Communications costs, network externalities and long-run growth

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Abstract

This paper examines the effects of per-period communication costs in a model of expanding product variety. A congestion externality associated with these communication costs drives the long-run growth rate down to zero. It is shown that decreases in communication costs lead to temporary growth growth in aggregate output, but in the long run the growth rate will be zero.

keywords: communication costs, network externalities, expanding variety, monopolistic competition

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1. Introduction

In recent years significant advances have been made in the communications industry with the application of new technologies such as the Internet, fiber optics and satellite based systems resulting in a dramatic decrease in the costs of communication. There is, in general, a consensus that this reduction in costs has provided an engine for economic growth in developed countries. Increased access to a larger base of knowledge that occurs with an increased level of economic integration leads to knowledge spillovers that accelerate the process of product development. The dynamics of this process have been examined in the endogenous growth literature, for example the models of Romer (1990) and Grossman and Helpman (1991). This paper extends the expanding variety model to examine the effects of per-period communication costs on long-run growth.

Communications networks possess many of the characteristics associated with a public good, the use of which requires "membership" through the payment of fixed connection and monthly fees. The costs incurred when using a network have, in general, been modelled in the literature as fixed costs and this is the approach that shall be taken in this paper. Harris (1995) presents a strong argument for modeling communication costs as fixed costs suggesting that once the necessary infrastructure is in place the actual costs of communications are negligible. Further, the public good nature of a

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communications network implies the existence of two externalities. The first is a cost-sharing effect where the average costs of connecting to and maintaining the network infrastructure are decreasing with the number of users. The second is a congestion effect where the cost of membership increase as the number of users increases and the network becomes crowded.

An adaptation of the model of expanding variety developed by Grossman and Helpman (1991) is considered with production of final goods, intermediates, and communications services. Monopolistically competitive firms in the intermediates sector require the use of a communications network when producing differentiated varieties of the intermediate good for supply to the final goods sector. The model adopts a specification for communication costs that has been introduced in the international trade literature. Kikuchi and Ichikawa (2002) develop a specification that allows for both congestion and cost-sharing externalities. The congestion externality dominates when the cost of establishing the network base is small and the number of firms connected to the network is large. Opposingly, when the cost of establishing the network base is large and the number of connected firms is small the cost-sharing externality dominates.

Introducing per-period communication costs into the expanding variety model has adverse effects for endogenous growth. In the models of Romer (1990) and Grossman and Helpman (1991), an increase in the stock of knowledge capital reduces the cost of developing new products offsetting the reduction in the market share of extant firms and allowing for endogenous growth. In the model introduced in this paper the congestion externality causes existing firms' profits to decrease at a faster rate than the decrease in entry costs. Therefore, while the structure of the model introduced in this paper closely follows the expanding variety models of the endogenous growth literature, the solution concept used to find steady-state equilibria is neo-classical in nature. Communication costs drive the rate of growth in intermediate varieties down to zero, and there is no growth in aggregate output in the steady-state equilibrium.

A reduction in communication costs allows for new entry into the market for intermediates moving the economy to a new equilibrium with greater aggregate output and consumption. The model concludes, therefore, that reductions in communication costs lead to short-term growth. This growth is only temporary, however, as the growth rate returns to zero in the long-run.

The paper proceeds as follows: Section 2 describes the basic set-up of the model, Section 3 examines the equilibrium dynamics, Section 4 discusses the effects of a decrease in communication costs, and Section 5 gives concluding remarks.

2. The model

The economy consists of three sectors: final goods, intermediate goods, and communications. The final goods sector is perfectly competitive with many firms producing a homogeneous good using a constant returns to scale technology. The intermediate goods sector produces a large number of varieties under increasing returns to scale. A fixed cost of entry and a large number of potentially producible varieties ensure that each variety is produced solely by one firm. Each of these firms requires a connection to a communications network. This is provided by a public utility operating as a natural monopoly in the communications sector.

