Knowledge Spillovers and Regional Growth in Europe

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Abstract

This paper uses ideas from endogenous growth theory and from regional economics to as an intuitive basis for specifying an econometric equation that takes regional economic growth as function of input growth and knowledge accumulation. It includes economic growth in surrounding regions along with other control variables. The purpose is to estimate the effects of regional R&D intensity and of R&D spillovers from other regions on regional growth. Using either a neoclassical specification or a endogenous specification, R&D intensity and R&D spillovers have significant effects on growth. The Romer hypothesis that knowledge accumulation raises the marginal product is consistent with our results.

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Seyit Kose and Ronald L. Moomaw

I. Introduction

Knowledge spillovers among regions have the potential to significantly affect regional growth and development. This paper investigates the nature and role of regional knowledge spillovers on regional growth in three countries—France, Italy, and Spain. Attempts to institute policies that reduce regional disparities require an understanding of the regional growth process. To further that understanding, in this paper we investigate the size, significance, and nature of regional spillovers of research and development (R&D) activity.

We have chosen to focus on R&D spillovers rather than knowledge spillovers because we want to gain insight into the mechanisms underlying knowledge spillovers. We recognize that knowledge spillovers can occur through other variables and control that possibility. Our approach is to adapt Romer's (1989) model of economic growth to a regional context. Others (including Badinger and Tondl (2002); Cheshire and Carbonaro (1996); Cheshire and Magrini (2000); Keilbach (2000); and Paci and Pigliaru (2002)) have drawn on endogenous growth models to study spatial spillovers. Like Badinger and Tondl, we specify our econometric model in a growth accounting framework that allows for Romer's endogenous growth. In fact, our econometric model is a modified version of Romer's (1989) model.

This paper provides new information on R&D intensity and R&D spillovers by using panel data and panel estimators to investigate their role in regional economic growth. We examine spillovers under the assumption that they are *two way*, i.e. that they flow into and out of all regions **and** under the assumption that the spillovers are from R&D intensive regions to regions that are less R&D intensive and thus measure an R&D *gap*.

II. Specifying the Econometric Model

Romer's (1993) endogenous growth model assumes that the economy has two sectors: an object sector and an idea sector. The object sector is the final output sector where output Q is determined by technology (or the stock of knowledge) A, human capital employed in final goods production H_q, labor quantity L, and capital stock K. Let

$$Q = A\, H_q^{\alpha}\, L^{\beta}\, K^{1-\alpha-\beta}\,. \qquad (1)$$

This production function exhibits constant returns to scale in human capital, labor, and physical capital with fixed A. With Romer's approach an increase in A does not immediately result in an increase in output. Rather, it increases the marginal product of capital and may increase the investment rate. Ultimately, the increase in A is associated with an increase K and the marginal product of capital remains constant.

The capital stock is embodied in a potentially infinite variety of producer durables that are created in the monopolistically competitive idea or design sector. Using the Dixit-Stiglitz model of monopolistic competition, Romer (1990) shows that knowledge or technology can be produced in the private sector even though it is inherently a nonrival, nonexclusive good. For this to happen, property rights (patents) and secrecy must make knowledge exclusive, allowing knowledge producers to charge for their product.

In Romer's economy, knowledge or technology is available to everyone at the same price, allowing swift diffusion throughout the economy. Romer sees the knowledge created as general knowledge, i.e. knowledge that can be transferred from one individual to another at zero marginal cost (Jensen and Meckling 1992). If knowledge is specific, i.e. knowledge that can be transferred from one individual to another only by incurring transfer costs, or if property rights are incomplete and unable to completely prevent transfer, its diffusion will take time and resources. In a spatial context, knowledge or technology diffusion from one region to another is impeded by distance. Thus, knowledge or technology can spillover from one region to another, and not be equally available to all regions.

Romer shows that the relationship between total capital stock and the variety of producer durables is

$$K = \eta\, A\, x \qquad \text{or} \qquad x = K / \eta A \qquad \text{or} \qquad A = K / \eta\, x \qquad (2)$$

where x implies an equal amount of each producer durable and η is the constant unit of foregone consumption necessary to produce one unit of the producer durable. Under this assumption, producer durables can be fragmented into two pieces, physical capital stock K and knowledge stock A as given in equation (2).

Romer's assumptions lead to a stationary state that results in the production function becoming

$$Q = H_q^{\alpha} L^{\beta} A x^{1-\alpha-\beta}. \quad (3)$$

Substituting equation (2) into equation (3) gives

$$Q = H_q^{\alpha} L^{\beta} K^{1-\alpha-\beta} A^{\alpha+\beta} \eta^{\alpha+\beta-1}. \quad (4)$$

This production function does not necessarily differ from the neoclassical model with technological change. Indeed, it can be interpreted is a neoclassical production function with human capital and labor augmented technological change by assuming that A is a constant. The essential difference between the neoclassical model and Romer's model arises from the assumption about technology or knowledge. In the neoclassical model, technological progress is assumed constant, while in this endogenous growth model it is a variable over time and across economic units.

