Ann Reg Sci (2002) 36:531–550

The Annals of
Regional Science

Urban externalities and city growth in Taiwan

Hsin-Ping Chen

Department of Economics, National Chengchi University, Taipei, Taiwan
(e-mail: spchen@nccu.edu.tw)

Received: February 2001/Accepted: April 2001

Abstract. The purpose of this paper is to investigate the influences of citywide and city-industry externalities on city growth. The effects of various externalities on city and industry growth for two different time periods in Taiwan are studied. The results indicate that employment growth at the city-industry level is: (1) negatively related to the initial city-industry employment; (2) positively related to the level of competition in the initial year; and (3) positively related to the degree of diversity in the initial year. The extent of the impact of the diversity externality is relatively large compared with the other effects. In addition, wage growth at the city-industry level is found to be: (1) negatively related to the initial city-industry wage rate; and (2) positively related to the degree of diversity in the initial year. Overall, we find that specialization hurts, competition helps, and city diversity helps both employment growth and wage growth. Our results favor Jacobs's theory, which would suggest that cross-industry externalities and local competition are more important for industry growth than are intra-industry spillovers.

JEL classification: R10, R11

1. Introduction

Recent studies in the field of economic growth have sought to explain the income growth of different countries in accordance with their countrywide characteristics. In the literature on endogenous growth models, it has been argued that dynamic externalities (particularly knowledge spillovers) are the essential driving force behind economic growth (Romer 1986). In such studies, much emphasis has been placed on the stock of accumulated knowledge. The effects of dynamic information externalities are often observed in places in which there is a focus on communication. Lucas (1988) noted that these externalities are more significant in cities. Besides knowledge spillovers and human capital, there are other important citywide attributes and externalities that affect the growth of economies across cities.

Unlike countries, cities are completely open as a result of increased labor mobility. Furthermore, cities are more specialized than national economies in

that agglomeration economies are more important for growth. The focus in the study of standard externalities in the urban environment is on static externalities, which are generated from the current information spillovers given market conditions. Static externalities explain the formation of cities and degree of specialization within cities rather than city growth (Henderson 1986). Traditional static externalities are associated with the extent of localization and urbanization. Positive externalities in relation to both of these characteristics suggest that bigger cities give rise to greater benefits. By contrast, the generation of negative externalities, such as congestion and commuting costs, suggest the existence of an optimal city size (Henderson 1974, 1996).

Dynamic externalities deal with the impact of the accumulation of prior information on current productivity to explain city growth. There are three types of theories that seek to explain dynamic externalities, namely, the Marshall-Arrow-Romer (MAR), Porter (1990) and Jacobs (1969) theories (Glaeser et al. 1992). The MAR theory is concerned with the generation of knowledge spillover externalities for productivity purposes between firms within an industry. Such externalities arise from ongoing intra-industry communications. Marshall (1890) applied this theory to cities. The MAR theory also suggests that a local monopoly will enhance growth more than local competition since the externalities that are internalized will speed up the process of innovation and growth.

Porter (1990) argues that geographically concentrated industries stimulate growth as in the case of the MAR theory; however, in contrast to the MAR theory, Porter's theory suggests that local competition fosters innovation. Unlike the MAR and Porter theories, Jacobs (1969, 1984) suggests that knowledge spillovers are mostly derived among industries, and that the ease with which ideas flow in cities also helps innovation. Furthermore, it is the geographical diversity of proximate industries rather than specialization that encourages innovation and growth. The heterogeneous features of modern cities have provided significant efficiency gains in economic growth. This kind of externality is both inter-industry and urbanized. Besides, Jacobs believes that local competition speeds up innovation. Both the MAR and Porter theories advocate localized dynamic externalities. They agree that regional specialization is good for growth. However, Jacobs believes in urbanized dynamic externalities, and predicts that industries located in highly industrially-diversified areas will grow faster.

In previous empirical studies of dynamic externalities, Jaffe et al. (1993) find externalities to be more localized. Glaeser et al. (1992) finds evidence of the existence of Jacobs-type dynamic externalities based on a study of the six largest industries in the United States. Miracky (1992) finds evidence of both MAR and Jacobs externalities. Models based on the kinds of externalities available in cities emphasize the role of diversity in enhancing economic efficiency.

