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Wider economic benefits from communication cost reductions: an endogenous growth approach

Johannes Bröcker*

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Abstract

The paper examines the impact of communication cost reductions on growth and welfare by means of an endogenous spatial growth model. Policy makers having to decide upon transport policies often claim certain policies such as infrastructure investments to have growth stimulating effects that generate “wider impacts” in terms of welfare, well beyond producer and consumer surplus effects typically measured by traditional cost-benefit analysis. It is well understood that such wider impacts cannot arise in a first-best environment with perfect competition and no externality. If the market allocation is however not first-best wider effects in general do occur and can in principle have both signs. As far as freight costs are concerned, existence of wider effects has been shown in the literature in a static NEG framework. Huge infrastructure projects such as high-speed trains have however no direct freight cost effect, but are nevertheless conjectured to generate wider impacts. The typical argument is that innovation needs face to face contact and generates positive externalities. Thus, cheaper contacts boost growth and generate benefits of the society as a whole beyond those that the users are privately willing to pay for. To verify these claims rigorously I set up a Romer-type endogenous growth model for a multiregional economy. In this model innovators need to learn from the existing stock of knowledge by communicating with others across space, which is a costly activity. I show that, at the margin, reducing these costs generates a welfare gain that consumers value more than the cost reduction itself.

JEL classification: D61, O18, O33, R13, R48

1 Introduction

Policy makers having to decide upon transport policies often claim certain policies such as infrastructure investments to have growth stimulating effects that generate “wider impacts” in terms of welfare, well beyond producer and consumer surplus effects typically measured by traditional cost-benefit analysis. It is well understood that such wider impacts cannot arise in a first-best environment with perfect competition and no externality.

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If the market allocation is however not first-best wider effects in general do occur and can in principle have both signs [6, 11, 8]. As far as freight costs are concerned, static multi-regional general equilibrium models with imperfect competition that are now standard in geographical economics are an appropriate analytical framework [10]. Huge infrastructure projects such as high-speed trains have however no direct freight cost effect, but are nevertheless suspected to generate wider impacts. The typical argument is that innovation needs face to face contact and generates positive externalities [3]. Thus, cheaper contacts boost growth and generate benefits of the society as a whole beyond those that the users are privately willing to pay for.

To verify these claims rigorously one needs a model with endogenous innovation produced by profit or utility maximising agents. It has to make explicit how innovation decisions are related to the cost of communication. I set up a single-region Romer-type endogenous growth model in Section 3, extended by introducing explicitly the cost of learning, an activity relying on communication and thus affected by communication cost. Section 4 extends the model to many regions, making the spatial dimension of communication cost explicit. In order not to burry the main argument under technical details, I start — as a prelude — with a simple illustration in a static framework in Section 2. Section 5 critically discusses the assumptions leading to the main proposition of this paper. The final Section concludes.

2 Illustration: a static model

The dynamic analysis to be presented in the subsequent sections shows that communication cost reductions generate welfare gains exceeding the cost reduction itself. Essentially, this result is due to the fact that innovation uses communication as an input and generates positive externalities. There is thus too little innovative activity in the market. Reducing communication cost reduces the cost of innovation by making learning from others — a necessary prerequisite of innovation — cheaper. It thus leads to an expansion of innovative activity, thereby shifting the allocation closer to the welfare optimum.

To show the essence of the argument let us first set up a simple static model with a positive knowledge externality and with communication as an input of knowledge production. There are two sectors, final consumer goods production and knowledge production, and one primary input, labour. Consumer goods are produced with labour and knowledge as inputs, knowledge is produced with R&D and communication as inputs. R&D as well as communication are produced one to one by labour. Knowledge exerts a positive externality on the production of consumer goods. I show that collecting a lump sum tax from the consumers to finance a learning subsidy makes the representative consumer better off than the non-intervention market equilibrium.

Let consumption C be produced using labour L_f and knowledge N according to

$$C = F(L_f, N_i, N_e).$$

F is a neoclassical production function. It is differentiable, strictly increasing, linear-homogeneous and concave in labour L_f and internal knowledge N_i . Internal knowledge represents the impact of knowledge on output that the firms control and pay for. In addition, knowledge exerts a positive externality represented by N_e . F is strictly increasing in N_e .

Knowledge is produced by labour for R&D, L_r , and labour for communication, L_c , according to

$$N_i = N_e = N(L_r, L_c),$$

with neoclassical production function N , strictly increasing, concave and linear-homogeneous. I assume differentiability for the sake of simplicity. Utility of the representative household is strictly increasing in consumption.

$$L = L_f + L_r + L_c$$

is the resource constraint of the economy.