According to the theory, which is summarized in equations (2)-(4), constant returns to scale in L, H_q and x holds, given that A is a constant number of diversified capital goods at any point of time (equation (2)). After adjustment is completed, an equal amount x of each variety x_i from A number of capital goods is employed in the production process in the steady state. The relative contribution of the aggregate amount of producer durables, Ax, to output is ($1-\alpha-\beta$). Further, because the producer durables are produced by combining ideas and raw capital units in the intermediate sector, the sector is compensated for cost of knowledge production and of raw capital by the share of output received by Ax.

The production process is constant returns to scale in L, H_q and K in equation (4) if growth in A is constant, as in neoclassical model. A, however, is a variable in the Romer model and as seen by inspecting equation (4) the production function exhibits and increasing returns to scale of $1+(\alpha+\beta)$ in L, H_q, K and A.

As a result, the knowledge stock variable A has two effects on growth in output. One is indirect through a finer division of physical capital in the production of new intermediate goods. By increasing the marginal product of capital, this increases the value of aggregate fixed capital in a closed economy or causes aggregate capital accumulation in an open economy. The other is directly through spillovers arising from knowledge stock A, which increases productivity of the traditional production factors without any cost and compensation.

The growth accounting decomposition of regional growth based on equation (4) is

$$Q'' = \varepsilon_H H_q'' + \varepsilon_L L'' + \varepsilon_K K'' + \varepsilon_A A'' \qquad (5)$$

where VAR” is the derivative of natural logarithm of any variable (VAR) with respect to time: VAR” = d(lnVAR)/dt and $\varepsilon_{VAR} = \partial(\ln Q)/\partial(\ln VAR)$ is the elasticity of output with respect to that variable. It follows that $\varepsilon_H = \alpha$; $\varepsilon_L = \beta$; $\varepsilon_K = 1-\alpha-\beta$; and $\varepsilon_A = \alpha+\beta$.

Output growth is decomposed into that due to growth in human capital, in labor, in capital, and in knowledge. Because panel capital data over European regions are not available to us, we follow Romer (1989) and estimate the equation using the investment share (I/Q) in output. In particular, capital growth is replaced by $(\partial Q/\partial K)(I/Q) - \varepsilon_K\lambda$ (where λ is the constant depreciation rate) giving

$$\begin{aligned} Q'' &= \varepsilon_H H_q'' + \varepsilon_L L'' + (\partial Q/\partial K)(I/Q) - \varepsilon_K\lambda + \varepsilon_A A'' \\ &= \varepsilon_H H_q'' + \varepsilon_L L'' + \kappa(I/Q) - \varepsilon_K\lambda + \varepsilon_A A'' \qquad (6) \end{aligned}$$

where $\kappa = \partial Q/\partial K$ is the marginal product of capital.

With output per employee (q = Q/L) and constant returns to scale in H_q, L and K (i.e., $\varepsilon_H + \varepsilon_L + \varepsilon_K = 1$) the equation for growth in per labor output is

$$q'' = -\varepsilon_K L'' + \varepsilon_H (H_q/L)'' + \kappa(I/Q) - \varepsilon_K\lambda + \varepsilon_A A'' \qquad (7)$$

This specification can be used to estimate a neoclassical growth equation or a Romer-type equation. In the neoclassical version, A”, strictly speaking, is exogenous. It may, however, differ among regions (countries), perhaps because R&D efforts differ exogenously among regions. For this to happen, we must drop the neoclassical assumption that knowledge or technology is a public good. In the Romer version, A” is endogenous because R&D efforts are endogenous in the model.

Both Magrini (1997) and Caniels (2000) assume that knowledge gradually spills over spatial economic units. The extent of the spillovers’ influence on a particular economy decays with physical distance and is affected by the economy’s characteristics. In a full specification of Romer’s theoretical model, Magrini (1997) divides knowledge into two categories, abstract and tacit, and gives a particular role for growth disparities to the tacit knowledge with regard to within- and between-regions knowledge spillovers. Caniels

(2000), on the other hand, assumes that the cross-regional disparities in long run total factor productivities exist because of the technology gaps across regions, and that technologically lagging regions with appropriate capabilities can close the gap faster and thus grow faster.