Quigley (1998) summarizes the possible reasons why diversity and city size influence the economic growth of cities. He suggests that heterogeneity or variety mostly correspond to the larger-sized urban areas, which would consequently encourage the growth of cities for various reasons, such as scale economies, shared inputs and reduced transaction costs, etc. A number of empirical studies confirm the presence of scale economies in urbanization, to the effect that city size encourages city growth (Shefer 1973; Sveikauskas 1975; Segal 1976; Nakamura 1985). Furthermore, Bostic et al. (1997) find evidence

that industrial diversity improves the city output level. Garcia-Mila and McGuire (1993) find that the industrial mix affects economic growth.

Overall, the empirical results show that larger city sizes and increased diversity promote the growth of cities and raise productivity. However, traditional models impose efficiency limits on city sizes due to the presence of negative externalities and higher land prices, housing prices and the costs of commuting (Mills 1967; Henderson 1974). Several empirical studies suggest that various economic costs increase with the scale of urbanization (O'Regan and Quigley 1996). Nevertheless, Quigley (1998) argues that large cities will continue to be an important source of economic growth according to recent surveys on urban diversity.

The externalities that may cause cities to grow refer to the production externalities of firms. Each firm possesses two major characteristics: industrial quality and geographical location. Both characteristics are the essential resources of location externalities. Based on these two characteristics, the externalities of firms are characterized according to two kinds: city-industry externalities and citywide externalities. City-industry externalities are generated from the industrial characteristics of the firm; similarly, citywide externalities are generated from the characteristics of the city's location. Previous studies on this issue mostly focus on only one kind of externality rather than considering both city-industry and citywide externalities to investigate the influences of externalities on city growth in a more complete way.

The purpose of this paper is to consider both kinds of externalities simultaneously to investigate their effects on city growth. We plan to identify the key dynamic externalities that drive city growth and industrial development. We empirically investigate how the growth of cities and industrial development have been influenced over the last 20 years in Taiwan by corresponding citywide and industrial externalities. The predictions of the various new economic growth theories are examined in this paper. Moreover, we ask whether the effects of externalities change over time. This is the first empirical study in Taiwan that examines the effect of both citywide and industrial externalities on the growth of the city and city-industry.

This remainder of this paper is organized as follows. Section 2 introduces both citywide and city-industry externalities. Section 3 describes the data and estimation results. Section 4 concludes.

2. External economies

The standard location and urbanization externality theories address the formation and specialization of cities (Henderson 1986), but not city growth. This is defined as static externalities, which deal with various aspects of the conditions currently prevailing in cities. Dynamic externalities, which have been widely discussed recently (Glaeser et al. 1992; Henderson et al. 1995; Bostic et al. 1997), try to explain both the formation and the growth of cities. Their focus is on certain aspects of the historical urban environment.

2.1. Static external economies: Localization and urbanization

Traditional static externalities arising from localization and urbanization contribute to the formation of cities. The static localized externalities are derived

from current local own-industry employment, while urbanization externalities refer to the benefits a firm enjoys as a result of the current agglomeration of local industries as a whole within a city (Henderson 1986).

2.2. Dynamic externalities: City-industry externalities and citywide externalities

Dynamic externalities, that refer to different aspects of historical conditions, contribute to the growth of cities. They are discussed in this paper both within the context of the city-industry and city. City-industry externalities refer to the externalities generated by both location (city) and industrial characteristics. There are different types of city-industry externality, namely, localization, specialization, competition and diversity within the environment. Citywide externalities refer to the externalities caused by the city characteristics.

2.2.1. City-industry externalities

Localization. The externalities which benefit a firm owing to agglomeration within a single industry are referred to as localization externalities. Their presence suggests that a region's specialization in an industry contributes to growth. The reasons for the existence of these externalities include access to natural resources, transportation advantages, and savings on moving inputs, etc. (Marshall 1890). The dynamic industrial localization externality is measured on the basis of employment within the industry at some base period.

Specialization. Specialization within a certain industry in a city is measured as the fraction of the city's employment that this industry represents in that city, relative to the share of the whole industry in national employment. This specialization measure is the ordinary location quotient, and represents the potential for MAR externalities.

$$\text{Specialization} = \frac{\text{Industry employment in city/total employment in city}}{\text{Industry employment in nation/total employment in nation}}$$

Competition. Our measure of the local competition of an industry in a city is the same as in Glaeser et al. (1992). It is measured as the ratio of the number of firms per worker in the city-industry to the number of firms per worker in the national industry. A value greater than one indicates either that an industry has more firms relative to its size in the city than it does in the nation or that the firms in the city are smaller than in the nation. Due to the limitations of our data, it is hard to distinguish smaller firms from more competitive firms. The competition variable measures the level of competition among firms in the city relative to firms in the nation. The smaller the size of firms in the city relative to those in the nation, the higher the value of the competition variable. This is a rough measure of the size of firms within the city relative to firms in the nation.