If markets are competitive and the consumer good is taken as the numéraire we get

$$w = \frac{\partial F}{\partial L_f} = \frac{\partial F}{\partial N_i} \frac{\partial N}{\partial L_r} = \frac{\partial F}{\partial N_i} \frac{\partial N}{\partial L_c}$$

with wage rate w . The wage rate is the private marginal productivity of labour, which is identical in all three types of use. The market equilibrium is of course inefficient. In the light of concavity the optimum is attained iff

$$\frac{\partial F}{\partial L_f} = \left(\frac{\partial F}{\partial N_i} + \frac{\partial F}{\partial N_e} \right) \frac{\partial N}{\partial L_r} = \left(\frac{\partial F}{\partial N_i} + \frac{\partial F}{\partial N_e} \right) \frac{\partial N}{\partial L_c}.$$

By paying a subsidy on knowledge production or use, the market can be made to reproduce the optimum. Let v_f and v_m denote customer's and mill price of knowledge, respectively, such that

$$v_m = v_f(1 + \eta)$$

with subsidy rate η , then the optimum is attained in the market if

$$\eta = \frac{\partial F}{\partial N_e} / \frac{\partial F}{\partial N_i}.$$

In practice there may however be restrictions such that one does not have such a first-best subsidy instrument at one's disposal, but instead one is able to subsidise communication. Let ζ be the subsidy rate on communication, such that the unit cost of communication is $w(1 - \zeta)$. Then, at the point $\zeta = 0$, we get

$$\frac{dC}{d\zeta} > 0, \tag{1}$$

provided that $L_f > 0$ and $L_c > 0$. The reason is that, if ζ goes up, the relative price of knowledge in relation to the wage rate goes down, and thus labour is shifted from direct use in production of the consumption good to the production of knowledge where, due to the positive externality, marginal productivity is larger. Labour is also shifted within the knowledge sector from R&D to communication, but this has a zero impact because, at $\zeta = 0$, marginal productivities of labour in R&D and in communication are equal. (See the Appendix for a formal proof of (1)).

Admittedly, there is nothing specific here in calling the externality generating activity "knowledge" and calling one of its inputs "communication". For any activity generating a positive externality it would hold true that subsidising the use of one of its inputs

is welfare increasing. In endogenous growth theory, however, knowledge production is an activity with very special properties, and the positive externality of this activity is vital for explaining sustained growth in a market economy. The assumption of a positive externality is here thus not just an ad-hoc assumption, it lies at the heart of the theory. The vital role of knowledge externalities is also well documented in an extensive empirical literature.

3 A single-region model of endogenous growth

I begin with describing the technology. Then I specify the utility of a consumer representing all households in the economy. Finally, I solve the market equilibrium and show how allocation and welfare respond to a subsidy on communication. The model is close to textbook models such as the model in Chapter 6 of Barro and Sala-i-Martin [4]. A main difference is that I stick to Romer's [9] original assumption that labour is the only input of the innovation industry, while Barro and Sala-i-Martin assume the input composition of the innovation industry to be the same as in final production. I come back to this difference in Section 5.

As before, let there be two sectors in the economy, a final goods production sector and a knowledge or innovation sector. Labour is the only primary factor. Final goods Y are produced according to

$$Y = L_f^{1-\alpha} N X^\alpha \quad (2)$$

by labour in final goods production, L_f , and N varieties of an intermediate input, each with quantity X . Symmetry guarantees that, in any solution to be considered, the quantities of intermediate inputs are all the same. Intermediates are produced by the final good one-to-one with a linear technology. Hence, consumption is what is left after subtracting intermediate inputs from output,

$$C = Y - NX. \quad (3)$$

Varieties are regarded as a continuum, such that $N \in \mathbb{R}_+$ is the variety measure. If labour input and X are fixed and N grows at rate $\hat{N} := \dot{N}/N$,¹ then output and C also grow at rate \hat{N} .

For each new variety one needs a blueprint that has to be produced by R&D labour. N is thus the (continuous) amount of blueprints and \dot{N} is the flow of new available blueprints per unit of time. The amount of R&D labour, L_r , is proportional to \dot{N} . R&D productivity, i.e. the amount of blueprints per unit of time generated by one unit of R&D labour, can be raised by communication. Communication means to use labour for learning from existing knowledge consisting of the stock of blueprints N already in use. Let L_c denote labour used for communication; thus L_c/\dot{N} is communication labour per blueprint to be developed. Communication means to look at existing blueprints in order to learn. In the next Section I explicitly introduce the spatial dimension of the learning process, but here there is only one region and one stock of knowledge to learn from. Labour L_c/\dot{N} is combined with existing blueprints according to a CD function to produce knowledge

¹Throughout, \dot{N} and so forth denote time derivatives, and \hat{N} and so forth denote log time derivatives, i.e. growth rates.

acquired by learning (call it “lessons”, ℓ),

$$\ell = N^{1-\nu}(L_c/\dot{N})^\nu.$$

The more lessons one has learned, the less R&D labour L_r is needed per blueprint to be developed,

$$L_r/\dot{N} = \psi\ell^{-\chi}.$$

ψ is an inverse productivity parameter of the knowledge industry, χ is the elasticity of productivity with respect to lessons. Inserting leads to the knowledge production function

$$\dot{N} = \phi L_r^{1-\beta} L_c^\beta N^\gamma, \quad (4)$$

with $\beta = \nu\chi/(1 + \nu\chi)$, $\gamma = (1 - \nu)\chi/(1 + \nu\chi)$ and $\phi = \psi^{-1/(1+\nu\chi)}$.