In order to empirically test the role of own-region R&D efforts and R&D spillovers across regions, we specify an equation based on the intuition of Romer's (1989) model and in the light of the above discussion of knowledge. We assume that the disparate regional growth is a consequence of multivariate process as specified in such empirical studies as Magrini (1999), Cheshire and Magrini (1999), and Cheshire and Carbonaro (1996) along with the regional adaptation of Romer-type theoretical model by Magrini (1997). That is to say, own R&D efforts together with particular local fixed characteristics and spatial connections of local economic units to each other over the geography allow regional knowledge accumulation. In addition to the generation of knowledge within locations, knowledge accumulation of spatial economic units results from knowledge spillovers across regions.

Specifically, we empirically test the influences of local employment in R&D activities implemented or funded by private or government sectors on labor productivity growth. Beside own sources devoted to R&D activity by these sectors, growth in labor productivity is determined by knowledge spillovers across regions due to the R&D efforts of other regions. We assume that the potential extent of knowledge spillovers hinges positively on its R&D gap with other regions or that it depends on the region's exposure to R&D spillovers (two way) from all other regions.

Moreover, certain other factors are likely to have significant influence on a region's growth rate of manufacturing labor productivity. Among the variables included as controls are industrial mix and its transformation and industrial specialization, as measured by the Herfindahl index, and its change. Further, to control the region's technological and economic characteristics including capital intensity, we use labor productivity lagged by one year. Finally, manufacturing productivity may be influenced by labor productivity growth in neighboring regions. Thus, we introduce the average labor productivity growth in neighboring regions. The use of this spatial lag variable is particularly important because we use administratively defined regions rather than functional economic regions as our unit of observation.

III. Estimates with a Neoclassical Flavor

We decided to use panel data estimators to approach the question of the effects of R&D on European regional growth (see Judge et al. 1988, p. 489-491; and Green 1997, p. 613-634). The use of panel data allows to introduce a fixed effect for every region in the specification, which, in turn, allows the control of idiosyncratic variables that are fixed in time. In particular, geographic features, transportation networks (over the short time), political and economic institutions, and cultural and language differences are all controlled. This reduces the chances of omitted variable bias and accounts for many of the spatial features that spill over from one region to another. We estimated each equation using the two-way random effects estimator, but the Hausman test rejected random effects in favor of fixed effects for all equations. The F-test for the presence of fixed effects rejected the null of no fixed effects in all cases. So all of the estimates discussed below were generated with the two-way fixed effects estimator.

The first equation to be estimated expands equation (7) by adding the above-mentioned variables. The specification is the region's labor productivity growth as a function of the growth of the labor input, the growth in human capital per unit of labor, the investment share, economic growth spillovers from other regions, initial-year labor productivity, growth of industrial specialization, and the growth of industrial mix. Finally, the R&D variables are added as logarithms, making their coefficients the elasticity of regional growth with respect to the relevant R&D variable. Each estimate has the region's own R&D intensity and a variable designed to capture the effects of R&D spillovers. One such variable captures the idea of an R&D gap, and another captures R&D exposure—a two-way spillover. The gap approach assumes that R&D spill-ins come only from regions that have greater R&D intensity. It is a one-way flow of information. We measure this by computing the difference—the gap--between the R&D intensity of every other region and the region under consideration. We then distance weight the positive differences and sum these differences. Alternatively, we compute the gap between the region in question and all neighboring regions with greater R&D intensity. We then average the positive gaps over the number of regions with such differences. R&D exposure sums the distance-weighted

R&D intensities for all other regions or it takes the average R&D intensity for neighboring regions.

In examining Table I, we first consider the growth accounting variables and the various control variables. Models 1 and 2 differ from Models 3 and 4 in that the former use a two-way approach to spillovers and the latter use a gap approach. These models differ only with regard to the R&D spillover measures used. Therefore it is not surprising, as inspection of the table reveals, that the coefficients for the remaining variables do not change much from one estimate to another.

Our first concern is with the estimates of the coefficients from the first three variables. These coefficients are, respectively, the negative of capital's share in the production function, the share of human capital, and the marginal product of capital. Taking Model 1 as representative, we see that capital's share is estimated as 0.29 and human capital's share as 0.60, leaving a share of 0.11 for raw labor. Capital's share is reasonable, and consequently the remaining share of 0.71 for labor is reasonable. The split of labor's share into that for human capital and raw labor, however, is not as intuitively satisfying. Finally the third coefficient directly related to the production function, the one for investment share, is 0.29. To understand the implications of this coefficient note that an increase in investment share from 0.18 to 0.28 (from 0.05 below the average to 0.05 above the average) would increase the growth rate by 2.9 percent.