$$\text{Competition} = \frac{\text{Firms in city-industry/workers in city-industry}}{\text{Firms in national industry/workers in national industry}}$$

Diversity of the environment in which industries are located. The city-industry diversity externality is a measure of the variety of industries in the city that

are outside the industry. The diversity of all industries other than industry j in city i is measured by the Hirschman-Herfindahl index ($HHI_{ij,t}$): $HHI_{ij,t} = \sum_{k \notin j}^{l} (E_{ik,t}/E_{i,t})^2$, where $E_{ik,t}$ is the amount of employment of industry k in city i at time t, and l is the total number of industries in the city. This index indicates the level of diversity in the environment. A larger value of $HHI_{ij,t}$ reflects more specialization and less diversity in the environment with respect to industry j in the city. This diversity measure represents Jacobs's externalities.

2.2.2. Citywide externalities

The are two kinds of externalities characterized by location (city): diversity and localization.

Citywide diversity. This measure indicates the degree to which a city's output is dominated by a single sector or a number of closely-related sectors. This externality is measured by the Hirschman-Herfindahl index ($HHI_{i,t}$): $HHI_{i,t} = \sum_{j=1}^{l} (E_{ij,t}/E_{i,t})^2$, where $E_{ij,t}$ is the amount of employment of industry j in city i at time t, and l is the total number of industries in the city. This citywide externalities index indicates the level of specialization or diversity within a city. An increase in $HHI_{i,t}$ reflects more specialization and less diversity in the city. This index is very similar to the city-industry diversity index. The only difference is that the citywide diversity index considers all industries within the city; the city-industry diversity index of industry j considers all industries within the city except industry j itself.

Citywide localization. We measure the degree of industrial localization in city i at time t by the index $LOC_{i,t}$ as in Bostic et al. (1997). Let $\overline{LOC}$ denote the threshold level of a city-industry's share of national employment above which it is considered localized. We use 10% as the threshold level to identify localized industries in this paper. The definition of the set of localized industries in city i is: $\Lambda_i \equiv \{j \mid LOC_{ij,t} \geq \overline{LOC}\}$, where $LOC_{ij} = E_{ij}/(\sum_i E_{ij})$. The measure for localization in city i is the share of the localized industries in the city: $LOC_{i,t} = \sum_{j \in \Lambda_{i,t}} E_{ij,t}/E_{i,t}$, where $E_{ij,t}$ is the amount of employment for industry j in city i at time t, and $E_{i,t}$ is the total employment in city i at time t.

The externalities, which benefit a firm owing to their agglomeration within a single industry in the city, are referred to as city-industry localization externalities. This externality is characterized by both industry and location (city). In particular, citywide localization measures the degree of industrial localization in the city, and is characterized only by the city. The measures of city-industry localization for various industries might be different within the same city; however, there is only one measure of citywide localization in the city.

3. The data and estimation

3.1. The data

The analysis in this paper is based on a sample of 21 Taiwan cities covering the period 1976 to 1996 (1976, 1986, and 1996). A map of Taiwan and its

