasticity of substitution implies mark-up pricing, so the price of each differentiated good, p_x, satisfies:

$$p_x = \frac{1}{\alpha} c_x \tag{3}$$

and monopoly profits are

$$\pi = (1 - \alpha) p_x \frac{X}{n} \tag{4}$$

where X is the total output of differentiated varieties by identical producers. This implies the price index for the composite commodity Y:

$$p_Y = n^{-\frac{1-\alpha}{\alpha}} p_x \tag{5}$$

Thus greater variety is equivalent to higher efficiency. As in Ethier (1982), we could interpret the invention of new goods as an increase in specialization, associated with productivity gains arising from the division of labor.

3.2 The Innovation Sector

Each worker requires κ_n units of location-specific capital (i.e. land) to produce innovation, and one unit of location-specific capital for a residence.

Advanced goods are invented by an innovative sector that thrives on proximity. The urban advantage in producing new ideas is a reflection of knowledge spillovers that depend on the face-to-face interactions of researchers, and are therefore local. Each innovator's productivity depends on the external effect S of aggregate human capital. In the manner of Fujita and Thisse (2003), we assume that the innovation knowledge spillovers in the city are a function of the number of innovators in the city L_n^U and of the number of innovators outside of the city L_n^R:

$$S_U = \left[\int_0^{L_n^U} h(j)\, dj + \eta \int_0^{L_n^R} h(j)\, dj \right]^\delta \tag{6}$$

where $\delta > 0$ measures the returns to scale in knowledge externalities, and $\eta \in (0, 1)$ is an inverse measure of the difficulty of achieving profitable spillovers by means of occasional long-distance communication, rather than day-to-day proximity. For innovators who locate outside of the city, low density implies that all interactions are sporadic, yielding spillovers

$$S_R = \left[\eta \int_0^{L_n^U + L_n^R} h(j)\, dj \right]^\delta \tag{7}$$

Each worker's knowledge stock is assumed for simplicity to be identical, depending on worldwide scientific progress. With a convenient normalization $h(j) = 1$ for all j. Hence

$$S_U = \left(L_n^U + \eta L_n^R \right)^\delta > S_R = \eta \left(L_n^U + L_n^R \right)^\delta \text{ for all } L_n^U, L_n^R \tag{8}$$

implying that it is efficient for all knowledge workers to congregate in the city.

Workers are heterogeneously endowed with creativity according to a Pareto distribution (cf. Helpman, Melitz, and Yeaple, 2004) with minimum $\underline{a} > 0$ and shape $\theta > 1$, so that

$$F(a) = 1 - \left(\frac{a}{\underline{a}}\right)^{-\theta} \text{ and } f(a) = \theta \underline{a}^{\theta} a^{-\theta-1} \tag{9}$$

and each urban innovator's output is aS_U. We assume that all individuals have the same output in manufacturing both the differentiated goods and the numeraire, and that all heterogeneity is in creativity. As a result, creative people sort perfectly into the innovative sector, and employment in this sector is characterized by a marginal worker with creativity t. Heterogeneity in the ability to innovate both acts as a check on the amount of innovation, because eventually the marginal innovator is not very good at innovating, and predicts more inequality in the innovative sector.

When all innovation occurs in the city, total employment in innovation is

$$L_n = L_n^U = L\left[1 - F(t)\right] = L\underline{a}^{\theta} t^{-\theta} \tag{10}$$

and therefore knowledge spillovers are

$$S_U = L_n^{\delta} = L^{\delta} \underline{a}^{\delta\theta} t^{-\delta\theta} \tag{11}$$

and the total amount of innovation is

$$n = LS_U \int_t^{\infty} af(a)\, da = L^{1+\delta} \underline{a}^{(1+\delta)\theta} \frac{\theta}{\theta - 1} t^{1-(1+\delta)\theta} \tag{12}$$

For notational convenience, define the inverse measure of productivity

$$\psi_n \equiv L^{-\frac{1}{(1+\delta)\theta-1}} \left(\frac{\underline{a}\theta}{\theta - 1}\right)^{-\frac{\theta}{(1+\delta)\theta-1}} \tag{13}$$

which is decreasing in the mean of the skill distribution $\underline{a}\theta/(\theta - 1)$, and in the size of the pool of workers L, because a larger pool means that more able people will be available to this sector

Then, as a function of the amount of innovation, employment equals:

$$L_n = \psi_n n^{\frac{\theta}{(1+\delta)\theta-1}} \tag{14}$$

and the output of the marginal innovator equals:

$$tS_U = \frac{\theta - 1}{\theta\psi_n} n^{\frac{\delta\theta-1}{(1+\delta)\theta-1}} \tag{15}$$

Free entry into this sector means that $\pi t S_U$ must equal the opportunity cost of labor for this marginal worker plus the cost of κ_n units of location-specific capital.

3.3 The Spatial Equilibrium

Production of manufacturing goods occurs with a Leontief technology, with κ_x unit of location-specific capital per worker employed in production, in addition to one unit of capital as a residence. Output per worker depends on local knowledge spillovers S^{μ}, with $\mu \in [0,1]$ measuring the importance of knowledge spillovers for manufacturing relative to innovation. It is also a function of the availability of labor-saving urban infrastructure. Producing one unit of advanced goods in the city requires $\psi_x S_U^{-\mu}$ units of labor, and producing it in the hinterland requires $\psi_x (1+\tau_x) S_R^{-\mu}$.

This set-up enables us to nest two extreme versions of the model. In the first version, there are no knowledge spillovers, which requires $\delta = 0$, but cities have innate productivity advantages due to transportation and other infrastructure. We assume that this infrastructure costs a fixed amount $F \leq K\left[(1+\tau_x)\eta^{-\delta\mu} - 1\right]/(1+\kappa_x)$ that is defrayed by real-estate taxation. In the second version, cities have no innate productivity advantages, but there are spillovers.

Production of the traditional good is unaffected by knowledge spillovers, requiring ψ_Z unit of labor in the city and $\psi_Z (1+\tau_z)$ in the hinterland, as well as κ_Z units of location-specific capital per unit of labor in production, plus one unit in consumption. We normalize the units of labor so that $\psi_Z (1+\tau_z)$ equals one.

We also allow innovators to derive a productivity benefit from the presence of urban infrastructure, so that a rural innovator's output is $aS_R/(1+\tau_n)$ for some parameter τ_n capturing the substitution of labor for infrastructure.