Badinger and Tondl (2002) and Keilbach (2000) estimate similar values for capital's share for European regions and German kreise, respectively. They find, however, that the human capital share is much smaller (from 0.10 to 0.17) than our estimate of 0.60. This implies a much higher share for raw labor than we find. Romer (1987) suggests that investment share in national studies generally has a coefficient of between 0.10 and 0.20, compared to our estimates of between 0.20 and 0.30 in Tables I and II. Because our results for the production function parameters are generally reasonable both in terms of what others have found and in terms of our expectations, we can proceed with some assurance regarding the estimated effects of R&D intensity and R&D spillovers on regional growth.

Table I. Estimating knowledge spillovers across regions: The effects of private sector R&D efforts on labor productivity growth: 1985-95.

Dependent Variable = *labor productivity growth*	Spillover: Two way		Spillover: Gap	
Independent Variables	Model 1	Model 2	Model 3	Model 4
employment growth	-0.2886***	-0.2822***	-0.2934***	-0.2879***
	(-10.25)	(-9.98)	(-10.24)	(-10.07)
human capital growth	0.5999***	0.6021***	0.5998***	0.6020***
	(27.41)	(27.49)	(26.51)	(27.05)
investment share	0.2880***	0.2861***	0.3119***	0.3158***
	(9.66)	(9.58)	(10.41)	(10.60)
economic growth spillover	0.1523***	0.1509***	0.1742***	0.1738***
	(5.20)	(5.15)	(5.97)	(5.98)
initial-year labor productivity	-0.1579***	-0.1590***	-0.1539***	-0.1573***
	(-9.36)	(-9.43)	(-8.92)	(-9.23)
growth of industrial specialization	-0.1104***	-0.1110***	-0.1223***	-0.1168***
	(-4.87)	(-4.91)	(-5.33)	(-5.12)
growth of industrial mix	0.0245	0.0242	0.0283*	0.0263
	(1.54)	(1.53)	(1.76)	(1.64)
Note: Models 1&2 are Two-way R&D Spillover Models and 3&4 are R&D Gap Models				
private sector R&D	0.0040**	0.0032*	0.0085**	0.0208***
	(1.93)	(1.54)	(1.74)	(2.82)
private sector R&D spillover__ distance weighted	0.0522***		0.0059	
	(3.99)		(0.95)	
private sector R&D spillover:__ first and second order neighbors		0.0175***		0.0231**
		(4.11)		(2.34)
m-Value	222.29***	224.19***	188.08***	195.21***
(Pr > m)	(<.0001)	(<.0001)	(<.0001)	(<.0001)
F-Value	19.88***	19.96***	18.92***	19.33***
(Pr > F)	(<.0001)	(<.0001)	(<.0001)	(<.0001)
R-Square	0.9082	0.9084	0.9054	0.9063
SSE	0.0515	0.0514	0.0530	0.0526
DFE	495	495	495	495

Notes: The values of the t-statistics are in parenthesis. *** implies significant at 1% level, ** at 5% level and * at 10% level, respectively. Hypotheses regarding the coefficients of all variables are one-tailed except for initial year labor productivity, the growth of industrial mix, and the growth of industrial specialization. All the coefficients estimated are the elasticity of the corresponding variables except for that of *investment share*, which is the marginal product of capital stock. The implied elasticity estimates of *investment share* variable, which is in non logarithm form, are 0.0663, 0.0659, 0.0718, and 0.0727 in models 1-4, respectively. Hausman m-test statistics reject the null hypothesis of random effects in favor of fixed effects at any ordinary significance level. Further, F-statistic values reject the null hypothesis of no fixed effects and no intercept at any ordinary significance level. The sample size is 570, which consists of 57 cross-section units over 10 years time series observations between 1985-95. SSE and DFE are respectively the sum of squared errors and the degrees of freedom of the model error term.

Before examining R&D results, however, we have other variables to consider. The coefficient for the economic growth spillover is positive and has a value of 0.15. We believe that this significant economic growth spillover tells us that we have an appropriate control for numerous influences that go beyond regional boundaries. With this variable and the fixed regional effects, the estimates of R&D's effects discussed below are obtained with many potential confounding effects controlled.

The coefficient of initial year or lagged labor productivity is negative with a value of about – 0.15. This is a reasonable result for this variable, which can be interpreted as a catch-up variable or as indicating the relative efficiency level of the region. In either case, a higher value of initial productivity indicates that the region has less scope for growth. (We do not discuss the results for the growth of industrial specialization and the growth of industrial mix; these variables serve only as control variables.)