The population growth rate is zero; a fixed endowment of labor is supplied inelastically. The preferences of the representative household are given by

$$U_t = \int_t^{\infty} e^{-\rho[\tau - t]}[logC(\tau)]d\tau, \tag{1}$$

where ρ is the subjective discount rate and $log\ C$ is the instantaneous utility derived from consumption of the final good at time τ. Households maximize the intertemporal utility in Eq. (1) subject to the flow budget constraint

$$\dot{A} + C = wL + rA, \tag{2}$$

and the initial condition $A(0) = A_0$, where w and r are the wage and interest rates and L and A are the labor and asset endowments, respectively. Intertemporal utility maximization is simplified using the following present-value Hamiltonian.

$$H = log\ C + \lambda(wL + rA - C), \tag{3}$$

where λ represents the present-value shadow price of income. Optimization leads to the following first-order conditions:

$$C = \frac{1}{\lambda}, \tag{4}$$

$$\frac{\dot{C}}{C} = r - \rho, \tag{5}$$

and the standard transversality condition:

$$\lim_{t\to\infty} [\lambda(t) \cdot A(t)] = 0.$$

Final goods, Y, are produced using a time-invariant Cobb-Douglas technology

$$Y = BX^{\alpha}L_Y^{1-\alpha}, \qquad X = \left(\int_{i=1}^{n} x_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}, \qquad 0 \leq \alpha \leq 1, \tag{6}$$

where L_Y is final goods labor demand, X is a composite good consisting of n varieties of the intermediate input, x_i is the final goods demand for variety i, and $\sigma > 1$ is the elasticity of substitution between varieties. The price of final goods is set as the numeraire of the model, $P_Y = 1$.

The Y-sector demands for labor and the composite good X equal their respective marginal value products.

$$w = \frac{(1-\alpha)Y}{L_Y}, \tag{7}$$

$$P_X = \frac{\alpha Y}{X}, \tag{8}$$

where $P_X = (\int_{i=1}^{n} p_i^{1-\sigma})^{\frac{1}{1-\sigma}}$ is the aggregate price index for varieties of the intermediate input with p_i denoting the price of variety i. Given the fixed expenditures of the final goods sector, profit maximization by final goods producers using the the composite good, X, provides the following demand function for a given variety i of the intermediate good:[1]

$$x_i = \alpha Y P_X^{\sigma-1} p_i^{-\sigma}, \tag{9}$$

[1] See Krugman and Helpman (1985).

where, assuming symmetry among varieties, the composite intermediate good and the price index respectively reduce to $X = n^{\frac{\sigma}{\sigma-1}}x$ and $P_X = n^{\frac{1}{1-\sigma}}p$. The demand for each variety of the intermediate good is now given by

$$x = \frac{\alpha Y}{np}. \tag{10}$$

Communications services are provided in the form of a communications network that is managed by a public utility that operates as a natural monopoly. The network infrastructure is capital intensive and constructed using funds borrowed from households. The cost of maintaining this infrastructure consists of interest payments to households and takes the following form:

$$r\gamma(n) = r(F + n^2), \tag{11}$$

where F is the base cost of network provision and n^2 is the cost of congestion associated with n connected network users. Following Harris (1995), the natural monopoly applies an average cost pricing rule.[2]

Firms in the intermediate network goods sector produce differentiated varieties of an intermediate input and compete in a monopolistically competitive market. The instantaneous operating profits of a representative firm i are

$$\pi_i = (p_i - w)x_i - r\frac{\gamma(n)}{n}, \tag{12}$$

where p_i is the price for product i. The first-order condition for profit-maximization determines price, which will be a constant mark-up over unit cost $p = \sigma w/(\sigma - 1)$. Substituting this pricing rule and the demand function from Eq. (11) into Eq. (13), and noting the symmetric demand for each variety, instantaneous profits can now be expressed as

$$\pi = \frac{\alpha Y}{\sigma n} - r\frac{\gamma(n)}{n}. \tag{13}$$

Development of a new intermediate variety requires ϕ/n units of the final good. Free-entry assures that the present-value of the future stream of profits will equal the fixed cost of product development.

$$\int_t^\infty e^{-[R(\tau)-R(t)]}\pi(\tau)d\tau = \frac{\phi}{n}, \tag{14}$$

where $R(s) = \int_s^\infty r(s)ds$.