We assume that the traditional sector is quite capital intensive, which is meant to reflect the heavy use of land in agriculture. The advanced production sector uses an intermediate level of capital, and innovation requires the least amount of capital, because that sector is in the business of producing ideas. As such,

$$\kappa_Z > \kappa_x > \kappa_n \geq 0 \tag{16}$$

We also assume that the value of urban infrastructure has the reverse ranking across sectors, so that

$$\tau_n \geq \tau_x \geq \tau_Z \geq 0 \tag{17}$$

The city is endowed with K units of location-specific capital and the hinterland is endowed with K_R units of this same capital. We assume that rural capital is not a scarce resource, because $K_R > (1+\kappa_Z) L$, so that there would be excess land even if everyone lived in the hinterland and worked in the most land-intensive sector. As a result, the price of rural capital will equal zero. On the other hand, urban capital is scarce, so that not all the population can be productively employed in the city even in the least land-intensive sector: $K < (1+\kappa_n) L$.

We are interested in the case where there is some advanced manufacturing in both the rural and urban areas. If the advanced producers are indifferent between these two locations, which is necessary for production to occur in both places, then the traditional producers, who have greater land requirements and less productivity losses due to distance from the city, will all prefer to locate in the hinterland. Since both the price of the traditional output and the labor requirement $\psi_Z (1+\tau_z)$ are normalized to one, the wage in the hinterland also equals one.

Workers must pay for their one unit of residential capital. Since they could earn a wage of one in the hinterland, they must then be paid a wage

$$w_U = 1 + w_K \tag{18}$$

in the city, where w_K is the price of location-specific capital in the urban area. This implies that the cost of producing one unit of each advanced good in the urban area equals $\psi_x \left[1 + (1 + \kappa_x) w_K\right] S_U^{-\mu}$ and the cost of producing the same good in the hinterland equals $\psi_x (1 + \tau_x) S_R^{-\mu}$.

When advanced manufacturing takes place in both the city and the rural area, then the price of urban capital must make advanced producers indifferent between the two locations, which requires that:

$$w_K = \frac{1}{1 + \kappa_x} \left[(1 + \tau_x) \left(\frac{S_U}{S_R} \right)^{\mu} - 1 \right] \tag{19}$$

Indifference for the marginal worker between the urban innovation sector and the two manufacturing sectors implies that the value of research output for the marginal researcher, net of capital costs, must equal the wage that could be earned in urban manufacturing:

$$\pi t S_U - w_K \kappa_n = w_U \tag{20}$$

As long as there is urban manufacturing, no innovators choose to locate out of the city. The latter would be the most profitable choice for an individual with creativity a if and only if

$$\frac{1}{S_R} < \frac{\pi a}{1 + \tau_n} < \frac{(1 + \kappa_n) w_K}{(1 + \tau_n) S_U - S_R} \tag{21}$$

and this is impossible when **??** holds, because then **??**, **??** and **??** imply

$$w_K = \frac{1}{1 + \kappa_x} \left[(1 + \tau_x) \left(\frac{S_U}{S_R} \right)^{\mu} - 1 \right] \leq \frac{1}{1 + \kappa_n} \left[(1 + \tau_n) \frac{S_U}{S_R} - 1 \right] \tag{22}$$

To complete the equilibrium, we note that the total production of advanced goods combines rural and urban production, or

$$X = \frac{L_n^{\delta\mu}}{\psi_x} \left(L_U + \frac{\eta^{\delta\mu}}{1 + \tau_x} L_R \right) \tag{23}$$

where L_U and L_R denote respectively urban and rural employment in advanced manufacturing. The total amount of labor used in the three sectors must sum to the total amount of labor in the economy, which implies:

$$L = L_n + L_U + L_R + Z \tag{24}$$

We are interested in the case where capital is scarce in the city and is completely used up by residential and production uses associated with the innovative sector and the production of differentiated goods:

$$K = (1 + \kappa_n) L_n + (1 + \kappa_x) L_U \tag{25}$$

3.4 Comparative Statics

The primary value of this model is to examine the impact that an improvement in communication technology would have on the success of the city. The state of transport and information technology can be summarized by the single parameter

$$\Delta \equiv (1+\tau_x)\,\eta^{-\delta\mu} - 1 > 0 \tag{26}$$

which captures the productivity gain that manufacturers derive from locating in the city. The urban advantage includes two different components. For $\tau_x > 0$, manufacturers benefit from the value of urban infrastructure, e.g. as a transport hub. For $\eta < 1$ and $\mu > 0$, they also profit from knowledge spillovers by co-locating with urban innovators.

As we show in the Appendix, the equilibrium of this model is defined by urban employment in innovation

$$L_n = \frac{(\theta-1)(1-\alpha)\,\beta(p_Y)}{\theta-(1-\alpha)\,\beta(p_Y)}\,\frac{(1+\kappa_x)\,L+\Delta K}{1+\kappa_x+(1+\kappa_n)\,\Delta} \tag{27}$$

Innovation reduces the cost of producing advanced goods, and therefore the Dixit-Stiglitz price index p_Y. This decrease in price may then increase the share of the budget spent on advanced goods if demand is sufficiently elastic: then the increase in demand for the advanced sector in turn drives innovation up further. To guarantee a stable equilibrium, we must assume that the budget share does not increase too much as price declines:

$$\frac{\alpha\,[\theta-(1-\alpha)\,\beta(p_Y)]}{(1-\alpha)\,[(1+\delta)\,\theta-1]+\alpha\delta\theta\mu} > -\frac{p_Y\beta'(p_Y)}{\beta(p_Y)} \tag{28}$$

The right-hand side of this equation is the own-price elasticity of the budget share of Y, which can identically be expressed as $\varepsilon-1$, where ε is the (absolute value of) own-price elasticity of demand for Y. The left-hand side captures the extent to which heterogeneous ability creates decreasing returns in the innovative sector (low θ). The decreasing returns that come from drawing less and less able people into the innovative sector must offset the increasing returns that come from greater variety (low α), as well as those deriving from knowledge spillovers (high δ and μ).

In a stable equilibrium where manufacturing locates in both the city and the hinterland, improvements in transportation and communication technology are described by a reduction in Δ. A decrease in the cost of distance may also reduce the value of urban infrastructure for innovators τ_n, and any decrease in η reduces the value of proximity for innovation as well as for manufacturing. However, as long as the innovative sector is not so large that the city is completely specialized, manufacturing rather than innovation is on the spatial margin, and therefore changes in the productivity of innovation in the hinterland do not impact equilibrium quantities.

A decline in Δ causes urban property values to decline. As it becomes easier to produce differentiated goods in the hinterland, the price of urban capital declines, since the value of being in the city for advanced manufacturers declines. This effect captures the decline of old manufacturing cities in the first twenty-five years after World War II, when manufacturing suburbanized and then went to lower density areas within the U.S. The wages for production workers in the city also fall, since they need to be paid less to compensate them for having to buy urban residential capital.