In the overall specification used for Table I, R&D affects labor productivity growth by a parallel shift in the function. The coefficient of R&D intensity, the region's R&D personnel per unit of labor, takes a positive value, and using the appropriate one-tailed test, is significant at 0.10 in one equation, at 0.05 in two, and at 0.01 in one. The coefficients—elasticities--indicate that a doubling of private sector R&D will result in an increase in the growth rate of between 0.3 and 2 percent. The spillover effects are large. Models 1 and 2 are two-way spillover models, which assume that knowledge potentially spills in from all regions: from those with greater and those with less research intensity. The two-way models suggest relatively strong spillins with smaller effects of private sector R&D within the region. With the two-way models (1&2) a doubling of the spillover potential leads to a 1.8 or 5.2 percent increase in the growth rate. With the gap spillover models (3&4) the spillover effects are smaller and the own-region R&D efforts correspondingly more important. We believe that this finding suggests that both types of spillovers are relevant. When the gap spillover measure is used, the own region's R&D intensity may pick up part of the two-way spillover effects. If so, this could account for the different effects of intensity and spillover in the two types of models.

In Table II we examine the effects of government R&D activity on the growth of labor productivity. The data available for government R&D constrained us to a shorter time period—1988-1995. Because we are using a different time period, it is important to consider whether our results differ because of it. So Model 1 of Table II is the same specification as Model 1 of Table I. Although some differences are apparent—in particular, the effects of investment share is smaller and the industrial mix effects are larger and estimated more precisely—the estimates are sufficiently similar that we would not expect the results in the rest of Table II for the government sector R&D to be sensitive to the different time periods.

Model 2 simply replaces the private sector R&D measures with the government sector measures. Government sector R&D within the region and the government sector gap measure (distance weighted) both have positive coefficients that indicate that government and private R&D affect manufacturing growth in similar ways. Surprisingly, putting the government and private R&D variables into the same equation indicates that the two types of R&D have independent effects on growth. Comparing the results for the private sector in Model 1 and those for the public sector in Model 2 with the comparable coefficients in Model 4 reveals that each coefficient in the comprehensive model is slightly larger and slight more precisely estimated than when private and government effects are estimated individually.

The results in this section are encouraging. They suggest that the growth accounting approach is a useful way to examine regional economic growth. Reasonable production function parameters are estimated, and most importantly, the estimates suggest that R&D intensities and spillovers play an important role in regional economic growth. In the next section, we estimate a model that follows Romer more closely.

IV. Estimates with a Romer Flavor

Romer's model implies that knowledge accumulation affects growth in two ways if the time period is too short for full adjustment. Knowledge accumulation increases the growth rate directly, so that a variable such as R&D intensity has a positive elasticity, as we found above. It also increases the marginal productivity of capital, which initiates endogenous growth. Equation (7) is modified to include a vector of

Table II. Estimating knowledge spillovers across regions: The effects of private and government sector R&D efforts on labor productivity growth: 1988-95.

Dependent Variable = *labor productivity growth* Independent Variables	Model 1	Model 2	Model 3	Model 4
employment growth	-0.2847***	-0.2650***	-0.2734***	-0.2557***
	(-8.87)	(-8.28)	(-8.62)	(-7.99)
human capital growth	0.6348***	0.6420***	0.6378***	0.6456***
	(24.12)	(24.68)	(24.71)	(24.85)
investment share	0.1862***	0.2133***	0.2143***	0.2183***
	(5.45)	(6.08)	(6.17)	(6.25)
economic growth spillover	0.0887***	0.0852***	0.0819***	0.0848***
	(3.21)	(3.09)	(3.00)	(3.10)
initial-year labor productivity	-0.1435***	-0.1542***	-0.1493***	-0.1620***
	(-7.52)	(-8.18)	(-7.96)	(-8.56)
growth of industrial specialization	-0.0981***	-0.0968***	-0.1056***	-0.0953***
	(-4.09)	(-4.10)	(-4.47)	(-4.03)
growth of industrial mix	0.0493***	0.0573***	0.0521***	0.0523***
	(2.67)	(3.15)	(2.88)	(2.87)
private sector R&D	0.0153***		0.0164***	0.0234***
	(2.89)		(3.16)	(2.81)
private sector R&D spillover:	0.0211***		0.0233***	
gap--distance weighted measure	(2.94)		(3.30)	
private sector R&D gap spillover:				0.0317***
--first and second order neighbors				(2.78)
government sector R&D		0.0154***	0.0164***	0.0163***
		(3.49)	(3.75)	(3.71)
government sector R&D spillover:		0.0186***	0.0195***	0.0197***
gap—distance weighted measure		(2.77)	(2.95)	(2.96)
m-Value				
(Pr > m)	84.30***	87.04***	100.58***	97.08***
F-Value	(<.0001)	(<.0001)	(<.0001)	(<.0001)
(Pr > F)	18.61***	18.90***	19.41***	19.24***
R-Square	(<.0001)	(<.0001)	(<.0001)	(<.0001)
SSE	0.9428	0.9434	0.9453	0.9448
DFE	0.0204	0.0202	0.0195	0.0197
	327	327	325	325