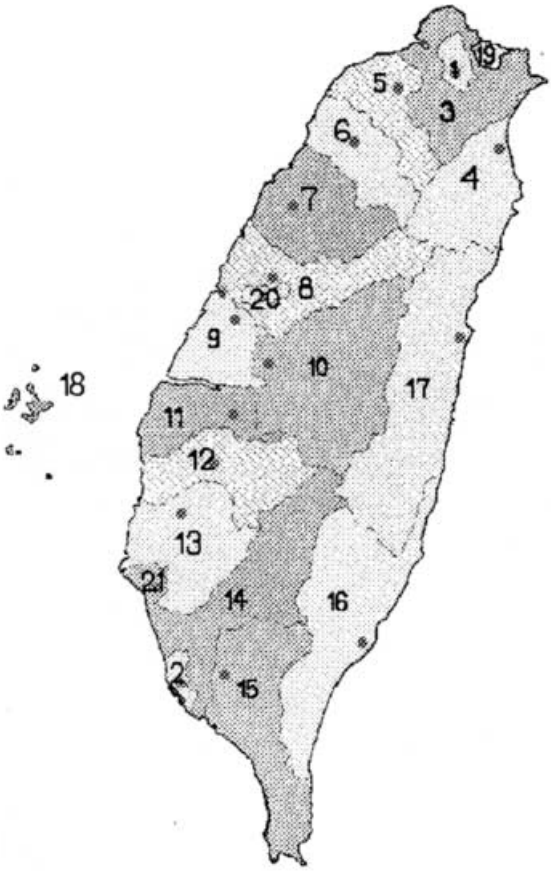

Fig. 1. Study area: Taiwan

major cities is shown in Fig. 1. Taiwan is divided into four regions (north, central, south and east) by the Directorate-General of Budget, Accounting and Statistics based on geographical conditions, industrial structure and transportation systems. These four regions were composed of 21 major cities in 1976 and two more cities were added in 1982. There have thus been 23 cities in the region since 1982. This study uses the original 21 cities as the observations in the regressions to maintain consistency during the period under study (1976–1996). It would have been the first best choice to use metropolitan areas as the unit of observation. However, there are only seven metropolitan areas in Taiwan, and this number of observations is too small for the regressions. Due to this constraint, we adopt the second best alternative, namely, the "city" as the unit of observation in this study. The city level data is obtained from the Report on the Survey of Personal Income Distribution in the Taiwan Area, and the Taiwan-Fukien Demographic Fact Book. The industrial level data is collected from the Report on the Industrial and Commercial Census: Taiwan-Fukien Area. The industry data comprises all 2-digit industries in 21 cities in Taiwan. There is a total of 69 groups of 2-digit industries classified by the Report on the Industrial and Commercial Census: Taiwan-Fukien Area. Even differences in the composition of a 2-digit industry may vary greatly

from one city to another and even from one year to another, but there exists certain common characteristics as long as they are in the same 2-digit industry categories. The city-industry empirical work in this study involves investigating the possible external effects on an industry according to its location and industrial characteristics. Per capita income is the distributed factor income, which is the sum of the compensation of employees, entrepreneurial income, and net property income. It does not include transfer payment income.

3.2. Estimation and results

There are two groups of regressions performed in this section. The first group of regressions is concerned with investigating the relationship between city growth and citywide externalities. The second group of regressions investigates the relationship between industrial development and the corresponding city-industrial externalities. Both groups of regressions are estimated for two different time periods (1976–1986, 1986–1996); and both groups include the corresponding initial conditions and regional dummies as explanatory variables.

In the case of the city growth regressions, the dependent variables include various city variables: city population, city output and city income. The citywide externalities include the diversity index (HHI) and localization. There are 21 observations in the regressions. As for the industrial development regressions, the dependent variables include city-industry employment growth and city-industry wage growth. The industrial externality variables include specialization, competition and diversity. There are 69 2-digit industries within the 21 cities; in the regression, we drop observations with missing data.

We first use the ordinary least squares (OLS) procedure to estimate the city growth regressions. The estimation results are presented in Table 1 (1976–1986) and Table 2 (1986–1996). Due to the small size of Taiwan, it is suspected that the spatial autocorrelation problem may exist. The *Moran I* statistics for spatial dependence derived from the least squares regression are thus reported in Tables 1 and 2, and weak spatial autocorrelation is observed in Table 1. In order to correct the spatial dependence problem, we use the maximum likelihood estimation (MLE) procedure to reestimate the relationships in Table 1. There are two alternative hypotheses for the diagnostics of spatial autocorrelation in regression analysis: the spatial error case and the spatial lag case (Anselin and Hudak 1992).[1] In this study, we maximize the log-likelihood function of the spatial lag model to estimate the coefficients. We use

[1] The regression model of the spatial error case:

$$y = X\beta + \varepsilon,$$

$$\varepsilon = \lambda W\varepsilon + \mu,$$

where λ is the spatial autoregressive coefficient and μ is an uncorrelated error term.

The regression model of the spatial lag case:

$$y = \rho Wy + X\beta + \varepsilon,$$

where ρ is the autoregressive coefficient.

Table 1. City growth and externalities (1976–1986) by OLS (Dependent variable: Growth in city variable)