The reduction in the cost of urban capital, however, is a boon to the innovative sector, because that capital is an input into production which has decreased in price. As the price of urban capital falls, the amount of urban innovation rises because it has become cheaper to produce. This is one reason why decreasing communication costs increase the amount of innovation.

A second reason is that improvements in communication technology cause the cost of producing the advanced good to fall. As this price falls, the budget share of Y increases if demand is elastic, or in other words if the elasticity of substitution between the two goods Y and Z in the utility function (σ) is above unity.[1] Then the market for the advanced sector expands, making innovation more profitable, and thereby attracting previously extra-marginal innovators.

Proposition 1 *As Δ declines because of an improvement in information and transportation technology, the price of advanced goods falls and all real incomes rise. Output of advanced manufacturing increases, while output of the traditional good and employment in its production contract. Innovation and employment in innovation increase.*

Improvements in transportation technology are essentially reductions in the cost of producing the advanced goods. We should therefore not be surprised that their price declines. Those declining good prices then drive real incomes up. As the advanced sector gains a cost advantage it expands, and the traditional sector contracts.

The improvement in communication technology also increases the amount of innovation for two reasons, as discussed above. The returns to innovation rise as communication costs fall and the cost of urban capital declines, as we discuss in the next proposition.

Proposition 2 *As Δ declines the price of urban capital falls. The output and employment levels in urban manufacturing decline and wages for production workers in the city fall. But innovation and employment in its production increase, and the total population of the city increases.*

This proposition suggests how we might expect changes in communication technology to impact various measures of urban success. The price of land, which is one widely used metric for the demand for a place, must fall, since the urban advantage that accrues to the sector that is on the margin between urbanizing and not declines. Urban manufacturing employment also declines because the urban edge in manufacturing falls. As the price of urban real estate falls, nominal wages in the city also fall, since those wages are set to keep real incomes for production workers equal between the city and the hinterland.

On the other hand, population in the city increases because urban capital is fixed and manufacturing is such a heavy user of capital relative to innovation. For this process to work, we must have conversion of old

[1] Furthermore, if advanced goods were a luxury their budget share would increase with real income, and therefore decrease with p_Y. However, we retain the conventional assumption of homothetic preferences.

manufacturing space to new residential space for innovators, and we have certainly seen much of that in old manufacturing areas such as lower Manhattan. Warehouses converted into lofts are a prime example of this process in action. The rise of the innovative sector in the city is another more positive sign of urban promise.

For the next proposition we assume that $\kappa_n = 0$ so that the distribution of innovators' income is Pareto like the distribution of ability. In this case, it follows that:

Proposition 3 *If $\kappa_n = 0$, the ratio of the income of the worker who earns more than $\bar{P}$ percent of the urban workforce to the income of the worker who earns more than $\underline{P}$ percent of the urban workforce rises as Δ declines whenever the first worker is in the innovative sector and the second worker is in manufacturing.*

This proposition shows that at least some measures of inequality will be increasing in the city as technology improves. Decreasing communication costs increase the share of the population working in the highly unequal innovative sector. The real-world analogy to this is that, as New Yorkers moved from working in highly equal unionized jobs in the textile industry to working in financial services, where the returns to ability (or luck) are immense, we witnessed a sizable increase in inequality.

3.5 A Purely Innovative City

We considered so far an equilibrium with some manufacturing both inside and outside of the city. We now consider the case where communication technology has improved to the point that goods production in the city entirely disappears and the city comes to specialize in innovation. To keep things simple, we continue to assume that the information costs associated with innovators leaving the city are such that innovation only occurs in the city. In this case, the city is entirely innovative and all innovation is in the city. The total amount of innovation in the city is limited by the amount of urban capital, so that the maximum city population is

$$\bar{L}_n = \frac{K}{1+\kappa_n} \tag{29}$$

Employment in innovation equals this upper limit for a positive value of Δ, and thus with a positive price of urban capital w_K, if and only if urban capital is sufficiently scarce:

$$\begin{array}{l} \frac{K}{(1+\kappa_n)L} < \frac{(\theta-1)(1-\alpha)\beta(\check{p}_Y)}{\theta-(1-\alpha)\beta(\check{p}_Y)} \\ \text{with } \check{p}_Y = \frac{1}{\alpha}\psi_x \psi_n^{\frac{1-\alpha}{\alpha}\frac{(1+\delta)\theta-1}{\theta}} \left(\frac{K}{1+\kappa_n}\right)^{-\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}} \end{array} \tag{30}$$

If this condition holds, then there is a threshold $\underline{\Delta} > 0$ such that if the cost of distance falls below $\underline{\Delta}$ innovation rises to the maximum level possible in the city.[2] In that case, Proposition **??** follows:

[2] Symmetrically, there is also a minimum level of innovation below which all advanced manufacturing, and possibly some traditional production, would occur in the city:

$$\underline{L}_n(\Delta) = \frac{K}{1+\kappa_n}\left[1+\frac{\alpha\theta}{(1-\alpha)(\theta-1)}\frac{\frac{1+\kappa_x}{1+\kappa_n}+\Delta}{1+\Delta}\right]^{-1} < \bar{L}_n$$

Although this corner solution is reached for a finite value of Δ, it does not seem to be relevant for a modern economy, and we simply assume that Δ is always sufficiently small for manufacturing to be profitable outside of the city.

Proposition 4 *If Δ declines below $\underline{\Delta}$, the amount of innovation, innovative employment and city population remain constant; output of advanced manufacturing increases; the price of advanced goods declines and all real incomes increase.*

If and only if $\beta'(p_Y) < 0$, as Δ declines below $\underline{\Delta}$ the price of urban capital increases, employment in the advanced sector increases, and output and employment in the traditional sector contract.

Once the city has completely specialized in innovation, further improvement in communication technology will not impact city population any more. They may instead start to increase the value of urban property if demand for the advanced good is sufficiently elastic. The elasticity of demand for the composite advanced good is important because it ensures that the falling production costs will make innovation more profitable. In that case, further improvements in communication technology increase the amount spent on advanced goods, which boosts demand for the ideas produced in the city. The model seems to suggest that during an earlier period, when manufacturing was still leaving cities like New York and Boston, improving communication technologies were associated with declining urban property values. However, in the post-1980 world, when these places have specialized highly in idea production, the rise in real-estate costs may reflect the continuing improvement in the ability of communicating ideas which has acted to increase the returns to innovation.

3.6 Two cities

Finally, we consider an extension of the model that is intended to capture the heterogeneous experiences of different older cities since 1970, and in particular the diverging fates of innovating and manufacturing cities. Divergence occurs in our model because manufacturing cities are merely hit by the declining value of their infrastructure, such as a port or a rail hub; while this is true also of innovating cities, they enjoy the counterbalancing positive effect of an increase in innovation, and therefore in local knowledge spillovers.