I now make an important assumption that is typical in endogenous growth literature, namely that the knowledge externality consisting in the cost reducing effect of existing knowledge is strong enough to outweigh the decreasing returns from limited primary and essential production factors. I will show in the sequel that the rate of growth to be permanently positive, but non-explosive, requires the “knife-edge” specification $\gamma = 1$, which is equivalent to

$$\chi = \frac{1}{1 - 2\nu} \quad \text{or} \quad \beta = \frac{\nu}{1 - \nu}.$$

We thus have to assume $\nu < 1/2$.

As usual, there is a single representative consumer living forever. Her preferences are described by the utility functional

$$U = \int_0^\infty \frac{C^{1-\theta} - 1}{1 - \theta} \exp(-\rho t) dt. \quad (5)$$

$\theta > 0$ is minus the elasticity of marginal utility flow with respect to consumption (same as inverse intertemporal elasticity of substitution), ρ is the rate of time preference.

Finally, the resource constraint of the economy requires labour in the three kinds of use not to exceed the given total stock L ,

$$L \geq L_f + L_r + L_c.$$

I prove constructively the existence of a steady state market equilibrium where all variables grow (or decline) at constant (possibly zero) rates. In the steady state labour is fully employed. Labour allocation L_f , L_r and L_c and the output of intermediate varieties X are constant. Assuming perfect competition in final production and choosing labour as numéraire yields output value (not quantity!) equal to $L_f/(1 - \alpha)$ and intermediate input value $\alpha L_f/(1 - \alpha)$.

Each intermediate producer is the exclusive supplier of her variety but has a negligible influence on the composite price of all intermediates. She therefore behaves non-strategically and faces a price elasticity of demand equal to $1/(1 - \alpha)$. Maximising profit yields a price equal to marginal cost divided by α . This yields total profit, P , in the intermediate industry

$$P = \frac{\alpha - \alpha^2}{1 - \alpha} L_f = \alpha L_f. \quad (6)$$

The Consumer maximises the utility functional (5) subject to the dynamic budget constraint

$$\dot{A} = L + \iota A - pC - T.$$

A is the nominal value of the asset held by the consumer, ι is the nominal interest rate, p is the output price and T is the tax collected to finance the subsidy. This leads to the Keynes-Ramsey rule

$$\hat{C} = (r - \rho)/\theta, \quad (7)$$

with real interest rate $r = \iota - \hat{p}$ (“real” means measured in terms of the consumption good). The real interest rate is profit over the value of the knowledge stock plus rate of appreciation minus rate of inflation,

$$r = \frac{\alpha L_f}{vN} + \hat{v} - \hat{p}. \quad (8)$$

v is the blueprint price.

Equations (7) and (8) are two of three dynamic equations of the model. The two corresponding boundary conditions needed to determine the solution are the initial and terminal condition for the household’s assets,

$$A(0) = v(0)N(0)$$

and

$$\lim_{t \rightarrow \infty} A(t)D(t) = 0. \quad (9)$$

$D(t)$ is the nominal discount factor with $\hat{D} = -\iota$. (9) is the transversality condition requiring the present value of the household’s asset to converge to zero. If it did not, the household could trade present consumption against future assets without a future loss, thus not behaving optimally.

Let us next look at the labour allocation in the innovation industry. Blueprints are assumed to be sold at unit cost v . From the CD function in (4) (with $\gamma = 1$) we get the expenditure for L_r and L_c , respectively, as

$$L_r = (1 - \beta)v\dot{N} \quad (10)$$

and

$$(1 - \zeta)L_c = \beta v\dot{N}. \quad (11)$$

ζ denotes the communication subsidy rate. Inserting into (4) (assuming $\gamma = 1$) yields

$$\dot{N} = N\phi(1 - \beta)^{1-\beta} \left(\frac{\beta}{1 - \zeta} \right)^\beta v\dot{N}. \quad (12)$$

Solving for v gives

$$v = \frac{g(\zeta)}{N\phi} \quad (13)$$

with

$$g(\zeta) := (1 - \beta)^{\beta-1} \beta^\beta (1 - \zeta)^\beta.$$

Furthermore, adding L_r and L_c from (10) and (11) we get the average labour productivity in the innovation sector as

$$\frac{\dot{N}}{L_n} = N\phi f(\zeta) \quad (14)$$

with

$$f(\zeta) := \frac{1}{g(\zeta) \left(1 - \beta + \frac{\beta}{1-\zeta}\right)}$$

L_n is labour in the innovation industry, $L_n := L_r + L_c$. Note that $g(\zeta) \leq 1/f(\zeta)$, with equality iff $\zeta = 0$. This is to say that the private cost per blueprint is less than or equal to the gross labour cost per blueprint (“gross” means before subsidies are subtracted). The difference is the subsidy per blueprint. Total subsidy payments are thus

$$S = \hat{N}(1/f(\zeta) - g(\zeta))/\phi.$$

Using (8) and noting that $-\hat{N} = \hat{p} = \hat{v}$, the real interest rate is

$$r = \frac{\phi\alpha L_f}{g(\zeta)}. \quad (15)$$

Obviously, $f(\zeta)$ is maximised at $\zeta = 0$ and decreasing in ζ for $\zeta \neq 0$. Thus $f'(0) = 0$ and $f'(\zeta) < 0$ for $\zeta \neq 0$. This expresses the fact that larger subsidies mean larger distortion of labour allocation and thus lower average labour productivity in the innovation sector. At $\zeta = 0$ this is however a second order effect; this observation lies at the heart of our main result regarding welfare gains due to communication cost subsidies.