Note that total households assets are the sum of investments in the infrastructure of the communications sector and the development of new products:

$$A = F + \phi + n^2. \tag{15}$$

Differentiating Eq. (15) with respect to time and using Eq. (11) and Eq. (15) gives an arbitrage condition for the rate of return on investment in a firm in the intermediate goods sector:

$$r = \frac{\alpha Y}{\sigma A} - \frac{\dot{n}}{n}\frac{\phi}{A}. \tag{16}$$

[2]See Kikuchi and Ichikawa (2002) for more detail on this specification of communication costs.

The model is closed with the assumption that the labor market clears. First, note that labor demand in the intermediates sector is given by

$$L_x = nx = \frac{\alpha(\sigma - 1)Y}{\sigma w}.$$

Then, the market-clearing condition for labor is

$$L = \frac{(\sigma - \alpha)Y}{\sigma w}. \tag{17}$$

Choosing units such that $B = (\sigma - \alpha)/[\alpha(\sigma - 1)]^{\alpha}[(1 - \alpha)\sigma]^{1-\alpha}$ the production function for final goods, Eq. (6), can now be rewritten as

$$Y = n^{\frac{\alpha}{\sigma-1}} L. \tag{18}$$

In the next section the model is reduced to a system of two differential equations and the transition dynamics and characteristics of steady-state equilibria are examined.

3. Dynamics

The system is described by two differential equations. The first is given by the houshold's flow budget constraint. Differentiating Eq. (15) with respect to time and using Eq. (17) and Eq. (18), Eq. (2) can be rewritten as

$$\frac{\dot{n}}{n} = \frac{Y - C}{\phi + 2n^2}. \tag{19}$$

The second differential equation is provided by the first-order conditions for intertemporal utility maximization. Using Eq. (17) and Eq. (19) in Eq. (5) gives the motion for consumption:

$$\frac{\dot{C}}{C} = \left(\frac{\alpha}{\sigma} - \frac{\phi}{\phi + 2n^2}\right)\frac{Y}{A} + \frac{\phi C}{(\phi + 2n^2)A} - \rho. \tag{20}$$

A steady-state equilibrium occurs when the rate of growth in intermediate varieties, $\dot{n}/n$, and output in the final goods sector, $\dot{Y}/Y$ are equal. With network congestion the increase in intermediate firm profits that arises with an increase in final goods output will be dominated by the loss that occurs as a result of increased congestion. Thus, growth in the number of varieties of the intermediate input will eventually stop and the economy will reach a steady state where $\dot{n}/n = \dot{C}/C = 0$. It follows, therefore, that in the steady state all final goods output is consumed. Using these conditions, the zero-growth loci for Eq. (19) and Eq. (20) are

$$C_n = Y, \tag{21}$$

$$C_C = \left(1 - \frac{\alpha}{\sigma}\frac{(\phi + 2n^2)}{\phi}\right)Y + \frac{\rho(\phi + 2n^2)}{\phi}A, \tag{22}$$

where C_n represents the $\dot{n} = 0$ locus and C_C represents the $\dot{C} = 0$ locus.

The short-run dynamics can be examined by linearizing the system around the steady state.

$$\begin{bmatrix} \dot{C} \\ \dot{n} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} C - \widetilde{C} \\ n - \widetilde{n} \end{bmatrix}$$

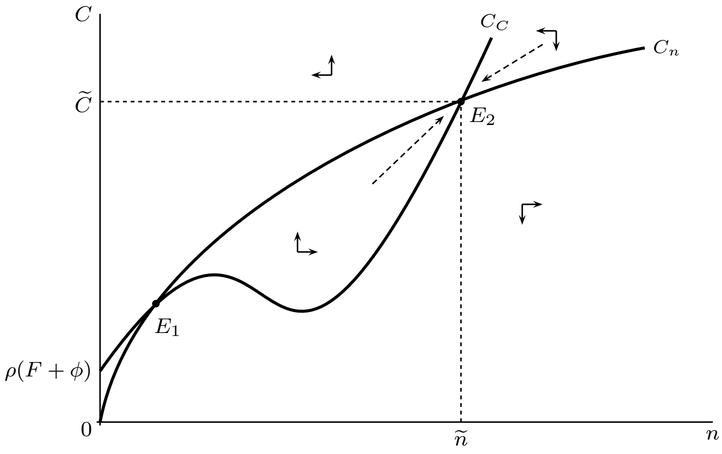

Figure 1: The phase diagram with steady-state equilibria

Steady-state values for n and C are denoted by $\widetilde{n}$ and $\widetilde{C}$. Denote the coefficient matrix by H, where