Suppose that city $i \in \{1,2\}$ host L_n^i innovators, with $L_n^1 > L_n^2 \geq 0$, while $L_n^R \geq 0$ are employed in innovation outside of both cities. Then knowledge spillovers are

$$S_1 = \left[L_n^1 + \eta\left(L_n^2 + L_n^R\right)\right]^\delta > S_2 = \left[L_n^2 + \eta\left(L_n^1 + L_n^R\right)\right]^\delta \geq S_R = \left[\eta\left(L_n^1 + L_n^2 + L_n^R\right)\right]^\delta \tag{31}$$

implying that is naturally efficient for all knowledge workers to congregate in the same location. While an unstable equilibrium where innovators split equally between the two cities is a possibility, we assume that the innovators, either through coordination or decentralized location choices, have succeeded in reaping the advantages of locating in a single place, and we will refer to the city where innovators cluster as the innovative city. The cities are otherwise assumed to be identical: in particular $K_1 = K_2 = K < (1+\kappa_n)L/2$, the last inequality ensuring again that not all the population can be urbanized given the scarcity of urban capital.

When the innovative city hosts both innovation and manufacturing, while the manufacturing city is entirely specialized in manufacturing, Proposition **??** follows:

Proposition 5 *As Δ declines, relative to the manufacturing city the innovative city will see the size of its innovative sector grow, the size of its manufacturing sector shrink, its population grow, and its average real income increase.*

When the value of urban infrastructure τ_x falls, property values in the manufacturing city fall relative to the innovative city

This proposition emphasizes that declining communication costs increase the degree of inequality across cities, as we saw in the previous section. As those costs decline, the innovative city sees its population and income grow more quickly than the income and population of the manufacturing city.

The second part of the proposition is meant to capture the increasing divergence of housing values in New York and Detroit. Older cities were built on their physical advantages as transportation hubs, whose importance has been steadily diminishing; those that did not find a new source of comparative advantage in the agglomeration of innovative individuals are bound to decline as their geographic edge is blunted.

4 Evidence on Urban Growth

In this section, we turn to the empirical implications of the model about disparity between areas. The model predicted that cities that specialized in innovation would benefit from declining communication costs, while cities that specialized in production would be hurt by those costs. The model also predicts that urban success will be accompanied by increasing specialization in innovative activities.

We start with the awkward task of defining specialization in innovation. We mean to define innovation broadly and we certainly believe that the financiers of Wall Street and the management consultants of Chicago are no less innovative than the software engineers of Silicon Valley. The finance sector in New York, for example, is clearly enormously innovative in ways that can and do reduce the costs of producing final goods. As such, to define innovation, we followed the prediction of the model that high human capital people will specialize in innovation. The prediction pushed us to use skilled occupations as a proxy for specialization in innovation. Specifically, we defined innovative occupations as those which were among the top twenty percent of occupations on the basis of education, where the share of workers with college degrees in 1970 is our measure of education. However, since our model is really about the private sector, we excluded those occupations which had more than one-half of their employees working for the government.

Table 2 gives a list of the twenty largest occupations ranked by education in 1970. While doctors and lawyers rank high on the list, perhaps justifiably so, the list of skilled occupations includes many different types of engineers. While there are many reasons to be skeptical about this method of measuring innovative activity, we think it provides a measure that is at least correlated with the level of innovation in the local economy. Moreover, at the very least this measure enables us to test the predictions of the model about the correlation between specialization in the high-skill sector and urban success.

In Figure 5, we show the correlation between this measure of innovative occupations and the metropolitan-area fixed effect in a wage regression based on year 2000 Census Individual Public Use Micro Sample data. The wage regression has controlled for individual human capital measures, like years of schooling and age. The correlation between the wage residual and the measure of skilled occupations reminds us that in places with more skilled occupations, the wages of everyone appear to be higher, perhaps because of human capital spillovers (as in Rauch, 1993).

The model predicts that those cities that specialized in innovation were more likely to benefit from the improvements in information technology that have occurred over the last twenty-five years. We test this hypothesis by looking at specialization in skilled occupations in 1980 and city growth since then. Figure 6 shows the 26 percent correlation between income growth at the metropolitan-area level and the initial share of employment in the more skilled occupations. A one percent increase in skilled occupations in 1980 is associated with an approximately four percent increase in income growth since then.

Table 3 considers in a multivariate regression the relationship between initial specialization in skilled occupations and growth in both income and population, another measure of urban success. In these regressions we are treating metropolitan areas as independent observations, and we are assuming that there is no unobserved heterogeneity that is correlated with our independent variables. The first regression shows the strong positive correlation between income and initial concentration in skilled occupations when we control for initial population, income and regional dummies. As the share of employment in these skilled occupations increases by one percent, we estimate that income grows by about five percent. This coefficient is almost unchanged from the coefficient estimated with no other controls. The second regression reproduces this result for the Northeast and the Midwest. The coefficient on skilled occupations increases slightly. In the third regression, we also control for the initial share of the adult population with college degrees. This control reduces our estimated coefficient on skilled occupations by about forty percent, but the coefficient remains statistically and economically significant.

Regressions (4), (5) and (6) look at the relationship between skilled occupations and population growth. Regression (4) shows that specialization in skilled occupations is not correlated with population growth across the entire set of metropolitan areas in the United States. Regression (5) shows that the correlation is significantly positive in the set of older metropolitan areas in the Northeast and Midwest. Regression (6) shows that in this case, controlling for initial skills does make the skill occupation coefficient insignificant. As such, specialization in innovation does not seem to be important in the growing areas of the sunbelt, but it does seem to be related to the success of older places (as in Glaeser and Saiz, 2004). One interpretation of the greater importance of innovation in the rustbelt than in the sunbelt is that the cities in the sunbelt do not have the same high costs of production that limit urban manufacturing in the older areas. Later development of these places means that land is more readily available and accessible by highways. An alternative interpretation emphasizes the role of skilled people in opposing new housing in California.

We now turn to the model's predicted correlations about increasing innovation. Figure 7 shows that places that began within a higher concentration of workers in skilled industries increased the degree of that concentration between 1980 and 2000. An increase in the initial share of skilled occupations of ten percent is associated with a growth in the share of skilled occupation of 5.6 percent. Just as skilled places became more skilled over the period (Berry and Glaeser, 2005), places that started in more skilled occupations increased their concentration in those occupations. This supports the predictions of the model that decreasing communication costs increase the differences in specialization between cities.

