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Communication costs, network externalities, and long-run growth

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Abstract

This note examines the effect of per-period communication costs in a model of expanding product variety. It is shown that while a decrease in communication costs leads to growth in aggregate output, this growth is only transitional with the growth rate falling to zero in the long run as the result of a congestion effect.

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1. Introduction

In recent years the application of new technologies such as the Internet, fiber optics and satellite based systems have resulted in a dramatic decrease in communication costs. 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 note 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. 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 communication are negligible. Further, the public good nature of a communications network implies the existence of two externalities. The first is a cost-sharing externality where average connection and maintenance costs decrease with network connections as fixed costs are shared by a larger number of users. The second is a congestion externality where average costs increase with the number of users as the network becomes crowded. This note adopts a specification for communication costs introduced by Kikuchi and Ichikawa (2002) that allows for both types of externalities.

An adaptation of the expanding variety model 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 perfectly competitive final goods sector. While the structure of the model follows the expanding variety models of the endogenous growth literature, the introduction of per-period communication costs leads to neo-classical outcome with zero growth in intermediate varieties and aggregate output in the steady-state. 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-run growth. This growth is only transitional, however, as the growth rate returns to zero in the long run.

The note proceeds as follows: Section 2 describes the basic set-up of the model, Section 3 examines the equilibrium dynamics and the effects of a decrease in communication costs, and Section 4 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. In the intermediates sector monopolistically competitive firms produce differentiated varieties. Each of these firms requires a connection to a communications network.

The population growth rate is zero and households supply labor inelastically. The preferences of a representative household are

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

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 a 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 labor and assets, respectively. Household assets are composed of investments made in the communications and intermediates sectors. Optimization leads to the following first-order conditions:

$$C = \frac{1}{\lambda}, \tag{3}$$

$$\frac{\dot{C}}{C} = r - \rho, \tag{4}$$

and the standard transversality condition:

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

where λ is the shadow value of income.

The production function for the final good is

$$Y = BX^\alpha L_Y^{1-\alpha}, \qquad X = \left(\int_{i=1}^{n} x_i^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}, \qquad 0 \leq \alpha \leq 1, \tag{5}$$

where L_Y is labor employed in the Y-sector, X is a composite good consisting of n varieties of the intermediate input x_i, and $\sigma > 1$. The final good is the model numeraire, $P_Y = 1$. The Y-sector demands for labor and the composite good X are given by their marginal value products:

$$w = \frac{(1-\alpha)Y}{L_Y}, \qquad P_X = \frac{\alpha Y}{X}. \tag{6}$$

Demand for intermediate varieties will be symmetric in equilibrium. Therefore, $X = n^{\frac{\sigma}{\sigma-1}} x$ and $P_X = n^{\frac{1}{1-\sigma}} p$, where p is the price of any intermediate variety. The demand for each intermediate variety is

$$x = \frac{\alpha Y}{np}. \tag{7}$$

Communications services are provided in the form of a network that is managed by a natural monopoly. ThIs network is capital intensive and constructed using funds invested by households. The cost of maintaining the network infrastructure consists of interest payments to households,

$$r\gamma(n) = r(F + n^2). \tag{8}$$

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.[1]

The instantaneous operating profits of a representative intermediates firm i are

$$\pi_i = (p_i - w)x_i - r\frac{\gamma(n)}{n}. \tag{9}$$

The first-order condition for profit-maximization determines price, which will be a constant mark-up over unit cost $p = \sigma w/(\sigma - 1)$. Given this pricing rule and Eq. (7) instantaneous profits can now be expressed as

$$\pi = \frac{\alpha Y}{\sigma n} - r\frac{\gamma(n)}{n}. \tag{10}$$

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.

$$\int_t^\infty e^{-[R(\tau)-R(t)]}\pi(\tau)d\tau = \frac{\phi}{n}, \tag{11}$$

where $R(s) = \int_s^\infty r(s)ds$. Note that total households assets are the sum of investments in network infrastructure and new product development:

$$A = F + \phi + n^2. \tag{12}$$

Differentiating Eq. (11) with respect to time and using Eq. (10) and Eq. (12) gives a no-arbitrage condition for the rate of return on investment in a firm in the intermediate goods sector:

$$r = \frac{\alpha Y}{\sigma A} - \frac{\dot{n}}{n}\frac{\phi}{A}. \tag{13}$$

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

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

Then, the market-clearing condition for labor is

$$L = \frac{(\sigma - \alpha)Y}{\sigma w}. \tag{14}$$

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

$$Y = n^{\frac{\alpha}{\sigma - 1}}L. \tag{15}$$

The next section examines transition dynamics and steady-state equilibria.

[1] See Kikuchi and Ichikawa (2002) for more detail.