$$h_{11} = \frac{\partial \dot{C}}{\partial C} = \frac{\phi}{(\phi + 2n^2)}\frac{Y}{A},$$
$$h_{12} = \frac{\partial \dot{C}}{\partial n} = \left(\frac{(F-n^2)}{A} - \frac{(\sigma-\alpha-1)}{(\sigma-1)} - \frac{(\sigma-\alpha)\phi}{(\sigma-1)2n^2}\right)\frac{2\rho n Y}{(\phi+2n^2)},$$
$$h_{21} = \frac{\partial \dot{n}}{\partial C} = -\frac{n}{\phi+2n^2},$$
$$h_{22} = \frac{\partial \dot{n}}{\partial n} = \frac{\alpha}{(\sigma-1)}\left(\frac{Y}{\phi+2n^2}\right).$$

The determinant of H is

$$|H| = \left(\frac{\alpha}{\sigma-1} - \frac{2n^2}{A}\right)\frac{\rho Y}{(\phi+2n^2)}.$$

$|H| < 0$ when

$$n > \left(\frac{\alpha(F+\phi)}{\alpha + 2(\sigma-1)}\right)^{1/2} = n^s.$$

The system is saddle-point stable for $\widetilde{n} > n^s$.

The phase diagram in Figure 1 summarizes the dynamics of the system. The concave shape of C_n requires that the marginal productivity of n to diminish. This will be the case when $1+\alpha-\sigma < 0$. The cubic shape of C_C is the result of several opposing effects of an increase in the number of intermediate varieties. These opposing effects are made clear with

$$\frac{\partial C_C}{\partial n} = \left(\frac{\sigma-\alpha}{\sigma} - \frac{[2(\sigma-1)+\alpha]2n^2}{\sigma\phi}\right)\frac{\alpha Y}{(\sigma-1)n} + \frac{\rho(\phi+2n^2)2n}{\phi}. \tag{23}$$

While increases in n increase the productivity of labor in the final goods sector, increasing the wage rate, the rate of return in the intermediates sector falls as a result of the congestion externality. Investment income, however, is monotonically increasing in n. With the assumption of diminishing marginal productivity for n in the final goods sector, the first term in Eq. (23) approaches zero, and the second term term dominates.

The C_n and C_C loci cross twice allowing for the existence of two steady-state equilibria. The equilibrium, E_1, is not stable as shown by the directions of movement for C and n. The second equilibrium, E_2 is a saddle point. The saddle paths for E_2 are described by the dashed arrows.

The next section examines the effects of a change in communication costs on the steady state.

4. Decrease in communication costs

A decrease in the base cost of network provision will increase the number of intermediate firms and increase the aggregate level of output. To see this, first note that the C_n locus does not shift with changes in F. The effects of a change in F on the C_C locus can be examined using the following:

$$\frac{\partial C_C}{\partial F} = \frac{\rho(\phi + 2n^2)}{\phi} > 0. \tag{24}$$

Therefore, decreases in communication costs will lead to a downward shift in the C_C locus. The economy will move up the C_n locus to achieve a new steady state with a greater number of intermediate varieties and a higher level of aggregate output. Because all final goods output is consumed in the steady state, the decrease in communication costs will clearly have a positive welfare effect.

5. Concluding Remarks

This paper examines the effects of network costs and congestion on growth in a dynamic model of monopolistic competition. The model includes three sectors: final goods manufacturing, intermediate inputs manufacturing and communications. The main focus of the analysis is the intermediates sector which requires the use a communications network. The inclusion of per-period fixed costs of communication that are characterized by network externalities leads to a steady-state equilibrium with zero growth in intermediate varieties and aggregate output. While the model closely follows the structure of the expanding variety models of the endogenous growth literature, the dynamics described by the model are neo-classical in nature.

The model is consistent with the idea that a decrease in communication costs has lead to an increase in economic growth. Reductions in communication costs move the economy to a steady state with a greater level of aggregate output. However, this growth will be temporary. Once the new steady state is reached the growth rate will return zero.

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