The dependence of the steady state on parameters is most easily seen in Figure 1. The *Ln-line* is

$$\hat{C}/\phi = L_n f(\zeta), \quad (16)$$

obtained from (14) and the fact that $\hat{C} = \hat{N}$. The *Lf-line* is

$$\hat{C}/\phi = \frac{\alpha L_f}{\theta g(\zeta)} - \frac{\rho}{\theta\phi}, \quad (17)$$

obtained from (7) by inserting r from (15).

It is immediate from the Figure that the growth rate is the bigger, the bigger L , α and ϕ and the smaller ρ . These are standard results in this type of endogenous growth models. Regarding the subsidy rate ζ that we focus on here, the effect on L_n is unambiguous; the bigger ζ the bigger L_n (and the smaller L_f , of course). The effect of an arbitrary increase of ζ on the growth rate \hat{C} is however ambiguous, because the slope of the Lf-line goes up while the slope of the Ln-line goes down. The intersection moves to the left, but can go up or down. At the point $\zeta = 0$, however, the effect is unambiguously positive, because there $f'(0) = 0$. Thus, at $\zeta = 0$, the Ln-line is marginally unaffected.

Finally, I come to the main conclusion from this Section concerning the effect of the subsidy rate on welfare. After removing an additive constant, utility is

$$U = \frac{1}{1-\theta} C_0^{1-\theta} \frac{1}{\rho - \hat{C}(1-\theta)} = \frac{1}{1-\theta} C^{1-\theta} \frac{1}{r - \hat{C}}.$$

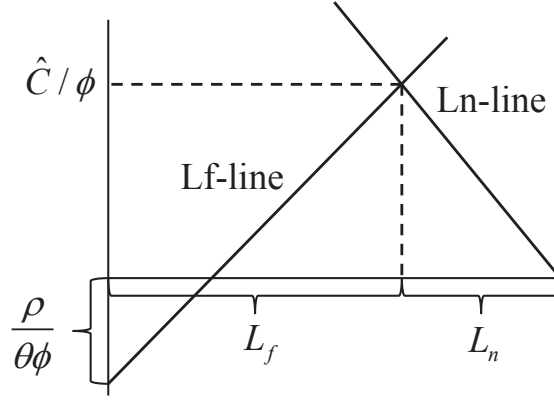


Figure 1: Determinants of growth rate

C_0 is consumption at $t = 0$. Denoting derivatives with respect to ζ as U' , C'_0 and so forth we get

$$U' = (1 - \theta) \frac{U}{C_0} C'_0 + \frac{U}{r - \hat{C}} (1 - \theta) \hat{C}'.$$

U is positive (negative) for $\theta > 1$ (for $\theta < 1$).² Thus $U(1 - \theta) > 0$, and therefore U' and $\tilde{U}' := U'/(U(1 - \theta))$ have the same sign. Inserting \hat{C}' from (16) yields

$$\begin{aligned} \tilde{U}' &= \frac{C'_0}{C_0} + \frac{\hat{C}'}{r - \hat{C}} \\ &= \frac{L'_f}{L_f} + \frac{\phi L'_n f(\zeta)}{r - \hat{C}} + \frac{\phi L_n f'(\zeta)}{r - \hat{C}}. \end{aligned}$$

The first term is negative. It represents the reduction of initial consumption due to a shift of labour from production of goods to production of blueprints. The second term is positive. It represents the increase of the growth rate due to the shift of labour, assuming unchanged average labour productivity in the innovation sector. Finally, the third term is again negative. It represents the loss of innovation productivity due to distortive labour allocation in the innovation sector.

In general one cannot say which term dominates, but for $\zeta = 0$ one can. For $\zeta = 0$ the last term vanishes. Noting that $L'_f = -L'_n$ the expression simplifies to

$$\tilde{U}' = L'_f \left(\frac{1}{L_f} - \frac{\phi f(0)}{r - \hat{C}} \right).$$

Using $r = \alpha L_f \phi / g(0)$ and $\hat{C} = L_n \phi f(0)$ at $\zeta = 0$, and noting that $f(0) = 1/g(0)$ we get

$$\tilde{U}' = L'_f \left(\frac{1}{L_f} - \frac{1}{\alpha L_f - L_n} \right) > 0.$$

This proves that a communication subsidy, if not too big, makes the consumer better off. Too big a subsidy reduces welfare; if the subsidy goes up, the remaining externality becomes smaller and less can be gained by internalising it, but the distortion of labour allocation in the innovation industry becomes more severe.