Notes: The values of the t-statistics are in parenthesis. *** implies significant at 1% level, ** at 5% level and * at 10% level, respectively. Hypotheses regarding the coefficients of all variables are one-tailed except for initial year labor productivity, the growth of industrial mix, and the growth of industrial specialization. All the coefficients estimated are the elasticity of the corresponding variables except for that of *investment share*, which is the marginal product of capital stock. The implied elasticity estimates of *investment share* variable, which is in non logarithm form, are 0.0439, 0.0502, 0.0505, and 0.0514 in models 1-4, respectively. Hausman m-test statistics reject the null hypothesis of random effects in favor of fixed effects at any ordinary significance level. Further, F-statistic values reject the null hypothesis of no fixed effects and no intercept at any ordinary significance level. The sample size is 399, which consists of 57 cross-section units over 7 years time series observations between 1988-95. SSE and DFE are respectively the sum of squared errors and the degrees of freedom of the model error term.

variables (P) that can have a direct effect on productivity growth (α_A P) and an indirect effect through a change in the marginal product of capital from κ to [$\kappa + \alpha_B$ P]. Equation (8) results

$$q'' = -\varepsilon_K L'' + \varepsilon_H (H_q/L)'' + [\kappa + \alpha_B P] (I/Q) + \alpha_A P. \qquad (8)$$

This model includes the same variables as the model reported in Table I. The difference is that four variables in the P vector are interacted with investment share (I/Q), allowing the variables to directly affect the marginal product of capital--[$\kappa + \alpha_B$ P]. The four interacted variables are the economic growth spillover, initial year labor productivity, R&D intensity, and R&D spillover. We expect that the coefficient of initial productivity times investment share to be negative, because a higher level of income for a given investment share suggests a greater capital intensity (Romer 1989) and a lower marginal product of capital. We expect the coefficient of R&D intensity (R&D spillover) times investment share to be positive because the associated knowledge accumulation raises the marginal product of capital. Finally, the interaction of the economic growth spillover with investment share could have a positive or negative coefficient. Rapid economic growth in surrounding regions could attract labor (either through commuting or migration) from the region in question. Thus, for a given investment share, capital intensity might be greater. Alternatively, the economic growth spillover might be a proxy for knowledge spillover and accumulation, which would increase the marginal product of capital.

The effect of each of these variables on economic growth is in two parts. Suppose growth = α_i * investment share + α_p * initial productivity + α_{ip} * investment share * initial productivity. The effect of a higher initial level of productivity on growth would be $\alpha_p + \alpha_{ip}$ * investment share. In all of the models in Table III, the coefficient of initial productivity is positive and the coefficient of the interaction term is negative. If investment share is at its average value of 0.23, the implied coefficient for initial productivity is –0.16, which is similar to its value in Table I. As investment share goes from its smallest observed value to its largest observed value, the coefficient goes from –0.21 to –0.07. Similarly, the effect of faster growth in neighboring regions on productivity growth is 0.71 (economic growth spillover) – 2.69 (economic growth spillover * investment share). At the average investment share, the implied coefficient

Table III. Estimating knowledge spillovers across regions: The effects of private sector R&D efforts on labor productivity growth: 1985-95.
Dependent Variable = *labor productivity growth*

	Spillover: Two way		Spillover: Gap	
Independent Variables	Model 1	Model 2	Model 3	Model 4
employment growth	-0.2468***	-0.2441***	-24.8769***	-0.2438***
	(-9.04)	(-8.91)	(-9.11)	(-8.84)
human capital growth	0.6369***	0.6366***	0.6327***	0.6414***
	(29.23)***	(29.32)	(28.80)	(29.38)
investment share	10.5942***	10.3959***	11.0236***	10.9185***
	(7.52)	(7.38)	(7.96)	(7.83)
economic growth spillover	0.7066***	0.7165***	0.7489***	0.7623***
	(2.90)	(2.94)	(3.09)	(3.12)
initial-year labor productivity	0.0777**	0.0719**	0.1135***	0.0933**
	(2.16)	(2.00)	(3.17)	(2.45)
growth of industrial specialization	-0.0785***	-0.0796***	-0.0868***	-0.0821***
	(-3.59)	(-3.63)	(-3.96)	(-3.73)
growth of industrial mix	0.0147	0.0143	0.0147	0.0153
	(0.97)	(0.94)	(0.97)	(1.01)
*investment share*economic growth spillover*	-2.6886**	-2.7247**	-2.8196***	-2.8592***
	(-2.48)	(-2.51)	(-2.60)	(-2.62)
*investment share*initial-year labor productivity*	-1.0266**	-1.0051***	-1.1952***	-1.0934***
	(-7.11)	(-7.06)	(-8.28)	(-6.96)
Note: Models 1&2 are Two-way R&D Spillover Models and 3&4 are R&D Gap Models				
private sector R&D	-0.0081*	-0.0077*	-0.0383***	-0.0055
	(-1.81)	(-1.71)	(-3.74)	(-0.29)
private sector R&D spillover__ distance weighted	0.0424***		-0.0386***	
	(2.80)		(-2.86)	
private sector R&D:__ first and second order neighbors		0.0107**		0.0084
		(2.10)		(0.33)
investment share private sector R&D*	0.0536***	0.0496***	0.2203***	0.1083
	(2.93)	(2.64)	(4.74)	(1.30)
investment share private sector R&D spillover__ distance weighted*	0.0055		0.2106***	
	(0.26)		(3.47)	
investment share private sector R&D: __first and second order neighbors*		0.0063		0.0530
		(0.90)		(0.48)
m-Value	116.79***	-	148.99***	179.86***
F-Value	22.15***	22.12***	21.94***	21.79***
R-Square	0.9183	0.9180	0.9184	0.9171
SSE	0.0458	0.0460	0.0458	0.0465
DFE	491	491	491	491