The model also predicts that there will be a positive correlation between places that specialized further in idea production and income growth. The extremely strong link between changes in income and changes in the share of workers in skilled occupations is borne out by the data, as shown in Figure 8. The correlation is 46 percent, and from 1980 to 2000, an increase in the specialization in skilled sectors by one percentage point is associated with a 5 percent increase in income. Places that specialized further in skilled occupations became richer.

While patents are only one form of innovation, they do at least represent a hard measure of innovative activity. As such, we can look at whether our measure of high human capital occupations is correlated with patenting and whether we see a correlation between increases in patenting and increases in income at the metropolitan area level. Our patent data come from the U.S. Patent and Trademark Office. The correlation between our measure of skilled occupations and the logarithm of the number of patents at the metropolitan level is 57 percent. The 18 percent correlation between increases in patenting and increases in income between 1990 and 2000 is also significant, with a regression coefficient of .066 and a standard error of .015. None of these correlations are overwhelming. Certainly, patented innovations reflect many local idiosyncrasies and do not fully capture the full range of relevant breakthroughs. Yet, there is certainly a pattern where skilled occupations and patents move together and that both correlate with rising income levels.

4.1 Inequality within Cities

A second implication of the model is that declining communication costs will increase the returns to innovative people and that urban inequality will rise. The model can also predict that inequality will rise faster in cities which are specialized in innovation and more successful.

Figure 9 shows that the 16 percent correlation between the increase in the variance of log incomes within metropolitan areas and the initial specialization of the metropolitan area in skilled occupations. Places that had more skilled occupations became more unequal. The correlation is weaker but it still significant if we measure inequality by the difference between the log wage at the 90th percentile of the income distribution and the log wage at the 10th percentile of the income distribution.

Table 4 examines whether these regressions hold up in a multivariate setting. Regression (1) shows that there is a positive correlation between initial specialization in skilled occupations and increases in the variance of log income even controlling for initial income, income variance, population and region dummies.

Regression (2) shows that this relationship becomes statistically insignificant once we control for the share of the population with college degrees. Interestingly, the coefficient on skilled occupations does not get smaller, but just less precisely estimated. Regressions (3) and (4) reproduce (1) and (2) using the difference in the 90th percentile log wage and the 10th percentile log wage. In this case, the coefficient is positive, but the results are uniformly insignificant.

Figure 10 shows that increasing inequality within cities is also, weakly, associated with rising income at the city level. Places that had faster income growth were also places that had more growth in the variance of log wages: urban success and urban inequality have gone together.

5 Conclusion

The past forty years have seen a remarkable range of urban successes and failures, especially among America's older cities. Some places, like Cleveland and Detroit, seem caught in perpetual decline. Other areas, like San Francisco and New York, had remarkable success as they became centers of idea-based industries.

In this paper, we suggested that these urban successes and urban failures might reflect the same underlying technological change: a vast improvement in communication technology. As communication technology improved, it enabled manufacturing firms to leave cities, causing the urban distress of Detroit or Manhattan in 1975. However, declining communication costs also increased the returns to new innovations, and since cities specialize in idea-production, this helped invigorate some cities.

The model suggests that future improvements in information technology will continue to strengthen cities that are centers of innovation, but continue to hurt cities that remain oriented towards manufacturing. Certainly, there is every reason to think that the free flow of people and capital across space will only continue to increase the returns to new ideas. The important question for the future of cities is whether urban areas will continue to have a comparative advantage in producing ideas.

The great challenge to urban areas therefore comes from the possibility that innovation will also leave dense agglomerations. While this is possible, there is a remarkable continuing tendency of innovative people to locate near other innovative people. Silicon Valley, for example, is built at lower densities than New York, because it is built for drivers not pedestrians, but it is certainly a dense agglomeration. As long as improvements in information technology continue to increase the returns to having new ideas, then the edge that proximity gives to innovation seems likely to keep such agglomerations strong.

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Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Table 1

Table 2

Table 3

Table 4

A Appendix

A.1 Proof of Propositions ?? and ??

Equations ??, ?? and ?? yield equilibrium factor rewards

$$\begin{cases} w_K = \frac{(1+\tau_x)\eta^{-\delta\mu}-1}{1+\kappa_x} \\ w_U = \frac{(1+\tau_x)\eta^{-\delta\mu}+\kappa_x}{1+\kappa_x} \end{cases}$$

and equations ??, ??, ??, ??, ?? and ?? then yield prices

$$\begin{cases} p_x = \frac{1}{\alpha}\psi_x\left(1+\tau_x\right)\eta^{-\delta\mu}L_n^{-\delta\mu} \\ p_Y = \frac{1}{\alpha}\psi_x\left(1+\tau_x\right)\eta^{-\delta\mu}\psi_n^{\frac{1-\alpha}{\alpha}\frac{(1+\delta)\theta-1}{\theta}}L_n^{-\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}} \end{cases}$$

and quantities

$$\begin{cases} n = \psi_n^{-\frac{(1+\delta)\theta-1}{\theta}}L_n^{\frac{(1+\delta)\theta-1}{\theta}} \\ X = \frac{1}{\psi_x}\left(L_U + \frac{\eta^{\delta\mu}}{1+\tau_x}L_R\right)L_n^{\delta\mu} \\ Y = \frac{1}{\psi_x}\psi_n^{-\frac{(1-\alpha)[(1+\delta)\theta-1]}{\alpha\theta}}\left(L_U + \frac{\eta^{\delta\mu}}{1+\tau_x}L_R\right)L_n^{\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}} \\ Z = \frac{1-\beta(p_Y)}{\alpha\beta(p_Y)}\left[\left(1+\tau_x\right)\eta^{-\delta\mu}L_U + L_R\right] \end{cases}$$

The factor-market clearing conditions ?? and ?? yield

$$\begin{cases} L_U = & \frac{K}{1+\kappa_x} - \frac{1+\kappa_n}{1+\kappa_x}L_n \\ L_R = & \frac{\alpha\beta(p_Y)}{1-(1-\alpha)\beta(p_Y)}L - \left[\alpha\beta\left(p_Y\right) + \frac{1-\beta(p_Y)}{1-(1-\alpha)\beta(p_Y)}\left(1+\tau_x\right)\eta^{-\delta\mu}\right]\frac{K}{1+\kappa_x} + \\ & -\left[\left(\kappa_x-\kappa_n\right)\alpha\beta\left(p_Y\right) - \frac{1-\beta(p_Y)}{1-(1-\alpha)\beta(p_Y)}\left(1+\kappa_n\right)\left(1+\tau_x\right)\eta^{-\delta\mu}\right]\frac{L_n}{1+\kappa_x} \end{cases}$$

and finally, considering also equations ?? and ??, the free-entry condition ?? becomes the equilibrium condition

$$L_n = \frac{(\theta-1)\left(1-\alpha\right)\beta\left(p_Y\right)}{\theta-\left(1-\alpha\right)\beta\left(p_Y\right)}\frac{\left(1+\kappa_x\right)L + \left[\left(1+\tau_x\right)\eta^{-\delta\mu}-1\right]K}{\kappa_x-\kappa_n+\left(1+\kappa_n\right)\left(1+\tau_x\right)\eta^{-\delta\mu}}$$

which defines a unique and stable equilibrium provided that

$$\frac{\alpha\left[\theta-\left(1-\alpha\right)\beta\left(p_Y\right)\right]}{\left(1-\alpha\right)\left[\left(1+\delta\right)\theta-1\right]+\alpha\delta\theta\mu} > -\frac{p_Y\beta'\left(p_Y\right)}{\beta\left(p_Y\right)}$$