²I omit the case $\theta = 1$ (logarithmic utility), which needs a special treatment without altering results.

4 A multiregional model

In this Section I extend the model to many regions in a straightforward way. The literature offers more complex models integrating endogenous growth and economic geography. Fujita and Thisse [7, Chapter 11] present a design, where innovations are produced by perfectly mobile skilled workers. It leads to endogenous agglomeration even in a symmetrical environment, while the steady state equilibrium of the model in this Section is symmetrical in a symmetrical environment.

Let the economy consist of n regions with identical technologies. In general, they may differ with regard to their respective sizes as well as their respective positions vis-à-vis the other regions. Later I will however restrict the analysis to the symmetric case, where regions are equally sized and do not differ with regard to their respective accessibilities to other regions. I introduce two types of spatial frictions, transportation costs and communication costs, both of the iceberg type. The capital market, however, is assumed to work frictionless across space.

Consumption and intermediate goods are now produced using intermediates from all regions. For region i , Equations (2) and (3) then become

$$Y_i = L_{f,i}^{1-\alpha} \sum_j N_j M_{ji}^\alpha \quad (18)$$

and

$$C_i = Y_i - N_i \sum_j X_{ij}. \quad (19)$$

X_{ij} is production per variety, delivered to the own as well as to all other regions, incurring iceberg transportation cost with cost factor $\tau_{ij} \geq 1$, such that, if X_{ij} units are sent off from region i , then only $M_{ij} = X_{ij}/\tau_{ij}$ units appear in the destination region j . One can understand (2) as a CD function combining L_f and a composite intermediate \bar{M}_i ,

$$Y_i = L_{f,i}^{1-\alpha} \bar{M}_i^\alpha, \quad (20)$$

with

$$\bar{M}_i := \left(\sum_j N_j M_{ij}^\alpha \right)^{1/\alpha}.$$

Similarly, the innovation technology (4) is extended to

$$\dot{N}_i = \phi L_{r,i}^{1-\beta} \sum_j (L_{c,ij}/\lambda_{ij})^\beta N_j^\gamma, \quad (21)$$

where $\lambda_{ij} \geq 1$ denotes the distance friction of communication. As before, I assume $\gamma = 1$ to assure permanent growth. Utility is as in (5), with U_i and C_i replacing U and C , respectively. Finally, the resource constraint

$$L_i \geq L_{f,i} + L_{r,i} + \sum_j L_{c,ij}$$

completes the specification.

Solving for the market solution we get the regional output price

$$p_i = (1 - \alpha)^{\alpha-1} \alpha^{-\alpha} w_i^{1-\alpha} q_i^\alpha.$$

w_i is the wage rate. Different from the single-region case, here we cannot simply set it equal to one because relative wages vary across regions and time. The composite price for diversified intermediates, q_i , is minimal expenditure per unit of the composite intermediate \bar{M}_i . It is

$$q_i = \left(\sum_j N_j (p_j \tau_{ji} / \alpha)^{1-\sigma} \right)^{1/(1-\sigma)},$$

with elasticity of substitution between varieties $\sigma := 1/(1 - \alpha) > 1$. As the marginal cost for an intermediate good from i is p_i , its mill price is p_i/α due to the monopolistic price mark-up explained above. Applying Hotelling's theorem one obtains a gravity equation for the value of trade from region i to region j ,

$$N_i p_i X_{ij} = N_i p_i \tau_{ij} M_{ij} = \alpha^\sigma N_i p_j Y_j \left(\frac{p_i \tau_{ij}}{q_j} \right)^{1-\sigma}.$$

This is the standard spatial version of the Dixit-Stiglitz model of monopolistic competition and horizontal product diversity.

Consumers maximise the utility functional under the dynamic budget constraint

$$\dot{A}_i = w_i L_i + \iota A_i - p_i C_i - T_i,$$

leading to the Keynes-Ramsey rule

$$\hat{C}_i = (r_i - \rho)/\theta$$

with real interest rate $r_i = \iota - \hat{p}_i$. ι is the nominal interest rate, which is uniform across regions due to the assumption of a frictionless global asset market. Note, however, that real interest rates are not uniform, because inflation/deflation rates may differ between regions. The initial boundary condition is

$$A_i(0) = \sum_j \delta_{ij} v_j N_j.$$

δ_{ij} with $\sum_i \delta_{ij} = 1$ is the share in the stock of blueprints of region j held by the household in region i . On a perfect foresight path, portfolio compositions are irrelevant, because all assets earn identical nominal returns. After an unanticipated shock they however matter a lot, because different assets differently appreciate or depreciate as a consequence of the shock, in general. The terminal boundary condition is analogous to (9).

The nominal interest rate is

$$\iota = \frac{\alpha L_{f,i}}{v_i N_i} + \hat{v}_i. \quad (22)$$

The fundamental difference from Equation (8) in the single-region model is that the left hand side is uniform across regions, while the right hand side is region specific.