Notes: See notes for Table I. A one-tail test is used for the R&D interactions with investment share and a two-tail test for the other interactions.

for the economic growth spillover is 0.09, and from the smallest to the largest observed investment share, the implied coefficient goes from 0.31 to –0.04. Both initial productivity and economic growth spillovers have a positive effect on productivity growth at very low values of investment share. As investment share increases, their effect on productivity growth diminishes. Moreover, higher levels of initial productivity and of economic growth in neighboring regions are associated with a lower marginal product of capital. To summarize, for most observed values of investment share, the economic growth spillover has a positive effect on regional growth and the initial productivity level has a negative effect.

The results for the four equations in Table III replicate those of Table I with the proviso that four interaction variables are added in Table III. In Table I local R&D intensity has a positive effect on growth in all equations, as do three of the four R&D spillover variables. In Table III, Model 4 the introduction of the interaction variables results in all of the R&D variables almost losing statistical significance. In the other models the R&D variables continue to be positively associated with economic growth.

The specification in Table III indicates that the positive effect of R&D growth comes through its positive effect on the marginal product of capital. This positive effect is consistent with the implications of the Romer model.

In Models 1 through 3 the effect of own-region R&D on economic growth is α_r + α_{ir} * investment share—in Model 1 it is –0.008 + 0.05 investment share. In Model 1 the elasticity of growth with respect to R&D ranges from -0.001 to 0.006 for the observed values of investment share. In Model 3, the elasticity ranges from -0.01 to 0.02 (and in Model 4 the range is from 0.01 to 0.025, although the relevant regression coefficient is significant only at the 0.10 level.

V. Conclusion

In this study we rely on ideas from economic growth theory and regional economics to specify an econometric equation to estimate the determinants of regional growth. Our model relies on input growth and knowledge accumulation to explain regional growth. Our focus is on the region’s R&D intensity and on the effects of R&D spillovers from other regions. Although we find significant—both quantitative and statistical—effects of R&D intensity and R&D spillovers on regional growth in three European countries, we caution that the results apply only to the 57 regions in France, Italy, and Spain for which we had appropriate data. Given that we used the fixed-effects estimator, our results do not support inferences regarding the population.

These results can be refined by developing new specifications to better characterize knowledge accumulation over space. Moreover, the construction of the variables that capture spillover can be improved. One of the issues that we barely touch is the rate at which R&D spillovers decay. Understanding this decay rate is important for using R&D expenditures as a regional development tool. We hope to address some of these issues in future research.

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Appendix A: Variable Definitions and Sources.

Cambridge Econometrics

The following variables were computed from data provided by Cambridge Econometrics. Growth rates are approximated by logarithmic differences.

labor productivity growth--annual growth rate of value added per employee.

employment growth—annual growth rate of total employment.

investment share—the share of investment in gross value added

initial-year labor productivity--the natural logarithm of gross value added per employee lagged one year.

economic growth spillover from first order neighbors—the average growth rate of valued added per employee in regions bordering the one under consideration (first order neighbors).

economic growth spillover from first and second order neighbors-- the average growth rate of valued added per employee for first order neighbors and the regions bordering the first order neighbors (second order neighbors.

growth of industrial specialization--The annual-growth rate in a region's Herfindahl Index. The Herfindahl Index is measured by sum of the squares of gross value added shares of the 9 sectors in total regional gross value added. It is used to compare the change in degree of sectoral concentration over time.

growth of industrial mix-- The annual-growth rate of a region's sectoral mix. The sectoral mix variable is

$$SECMIX_{r\,t} = \{\sum_{j=1}^{9} (GVA_{r\,j} / GVA_{r}) * (GVA_{EU\,j} / EMP_{EU\,j})\} / \{\sum_{j=1}^{9} (GVA_{EU\,j} / GVA_{EU}) * (GVA_{EU\,j} / EMP_{EU\,j})\}$$

where GVA is gross value added, EMP is total employment, the r subscripts identifies regions, the j subscript identifies sector, the EU subscript identifies the aggregate of the 57 in the study. It represents the extent to which a region has gross value added per employee over or below the European average due to its industrial composition. The variable was suggested by Partridge and Rickman (1999).