In an interior equilibrium (i.e. for $L_U \geq 0$ and $L_R \geq 0$) as Δ declines:

1. Factor rewards in the city decline, since

$$w_K = \frac{\Delta}{1+\kappa_x} \Rightarrow \frac{\partial \log w_K}{\partial \log \Delta} = 1$$

and

$$w_U = 1 + w_K \Rightarrow \frac{\partial w_K}{\partial w_U} = 1$$

2. Employment in innovation increases, since for $\beta'\left(p_Y\right) \leq 0$ the equilibrium system

$$\begin{cases} L_n = \frac{(\theta-1)(1-\alpha)\beta(p_Y)}{\theta-(1-\alpha)\beta(p_Y)}\frac{(1+\kappa_x)L+\Delta K}{1+\kappa_x+(1+\kappa_n)\Delta} \\ p_Y = \frac{1}{\alpha}\psi_x\left(1+\Delta\right)\psi_n^{\frac{(1-\alpha)[(1+\delta)\theta-1]}{\alpha\theta}}L_n^{-\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}} \end{cases}$$

implies

$$\begin{cases} \frac{dL_n}{L_n} = -\frac{(1+\kappa_x)[(1+\kappa_n)L-K]}{[1+\kappa_x+(1+\kappa_n)\Delta][(1+\kappa_x)L+\Delta K]}d\Delta + \theta\frac{p_Y\beta'(p_Y)}{\beta(p_Y)}\frac{dp_Y}{p_Y} \\ \frac{dp_Y}{p_Y} = \frac{1}{1+\Delta}d\Delta - \frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}\frac{dL_n}{L_n} \end{cases}$$

and therefore

$$\frac{\partial L_n}{\partial \Delta} = -\frac{\frac{(1+\kappa_x)[(1+\kappa_n)L-K]}{[1+\kappa_x+(1+\kappa_n)\Delta][(1+\kappa_x)L+\Delta K]} + \frac{\theta}{1+\Delta}\left|\frac{p_Y\beta'(p_Y)}{\beta(p_Y)}\right|}{1-\left|\frac{p_Y\beta'(p_Y)}{\beta(p_Y)}\right|\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha}} L_n < 0$$

by the stability condition **??**. As the technology of production does not change, this implies that the amount of innovation increases.

3. The prices of advanced goods and the relative price index decline, since

$$p_x = \frac{1}{\alpha}\psi_x (1+\Delta) L_n^{-\delta\mu} \Rightarrow \frac{\partial p_x}{\partial \Delta} = p_x \left(\frac{1}{1+\Delta} - \frac{\delta\mu}{L_n}\frac{\partial L_n}{\partial \Delta}\right) > 0$$

and

$$\frac{\partial p_Y}{\partial \Delta} = p_Y \left\{\frac{1}{1+\Delta} - \frac{(1-\alpha)[(1+\delta)\theta - 1] + \alpha\delta\theta\mu}{\alpha\theta L_n}\frac{\partial L_n}{\partial \Delta}\right\} > 0$$

It follows that the real income of all agents increases.

4. Employment in urban manufacturing contracts, since

$$L_U = \frac{K}{1+\kappa_x} - \frac{1+\kappa_n}{1+\kappa_x} L_n \Rightarrow \frac{\partial L_U}{\partial \Delta} = -\frac{1+\kappa_n}{1+\kappa_x}\frac{\partial L_n}{\partial \Delta} > 0$$

As the technology of production does not change, this implies that the output of urban manufacturing declines.

5. Urban population increases, since

$$\frac{\partial L_n}{\partial \Delta} + \frac{\partial L_U}{\partial \Delta} = \frac{\kappa_x - \kappa_n}{1+\kappa_x}\frac{\partial L_n}{\partial \Delta} < 0$$

6. Total output of advanced goods expands, because

$$\begin{aligned} X &= \frac{\alpha\theta}{(1-\alpha)(\theta-1)\psi_x}\frac{1+\frac{1+\kappa_n}{1+\kappa_x}\Delta}{1+\Delta} L_n^{1+\delta\mu} \\ &\Rightarrow \frac{\partial X}{\partial \Delta} = -X\left\{\frac{(\kappa_x - \kappa_n)}{(1+\Delta)[1+\kappa_x+(1+\kappa_n)\Delta]} - \frac{1+\delta\mu}{L_n}\frac{\partial L_n}{\partial \Delta}\right\} < 0 \end{aligned}$$

A fortiori, output of advanced manufacturing outside of the city expands, and output of the Dixit-Stiglitz aggregate expands, because

$$Y = X\left(\frac{L_n}{\psi_n}\right)^{\frac{(1-\alpha)[(1+\delta)\theta-1]}{\alpha\theta}} \Rightarrow \frac{\partial \log Y}{\partial \Delta} = \frac{\partial \log X}{\partial \Delta} + \frac{(1-\alpha)[(1+\delta)\theta-1]}{\alpha\theta}\frac{\partial \log L_n}{\partial \Delta} < 0$$

7. Output of the traditional good contracts, because

$$\begin{aligned} Z &= \frac{\theta[1-\beta(p_Y)]}{\theta-(1-\alpha)\beta(p_Y)}\left(L + \frac{\Delta K}{1+\kappa_x}\right) \\ &\Rightarrow \frac{\partial Z}{\partial \Delta} = Z\left\{\frac{K}{(1+\kappa_x)L+\Delta K} + \frac{\theta+\alpha-1}{[\theta-(1-\alpha)\beta(p_Y)][1-\beta(p_Y)]}\left|\beta'(p_Y)\right|\frac{\partial p_Y}{\partial \Delta}\right\} > 0 \end{aligned}$$

A.2 Proof of Proposition ??