Let us now study labour allocation in the innovation sector, which is a bit more tedious than in the preceding Section. The unit cost of a blueprint is

$$v_i = w_i \min_{L_{r,i}, L_{c,ij}} \left\{ L_{r,i} + \sum_j L_{c,ij} (1 - \zeta_{ij}) \text{ subject to } \dot{N} = 1 \right\}.$$

Applying standard calculus one obtains

$$v_i = w_i \frac{g(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m})}{\bar{N}\phi}, \quad (23)$$

with the vector of subsidy rates $\boldsymbol{\zeta}_i := (\zeta_{i1}, \dots, \zeta_{in})$, communication cost vector $\boldsymbol{\lambda}_i := (\lambda_{i1}, \dots, \lambda_{in})$ and vector $\mathbf{m} := (m_1, \dots, m_n)$ of relative knowledge stocks $m_j := N_j/\bar{N}$. \bar{N} is the average stock of blueprints per region,

$$\bar{N} := \sum_i N_i/n.$$

The function $g(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m})$ is

$$g(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m}) := (1 - \beta)^{1-\beta} \beta^\beta \left(\sum_j \left(\lambda_{ij}(1 - \zeta_{ij}) \right)^{\beta/(1-\beta)} (m_j)^{1/(1-\beta)} \right)^{\beta-1}.$$

The average labour productivity in the innovation sector is

$$\frac{\dot{N}_i}{L_{n,i}} = \bar{N}\phi f(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m}) \quad (24)$$

with

$$f(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m}) = \frac{1}{g(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m})} \left(1 - \beta + \beta \frac{\sum_j (1 - \zeta_{ij})^{1/(\beta-1)} m_j^{1/(1-\beta)} \lambda_{ij}^{\beta/(\beta-1)}}{\sum_j (1 - \zeta_{ij})^{\beta/(\beta-1)} m_j^{1/(1-\beta)} \lambda_{ij}^{\beta/(\beta-1)}} \right)^{-1}.$$

It is still true that v_i cannot exceed the average gross labour cost per blueprint and is smaller unless $\boldsymbol{\zeta}_i = 0$,

$$v_i = w_i \frac{g(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m})}{\bar{N}\phi} \leq w_i \frac{L_{n,i}}{\dot{N}_i} = w_i \frac{1}{\bar{N}\phi f(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m})}.$$

Thus $g(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m}) \leq 1/f(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m})$ with equality iff $\boldsymbol{\zeta}_i = 0$. It is also still true that $f(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m})$ is maximised at $\boldsymbol{\zeta}_i = 0$. Thus

$$\frac{\partial f(0, \boldsymbol{\lambda}_i, \mathbf{m})}{\partial \zeta_{ij}} = 0 \text{ for all } j.$$

The subsidy paid to innovators in region i is the difference between gross labour costs of innovation and labour cost paid by the innovators, i.e.

$$S_i = w_i \dot{N}_i \frac{1/f(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m}) - g(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m})}{\bar{N}\phi}.$$

I assume the state budget to be always balanced. There has to be a tax scheme making sure that $\sum_i S_i = \sum_i T_i$. It should however be noted that due to Ricardo-equivalence holding in this type of models it would not alter anything if I allowed the state to issue bonds as a financing instrument. Note that for $n = 1$ and $\lambda = 1$ we return to the single-region model as a special case.

The dynamics of the system can be rather complex. While the single-region economy is always in a steady state and jumps from one steady state immediately to another one if shocked, the multiregional model exhibits transition phases if shocks affect different regions differently. A numerical solution is needed for a full understanding of these transition paths. This can be done by integration methods for two-point boundary value problems [5] but is beyond the scope of the present paper.

Some intuition can however be gained from a look at Equation (22). Consider a region i 's response to a preferential communication cost reduction in favour of region i . Assume the region to be small as compared to the entire economy, and for a moment forget about the appreciation term \hat{v}_i . As the the region is small, v can be regarded as unaffected by the cost reduction shock. As $g(\boldsymbol{\zeta}_i, \boldsymbol{\lambda}_i, \mathbf{m})$ jumps down, equality in Equation (22) has to be restored. This is brought about in three ways: First, the wage rate jumps upwards; this, secondly, leads to an instantaneous shift of labour from production to innovation, letting the nominator in (22) jump down. The wage rate overshoots; in the course of time it cripples down again, though not back to the original level, because in the favoured region N_i and thus, in the long run steady state, also N_i will be larger than before. Therefore \hat{v}_i , tied to \hat{w}_i by Equation (23), will also instantaneously jump downwards, which is a third way to restore equality in Equation (22).