3. Dynamics

The system is described by two differential equations. The first is given by Eq. (2). Differentiating Eq. (11) with respect to time and using Eq. (13) and Eq. (14), Eq. (2) can be rewritten as

$$\frac{\dot{n}}{n} = \frac{Y - C}{\phi + 2n^2}. \tag{16}$$

The second differential equation is provided by the first-order conditions for intertemporal utility maximization. Using Eq. (13) and Eq. (16) in Eq. (4) gives

$$\frac{\dot{C}}{C} = \left(\frac{\alpha}{\sigma} - \frac{\phi}{\phi + 2n^2}\right)\frac{Y}{A} + \frac{\phi C}{(\phi + 2n^2)A} - \rho. \tag{17}$$

With network congestion the increase in intermediate firm profits that arises with an increase in aggregate output will be dominated by the loss incurred with greater network congestion. Growth in the number of varieties of the intermediate input will eventually stop and the economy will reach a steady state where $\dot{n}/n = \dot{C}/C = 0$. The zero-growth loci for Eq. (16) and Eq. (17) are

$$C_n = Y, \tag{18}$$

$$C_C = \left(1 - \frac{\alpha}{\sigma}\frac{(\phi + 2n^2)}{\phi}\right)Y + \frac{\rho(\phi + 2n^2)}{\phi}A. \tag{19}$$

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

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

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

$$h_{11} = \frac{\phi}{(\phi + 2n^2)}\frac{Y}{A},$$

$$h_{12} = \left(\frac{(F - n^2)}{A} - \frac{(\sigma - \alpha - 1)}{(\sigma - 1)} - \frac{(\sigma - \alpha)\phi}{(\sigma - 1)2n^2}\right)\frac{2\rho n Y}{(\phi + 2n^2)},$$

$$h_{21} = -\frac{n}{\phi + 2n^2},$$

$$h_{22} = \frac{\alpha}{(\sigma - 1)}\left(\frac{Y}{\phi + 2n^2}\right).$$

Then,

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

$|H| < 0$ when

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

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

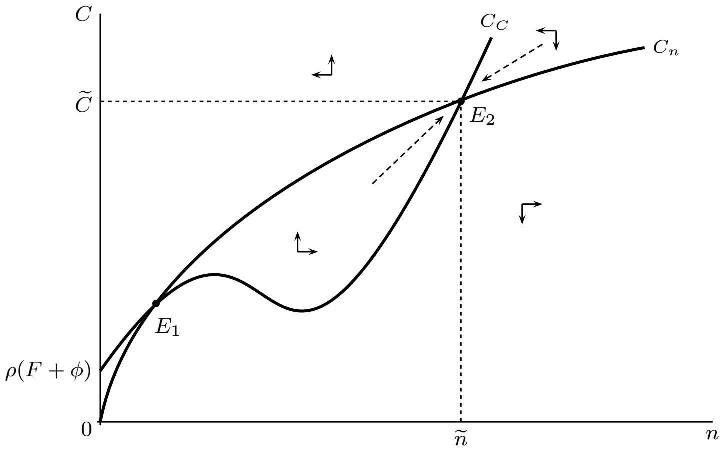

Figure 1: Steady-state equilibria

The phase diagram in Figure 1 summarizes the dynamics of the system. 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 with the stable arms described by the dashed arrows.

The concave shape of C_n requires that the marginal productivity of n diminish. This will be the case when $\sigma > 1 + \alpha$. The cubic shape of C_C is the result of several opposing income effects.

$$\frac{\partial C_C}{\partial n} = \left(\frac{\sigma - \alpha}{\sigma} - \frac{[2(\sigma-1)+\alpha]2n^2}{\sigma\phi}\right)\frac{\alpha Y}{(\sigma-1)n} + \frac{(2F+3\phi+4n^2)2\rho n}{\phi}$$

While an increase in n increases the productivity of labor in the Y-sector, increasing the wage rate, profits in the intermediates sector falls as a result of congestion. These two opposing effects are described by the first term. Investment income from the communications sector, however, is monotonically increasing in n. With a diminishing marginal productivity for n in the final goods sector, the first term approaches zero, and the second term dominates.

A decrease in the base cost of network provision, F, 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

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

A decrease in communication costs will shift the C_C locus downwards, and the economy will move up the C_n locus to a new steady state with a greater number of varieties and a higher level of aggregate output. The economic growth induced by the reduction in communication costs will only be transitional, however, with the growth rate returning to zero in the long run.

4. Concluding remarks

This note examines the effects of per-period communication costs and network externalities on growth in a model of expanding variety. The model includes three sectors: final goods, intermediates, and communications and focuses on the intermediates sector where firms producing differentiated varieties require connection to a communications network. It is shown that the existence of a congestion externality 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 with a long-run growth rate of zero.

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. This economic growth is temporary, however, and once a new stationary equilibrium is reached the growth rate returns zero.

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