The income of an urban innovator with productivity a is

$$y(a) = a\pi S_U - w_K \kappa_n$$

Thus for $\kappa_n = 0$, the income distribution of innovators follows a Pareto distribution with shape θ and minimum $1 + w_K$ dictated by the indifference condition of the marginal innovator. Recalling definition **??**, the value of percentile p in a Pareto distribution with minimum $1 + w_K$ is $(1 + w_K)(1 - p)^{-\frac{1}{\theta}}$.

If fraction λ of the city population is employed in manufacturing and $1 - \lambda$ in innovation, the value of percentile $\underline{P} \leq \lambda$ of the urban income distribution is the homogeneous income of manufacturing workers $1 + w_K$; while percentile $\bar{P} > \lambda$ corresponds to percentile $p = \left(\bar{P} - \lambda\right) / (1 - \lambda)$ of the income distribution of innovators. Thus their ratio is

$$R = \left(\frac{1-\lambda}{1-\bar{P}}\right)^{\frac{1}{\theta}} \Rightarrow \frac{\partial R}{\partial \Delta} = -\frac{1}{\theta}\frac{1}{1-\lambda} R \frac{\partial \lambda}{\partial \Delta} < 0$$

A.3 Proof of Proposition ??

When the city is completely specialized and all innovation occurs in the city, equation **??** denotes total employment in innovation, while $L_U = 0$. Then prices are

$$\begin{cases} p_x = \frac{1}{\alpha}\psi_x (1+\Delta)\bar{L}_n^{-\delta\mu} \\ p_Y = \frac{1}{\alpha}\psi_x (1+\Delta)\psi_n^{\frac{1-\alpha}{\alpha}\frac{(1+\delta)\theta-1}{\theta}} \bar{L}_n^{-\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}} \end{cases}$$

and quantities

$$\begin{cases} n = \psi_n^{-\frac{(1+\delta)\theta-1}{\theta}} \bar{L}_n^{\frac{(1+\delta)\theta-1}{\theta}} \\ X = \frac{1}{(1+\Delta)\psi_x} L_R \bar{L}_n^{\delta\mu} \\ Y = \frac{1}{(1+\Delta)\psi_x}\psi_n^{-\frac{(1-\alpha)[(1+\delta)\theta-1]}{\alpha\theta}} L_R L_n^{\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}} \\ Z = \frac{1-\beta(p_Y)}{\alpha\beta(p_Y)} L_R \end{cases}$$

and by the labor-market clearing condition **??**

$$\begin{cases} n = \psi_n^{-\frac{(1+\delta)\theta-1}{\theta}} \bar{L}_n^{\frac{(1+\delta)\theta-1}{\theta}} \\ X = \frac{\alpha\beta(p_Y)}{1-(1-\alpha)\beta(p_Y)}\frac{1}{(1+\Delta)\psi_x}\left(L - \bar{L}_n\right)\bar{L}_n^{\delta\mu} \\ Y = \frac{\alpha\beta(p_Y)}{1-(1-\alpha)\beta(p_Y)}\frac{1}{(1+\Delta)\psi_x}\psi_n^{-\frac{(1-\alpha)[(1+\delta)\theta-1]}{\alpha\theta}}\left(L - \bar{L}_n\right)\bar{L}_n^{\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}} \\ Z = \frac{1-\beta(p_Y)}{1-(1-\alpha)\beta(p_Y)}\left(L - \bar{L}_n\right) \end{cases}$$

Finally, the free-entry condition **??** yields the equilibrium price of urban capital

$$w_K = \frac{(\theta-1)(1-\alpha)\beta(p_Y)}{\theta[1-(1-\alpha)\beta(p_Y)]}\frac{1}{1+\kappa_n}\left[\frac{L}{\bar{L}_n} - \frac{\theta-(1-\alpha)\beta(p_Y)}{(\theta-1)(1-\alpha)\beta(p_Y)}\right]$$

which is positive by condition **??**.

Innovation does not expand out of the city as long as

$$(1+\tau_n)\eta^{-\delta} \geq 1 + (1+\kappa_n) w_K = \frac{(\theta-1)(1-\alpha)\beta(p_Y)}{\theta[1-(1-\alpha)\beta(p_Y)]}\left(\frac{L}{\bar{L}_n} - 1\right)$$

Then as Δ declines below $\underline{\Delta}$, it is straightforward that:

1. The amount of innovation is fixed at $\bar{n}$ by the urban capacity constraint; employment in the innovative sector and city population are likewise constrained.

2. The relative price of differentiated goods p_x declines. The price index for the advanced sector p_Y declines, and therefore the the real income of all agents increases.

3. Output of the differentiated goods X and of their aggregate Y increases.

If and only if $\beta'(p_Y) < 0$, as Δ declines below $\underline{\Delta}$:

1. The relative price of urban capital increases, since

$$\frac{\partial w_K}{\partial \Delta} = 0 \text{ and } \frac{\partial w_K}{\partial p_Y} = \frac{[1 + (1 + \kappa_n) w_K]}{(1 + \kappa_n)[1 - (1 - \alpha)\beta]} \frac{\beta'(p_Y)}{\beta(p_Y)}$$

2. The traditional sector contracts

$$\frac{\partial Z}{\partial \Delta} = 0 \text{ and } \frac{\partial Z}{\partial p_Y} = -\frac{\alpha\left(L - \bar{L}_n\right)}{[1 - (1 - \alpha)\beta(p_Y)]^2}\beta'(p_Y)$$

Thus employment in the traditional sector contracts and conversely employment in the advanced sector expands.

A.4 Proof of Proposition ??

Equilibrium factor rewards are

$$\begin{cases} w_K^1 = \frac{(1+\tau_x)\eta^{-\delta\mu}-1}{1+\kappa_x} \\ w_U^1 = \frac{(1+\tau_x)\eta^{-\delta\mu}+\kappa_x}{1+\kappa_x} \\ w_K^2 = \frac{\tau_x}{1+\kappa_x} \\ w_U^2 = 1 + \frac{\tau_x}{1+\kappa_x} \end{cases}$$

prices are

$$\begin{cases} p_x = \frac{1}{\alpha}\psi_x(1+\tau_x)\eta^{-\delta\mu}L_n^{-\delta\mu} \\ p_Y = \frac{1}{\alpha}\psi_x(1+\tau_x)\eta^{-\delta\mu}\psi_n^{\frac{1-\alpha}{\alpha}\frac{(1+\delta)\theta-1}{\theta}}L_n^{-\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}} \end{cases}$$

and letting L_1 and L_2 denote employment in manufacturing in the two cities, quantities are

$$\begin{cases} n = \psi_n^{-\frac{(1+\delta)\theta-1}{\theta}}L_n^{\frac{(1+\delta)\theta-1}{\theta}} \\ X = \frac{1}{\psi_x}\left(L_1 + \eta^{\delta\mu}L_2 + \frac{\eta^{\delta\mu}}{1+\tau_x}L_R\right)L_n^{\delta\mu} \\ Y = \frac{1}{\psi_x}\psi_n^{-\frac{(1-\alpha)[(1+\delta)\theta-1]}{\alpha\theta}}\left(L_U + \eta^{\delta\mu}L_2 + \frac{\eta^{\delta\mu}}{1+\tau_x}L_R\right)L_n^{\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}} \\ Z = \frac{1-\beta(p_Y)}{\alpha\beta(p_Y)}(1+\tau_x)\eta^{-\delta\mu}\left(L_1 + \eta^{\delta\mu}L_2 + \frac{\eta^{\delta\mu}}{1+\tau_x}L_R\right) \end{cases}$$