Fortunately, there is a special and intuitive case that is easily tackled analytically. Let the economy be symmetrical in the following sense: first, all regions have equal size, $L_i = L$ for all i , and second, the position a region vis-à-vis the other regions does not differ across regions. By this I mean that for each region there is a perturbation of the order of all regions such that the vectors $(\tau_{i1}, \dots, \tau_{in})$, $(\lambda_{i1}, \dots, \lambda_{in})$ and $(\zeta_{i1}, \dots, \zeta_{in})$ after perturbing their respective entries do not differ across regions. Equally spaced points on a circle, nodes of a regular lattice on a torus or the ends of star rays of equal lengths are typical examples of a symmetrical geography. In this case region's subscripts can be omitted in Equations (22) and (24). We can pick anyone of the identical regions and draw the Lf-lines and Ln-lines defined by equations (17) and (16), with $f(\boldsymbol{\zeta}, \boldsymbol{\lambda}, \mathbf{1})$ and $g(\boldsymbol{\zeta}, \boldsymbol{\lambda}, \mathbf{1})$ substituting $f(\zeta)$ and $g(\zeta)$, respectively. The conclusions are exactly as for the single-region case. Finally, the proof for the welfare gain also goes through exactly as on page 7, whereby U' and so forth now stand for partial derivatives with respect to any element of the vector $\boldsymbol{\zeta}$.

5 Discussion

The main conclusion from the last two Sections is that communication generates a positive externality within an endogenous growth framework. A policy intervention reducing private communication cost induces benefits that consumers value higher than the cost reduction itself. A marginal cost reduction is beneficial even if consumers must pay the full amount of the cost reduction. This implies that benefits are underestimated by traditional cost-benefit analysis that does not take the positive externality into account.

The result hinges on two fundamental characteristics common to most endogenous growth models and one assumption that I added. The two fundamental characteristics are first the proposition that innovation and growth is too small in a market equilibrium and second the assumption of knowledge spill-overs. The added assumption is that these spill-overs do not just flow through the air but have to be realised by a costly communication

activity. I regard the latter assumption natural enough to need no further discussion or justification. An empirical quantification of this spill-over mechanism is however an open question left to future research.

Regarding the mentioned market failure pertinent to most endogenous growth models, it has to be mentioned that the proposition of too low growth, though typical, does not hold in all versions under all parameter profiles. In the so-called neo-Shumpeterian product ladder model introduced by Aghion and Howitt [2] growth can be both, too fast or too slow. This is due to the destructive side of innovation. The product ladder model assumes that each new product completely replaces an existing one. Instead, in Romer-type models like ours new products are added to the diversity bundle without affecting utility from existing ones, neither positively or negatively. The destructive aspect that could lead to excessive innovation, because it is neglected by the innovators, is absent. Though never taken into consideration in endogenous growth theory, in the real world there is also constructive innovation, i.e. new goods in the market that make existing ones not less but more valuable. Taking this into account the Romer assumption lying in the middle between destructive and constructive innovation does not seem too bad. It is not clear from the literature whether excessive innovation is a real issue or just a theoretical curiosity. But still, the topic needs further scrutiny, and the conclusions will matter not just for our, but for any welfare economic application of endogenous growth theory.

Finally, can one rely on the assumption of a positive knowledge externality? In our specification long run growth is impossible without knowledge spill-overs. One could therefore argue that the empirical fact of long run positive growth is a sufficient proof of the existence of spill-overs. This argument does however not go through without qualification. One can modify the design of the model in such a way that it generates steady state positive growth rates with smaller or even zero knowledge externalities. To show this, let us generalise the production system. I take the single-region case for the sake of simplicity. Mutatis mutandis the argument applies to the multiregional system as well. First, write the production function (like Equation (20)) as

$$Y = L_f^{1-\alpha} \bar{M}_f^\alpha. \quad (25)$$

M_f is the input of the composite intermediate

$$\bar{M} := N^{1/\eta} X \quad (26)$$

used in final production. So far I assumed $\alpha = \eta$. Now I allow η to differ from α (and thus σ to differ from $1/(1 - \alpha)$). Second, I assume the innovation sector to use not only labour but also the diversified bundle of intermediates as an input. Replace L_n in (14) with a CD composite of labour and the intermediate index \bar{M} with expenditure shares $\epsilon \geq 0$ and $1 - \epsilon > 0$, respectively,

$$\dot{N} = L_n^{1-\epsilon} \bar{M}_n^\epsilon N^\gamma \phi f(\zeta). \quad (27)$$

The ratio of labour to intermediates is thus the same for R&D and communication. I reintroduce γ to allow it to differ from one. Still, communication cost, now composed of cost components for labour and intermediates, is assumed to be subsidised. The total amount of the intermediate composite is now $\bar{M} = \bar{M}_f + \bar{M}_n$. While our original design meant that innovation does not benefit from technical progress, now a growing N does not only make final goods production but also blueprint production more productive.

Obviously, the more the innovation sector also benefits from growing product diversity, the smaller are the spill-overs needed for making the growth engine run.