EuroStat

Research and Development personnel data are from the Eurostat Regio data base. The availability of this data constrained our study to 57 Nuts 2 regions in France (21 regions), Italy (19 regions), and Spain (17 regions). One such region from Italy, one from Spain, and 5 from France were excluded because of missing R&D data. R&D personnel per regional employee were computed by combining this data from the Cambridge Econometrics data.

private sector R&D intensity-- The natural logarithm of personnel employed in business sector research and development activities per 100,000 total employees in the region. Government sector R&D is analogous.

private sector R&D spillover: two-way: distance weighted—The natural logarithm of R&D personnel per 100,000 total employees in all other regions divided by distance from the region in question is aggregated. The over all aggregation of the distance weights is equalized to one, so that the interaction of distance weight elements with observations of any simply affects the variation of the relevant variable rather than its mean value. The geographic distance between regions is measured as a straight line on the map, which defines the centers of European regions (NUTS2), as follows. The distance between urban centers of regions within a national border is measured directly. However, the portion of the distance crossing a national border is doubled. The portion of the distance crossing a second national border is tripled. It assumes that the national borders represents cultural, linguistic, ethnic, institutional, social, national etc. disparities which are much more diverse across nations than across regions within a nation. So they can be significant obstacles to formal or informal human interactions. Moreover, considering the regions made up an island or a group of islands the portion of the distance corresponding to over sea is doubled. This implies that formal or informal communication with this type of isolated regions is more costly and harder relative to others.

private sector R&D spillover : two way: first and second order neighbors—The average of the natural logarithm of R&D personnel per employee over all first and second order neighbors. See economic growth spillover for neighbor definitions.

private sector R&D spillover: gap: distance weighted.—to compute this variable for region r we first subtract the R&D intensity in r from each other region s. All negative values are assigned the value 0. Each positive value is divided by distance. Then these values are aggregated. As above, the over all aggregation of the distance weights is equalized to one.

private sector R&D spillover: gap: with first and second order neighbors-- to compute this variable for region r we first subtract the R&D intensity in r from each neighbor s. All negative values are assigned the value 0. Each positive value is summed and divided by the number of neighbor regions that have a positive value.

OECD

human capital growth: To compute this variable regional enrollment in higher education is computed by allocating national enrollment in higher education from the OECD Education Database to the regions based on the regional proportion of gross national value added. The regional enrollment is divided by total employment to human capital accumulation per unit of labor. The annual growth rate of this variable is our proxy for human capital growth.

Appendix B: Descriptive Statistics

Variables	Mean	Std. Dev.	Min.	Max.
labor productivity growth	0.0181	0.0256	-0.0902	0.1064
employment growth	0.0039	0.0245	-0.1224	0.0959
human capital growth	0.0417	0.04012	-0.0901	0.1603
investment share	0.2303	0.0280	0.1471	0.2817
initial-year labor productivity	10.3893	0.1848	9.7262	10.8757
current-year labor productivity	10.4074	0.1844	9.7690	10.8848
growth of industrial specialization	0.0029	0.0237	-0.1029	0.0709
growth of industrial mix	-0.0007	0.0298	-0.1492	0.1425
private sector R&D intensity	7.4187	1.3769	2.0852	9.8110
private sector R&D spillover: gap: distance weighted	0.7362	0.8648	0	5.1591
private sector R&D spillover: gap: with first order neighbors	0.7362	0.9050	0	5.1382
private sector R&D spillover: gap with first and second order neighbors	0.7362	0.8893	0	5.0464
private sector R&D spillover: two way: distance weighted	7.4187	1.1195	4.2145	9.6163
private sector R&D spillover: two way: first order neighbors	7.6864	4.0324	0	17.0511
private sector R&D spillover: two way: first and second order neighbors	7.7231	3.3428	0	14.4315
economic growth spillover from first order neighbors	0.0180	0.0177	-0.0902	0.1064
economic growth spillover from first and second order neighbors	0.0182	0.0133	-0.0387	0.0591

Notes: Total number of observations, N = 570, consist of 57 cross-section units over 10 years of time-series observations between 1985-95.