Factor-market clearing implies

$$\begin{cases} L_1 = \frac{K}{1+\kappa_x} - \frac{1+\kappa_n}{1+\kappa_x}L_n \\ L_2 = \frac{K}{1+\kappa_x} \\ L = L_n + L_1 + L_2 + L_R + Z \end{cases}$$

so that the free-entry condition becomes the equilibrium condition

$$L_n = \frac{(\theta-1)(1-\alpha)\beta(p_Y)}{\theta-(1-\alpha)\beta(p_Y)}\frac{(1+\kappa_x)L + \left[(1+\tau_x)\eta^{-\delta\mu}+\tau_x-1\right]K}{\kappa_x-\kappa_n+(1+\kappa_n)(1+\tau_x)\eta^{-\delta\mu}}$$

The comparative statics are analogous to those in Propositions ?? and ??, even if τ_x and $\eta^{-\delta\mu}$ now appear independently and not only combined in the single parameter Δ. The equilibrium system

$$\begin{cases} L_n = \frac{(\theta-1)(1-\alpha)\beta(p_Y)}{\theta-(1-\alpha)\beta(p_Y)}\frac{(1+\kappa_x)L+\left[(1+\tau_x)\eta^{-\delta\mu}+\tau_x-1\right]K}{\kappa_x-\kappa_n+(1+\kappa_n)(1+\tau_x)\eta^{-\delta\mu}} \\ p_Y = \frac{1}{\alpha}\psi_x(1+\tau_x)\eta^{-\delta\mu}\psi_n^{\frac{1-\alpha}{\alpha}\frac{(1+\delta)\theta-1}{\theta}}L_n^{-\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}} \end{cases}$$

implies

$$\left\{\begin{array}{rcl}\frac{dL_n}{L_n} & = & -\frac{\left\{(1+\kappa_n)(1+\kappa_x)\eta^{-\delta\mu}L-\left[\kappa_x-\kappa_n+(2+\kappa_n+\kappa_x)\eta^{-\delta\mu}\right]K\right\}}{[\kappa_x-\kappa_n+(1+\kappa_n)(1+\tau_x)\eta^{-\delta\mu}]\{(1+\kappa_x)L+[(1+\tau_x)\eta^{-\delta\mu}+\tau_x-1]K\}}d\tau_x+ \\ & & -\frac{(1+\tau_x)\{(1+\kappa_x)(1+\kappa_n)L-[1+\kappa_x-(1+\kappa_n)\tau_x]K\}}{[\kappa_x-\kappa_n+(1+\kappa_n)(1+\tau_x)\eta^{-\delta\mu}]\{(1+\kappa_x)L+[(1+\tau_x)\eta^{-\delta\mu}+\tau_x-1]K\}}d\left(\eta^{-\delta\mu}\right)+ \\ & & +\theta\frac{p_Y\beta'(p_Y)}{\beta(p_Y)}\frac{dp_Y}{p_Y} \\ \frac{dp_Y}{p_Y} & = & \frac{1}{1+\tau_x}d\tau_x+\frac{1}{\eta^{-\delta\mu}}d\left(\eta^{-\delta\mu}\right)-\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha\theta}\frac{dL_n}{L_n}\end{array}\right.$$

and therefore, for all $\beta'(p_Y)\leq 0$

$$\frac{dL_n}{d\tau_x}=-\frac{\frac{(1+\kappa_n)(1+\kappa_x)\eta^{-\delta\mu}L-\left[\kappa_x-\kappa_n+(2+\kappa_n+\kappa_x)\eta^{-\delta\mu}\right]K}{[\kappa_x-\kappa_n+(1+\kappa_n)(1+\tau_x)\eta^{-\delta\mu}]\{(1+\kappa_x)L+[(1+\tau_x)\eta^{-\delta\mu}+\tau_x-1]K\}}+\frac{\theta}{1+\tau_x}\left|\frac{p_Y\beta'(p_Y)}{\beta(p_Y)}\right|}{1-\left|\frac{p_Y\beta'(p_Y)}{\beta(p_Y)}\right|\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha}}L_n<0$$

and

$$\frac{dL_n}{d\left(\eta^{-\delta\mu}\right)}=-\frac{\frac{(1+\tau_x)\{(1+\kappa_x)(1+\kappa_n)L-[1+\kappa_x-(1+\kappa_n)\tau_x]K\}}{[\kappa_x-\kappa_n+(1+\kappa_n)(1+\tau_x)\eta^{-\delta\mu}]\{(1+\kappa_x)L+[(1+\tau_x)\eta^{-\delta\mu}+\tau_x-1]K\}}+\frac{\theta}{\eta^{-\delta\mu}}\left|\frac{p_Y\beta'(p_Y)}{\beta(p_Y)}\right|}{1-\left|\frac{p_Y\beta'(p_Y)}{\beta(p_Y)}\right|\frac{(1-\alpha)[(1+\delta)\theta-1]+\alpha\delta\theta\mu}{\alpha}}L_n<0$$

recalling the scarcity assumption $(1+\kappa_n)L>2K$ and the stability condition **??**.

As Δ falls, because of a decline in any combination of τ_x and $\eta^{-\delta\mu}$, L_n increases: this implies that in the first city the innovative sector grows, the manufacturing sector contracts, and population grows—none of which happens in the second city. Relative real income grows with L_n because all inframarginal innovators are earning a positive profit from their creativity.

Moreover, the relative value of urban capital in the innovative city increases when urban infrastructure becomes less valuable, because

$$\frac{w_K^1}{w_K^2}=\frac{(1+\tau_x)\,\eta^{-\delta\mu}-1}{\tau_x}\Rightarrow\frac{\partial\left(w_K^1/w_K^2\right)}{\partial\tau_x}=-\frac{\eta^{-\delta\mu}-1}{\tau_x^2}<0$$