Permanent steady state growth requires that \dot{N} and N grow at the same rate (otherwise \hat{N} would not be constant) as well as Y and NX to grow at the same rate (otherwise $Y = C + NX$ and C could not grow at constant rates). Taking time derivatives in logs in (26) and using $\hat{N} + \hat{X} = \hat{Y} = \alpha\hat{M}$ from (25) yields

$$\hat{M} = (1/\eta - 1)\hat{N} + \hat{N} + \hat{X} = (1/\eta - 1)\hat{N} + \alpha\hat{M}.$$

Solving for \hat{M} and inserting into log time derivative of (27) yields

$$\frac{1 - \gamma}{\epsilon} \hat{N} = \frac{1}{\eta} \frac{1 - \eta}{1 - \alpha} \hat{N}.$$

The necessary condition for permanent growth therefore reads

$$\gamma = 1 - \frac{\epsilon}{\eta} \frac{1 - \eta}{1 - \alpha}. \quad (28)$$

The externality elasticity γ necessary for growth is the smaller, the bigger the respective shares of intermediates in production and innovation, α and ϵ , and the smaller η , i.e. the smaller the elasticity of substitution between varieties $\sigma = 1/(1 - \eta)$. The special case assumed thus far is $\epsilon = 0$, implying the necessary assumption $\gamma = 1$. As condition (28) shows, no externality, i.e. $\gamma = 0$, is principally possible if, for a given α , the share of intermediates in blueprint production is large enough and the elasticity of substitution between varieties is small enough. In a standard text book version called the “lab-equipment model” [1, Chapter 13] it is assumed that $\epsilon = \eta = \alpha$, yielding $\gamma = 0$. The input compositions of final and blueprint production in other words are assumed to coincide, and the elasticity of substitution between varieties is $\sigma = 1/(1 - \alpha)$. I regard both assumptions as fairly implausible. As to the former, innovation and communication are labour intensive activities. ϵ is thus plausibly positive but smaller than α . As to the latter, the input share in gross output is roughly one half in modern economies, such that $\eta = \alpha$ implies an elasticity of substitution between varieties equal to two, which is considerably smaller than standard assumptions made in empirical applications of Dixit-Stiglitz models; σ is typically assumed to be at least equal to five, which would require η to be at last 0.8. It seems to be highly plausible to assume $0 < \epsilon < \alpha < \eta < 1$, implying $0 < \gamma < 1$. To summarise, in the generalised model a plausible parameter profile would lead to a γ -parameter less than one, but definitely larger than zero, supporting the idea of knowledge externality being a necessary ingredient of an endogenous growth model. Finally, the empirical evidence of knowledge spill-overs, their vital role in the growth process and also the distance effect in spill-over intensity supporting the importance of communication cost in knowledge acquisition is overwhelming [3].

6 Conclusion

I have shown within a Romer-type endogenous growth model that communication cost reductions generate benefits that households value more than the cost reduction itself. If they had to pay fully for the cost reduction, they still would gain a net benefit. In other

words, communication exerts a positive externality. An equivalent proposition is that there are wider positive economic effects of communication cost reductions. In a traditional cost-benefit analysis (CBA) the monetary equivalent of a marginal cost reduction is the amount of the cost reduction itself (“the cost of a cost is its cost”). In case of investments reducing the cost of business travel the benefit is thus higher than what a traditional CBA would indicate. The mechanism leading to this result is that innovators get wrong market signals. They value the innovation too low because they disregard that innovations makes the development of new blueprints by later innovators cheaper. Later innovators cannot be prevented from learning from existing knowledge without pay. It is argued in the discussion that the spill-overs being the essential kernel of the argument are well justified by a plausible parameter profile of the endogenous growth model as well as by a wide empirical literature.

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Appendix

To prove (1), let $v/w = \min_{L_r, L_c} \{L_r + L_c(1 - \zeta)\}$ subject to $N(L_r, L_c) = 1$ denote the relative knowledge price. By Hotelling's theorem we get, at $\zeta = 0$,

$$\frac{d(v/w)}{d\zeta} = -L_c^* < 0,$$

where L_c^* denotes labour for communication per unit of knowledge, which is positive by assumption. Due to the decreasing marginal rate of substitution follows

$$\frac{d(L_f/N)}{d\zeta} < 0,$$

which in turn implies

$$-\frac{dL_f}{d\zeta} = \left(\frac{dL_r}{d\zeta} + \frac{dL_c}{d\zeta} \right) > 0.$$

We thus obtain

$$\begin{aligned} \frac{dC}{d\zeta} &= \frac{\partial F}{\partial L_f} \frac{dL_f}{d\zeta} + \left(\frac{\partial F}{\partial N_i} + \frac{\partial F}{\partial N_e} \right) \left(\frac{\partial N}{\partial L_r} \frac{dL_r}{d\zeta} + \frac{\partial N}{\partial L_c} \frac{dL_c}{d\zeta} \right) \\ &= w \frac{dL_f}{d\zeta} + w \left(\frac{dL_r}{d\zeta} + \frac{dL_c}{d\zeta} \right) + \frac{w}{v} \frac{\partial F}{\partial N_e} \left(\frac{dL_r}{d\zeta} + \frac{dL_c}{d\zeta} \right) \\ &= \frac{w}{v} \frac{\partial F}{\partial N_e} \left(\frac{dL_r}{d\zeta} + \frac{dL_c}{d\zeta} \right) > 0. \end{aligned}$$