Dependent variable	(1) City population	(2) City output ($'000/per capita)	(3) City income (per capita)
Intercept	0.617	−0.205	2.222
	(2.242)	(8.383)	(2.785)
Population 1976 (Log)	−0.007	−0.197	0.154
	(0.184)	(0.683)	(0.236)
Per capita income 1976	0.01	−0.1	0.04
($'000/per capita)	(0.01)	(0.07)	(0.03)
Human capital:			
Median years of schooling 1976	−0.135	1.045*	−0.190
	(0.094)	(0.350)	(0.128)
Externalities:			
Diversity (HHI) 1976	0.174	3.072	−1.546**
	(0.525)	(1.954)	(0.749)
Localization 1976	0.657	−2.503**	−0.357
	(0.360)	(1.340)	(0.432)
Geographical dummies			
North	−0.106	0.871	0.542
	(0.271)	(1.007)	(0.362)
Central	−0.076	1.124	0.431
	(0.248)	(0.921)	(0.353)
South	−0.080	1.105	0.102
	(0.265)	(0.988)	(0.353)
N	21	21	21
Adj. R^2	0.38	0.47	0.28
Moran's I	0.027**	−0.249	0.001**

Note: Numbers in parentheses are standard errors.
Diversity: Hirschman-Herfindahl index.
Localization: Share of the city employment in localized industries, 10%.
* Significant at the 5% level.
** Significant at the 10% level.

the built-in nonlinear optimization functions of the *Limdep (minimize)* software package to implement the ML estimation. The starting value is specified as the OLS estimates for the parameters of the model.

In the case of the industrial development regressions, we also first of all use the OLS procedure. In ways similar to the city growth regressions, the reported *Moran I* statistics exhibit spatial dependence problems. We thus specify the spatial lag model of industrial growth and use the MLE procedure to estimate it. The results are explained as follows.

Table 1 examines the relationship between city growth and certain initial conditions and citywide externalities using city-level data in Taiwan between 1976 and 1986. There are three regional dummies used as independent variables, the eastern region being excluded from the regression. The first column includes the regressions of city population growth on the initial population, initial income per capita, the initial human capital level, initial citywide externalities and geographical dummies. All of the growth variables in this paper are measured in terms of the growth rate for the entire decade, and appear in decimal form. The human capital in each city is measured by the

Table 2. City growth and externalities (1986–1996) by OLS (Dependent variable: Growth in city variable)

Dependent variable	(1) City population	(2) City output ($'000/per capita)	(3) City income (per capita)
Intercept	−0.838	1.634	5.743
	(0.879)	(3.026)	(1.550)
Population 1986 (Log)	0.096	−0.272	−0.253**
	(0.070)	(0.242)	(0.122)
Per capita income 1986	0.006*	0.007	−0.009**
($'000/per capita)	(0.002)	(0.007)	(0.005)
Human capital:			
Median years of schooling 1986	−0.100*	0.403*	0.067
	(0.029)	(0.100)	(0.072)
Externalities:			
Diversity (HHI) 1986	0.344	−0.212	0.595
	(0.197)	(0.680)	(0.409)
Localization 1986	−0.185	−0.155	0.080
	(0.145)	(0.501)	(0.267)
Geographical dummies			
North	−0.019	−0.574	−0.271
	(0.119)	(0.408)	(0.253)
Central	−0.072	−0.724**	−0.443**
	(0.110)	(0.380)	(0.245)
South	−0.106	−0.629	−0.301
	(0.114)	(0.393)	(0.239)
N	21	21	21
Adj. R^2	0.57	0.77	0.65
Moran's I	−0.105	−0.128	−0.335

Note: Numbers in parentheses are standard errors.
Diversity: Hirschman-Herfindahl index.
Localization: Share of the city employment in localized industries, 10%.
* Significant at the 5% level.
** Significant at the 10% level.

median years of schooling. The citywide externalities are represented by the degrees of diversity and localization. The degree of diversity is measured by means of the HHI index. The larger the index, the less diversity and more specialization there is in the city. The extent of city localization is measured by the share of the localized industries in each city. We use 10% as the threshold level to identify localized industries.

The results of the test for spatial autocorrelation are shown by *Moran's I*[2] in Table 1. The spatial weights matrix is essential for the measurement of

[2] *Moran's I test* is used to test for spatial dependence. It is defined as

$$I = (N/S_0)e'We/e'e$$

where $S_0 = \sum_i \sum_j w_{ij}$, and W is the spatial weights matrix. The distribution of this statistic is normal. According to Anselin and Hudak (1992), "The rows and columns of the spatial weights matrix W correspond to the observations. The non-zero elements for a raw-column pair reflect contiguous locations.... For application s with a small number of observations, contiguity can be derived from a visual inspection of boundaries on a map."

Table 3. City growth and externalities (1976–1986) by MLE (Dependent variable: Growth in city variable)

Dependent variable	(1) City population	(2) City output ($'000/per capita)	(3) City income (per capita)
Intercept	0.592	2.584	−1.259
	(0.123)	(0.256)	(0.207)
Population 1976 (Log)	0.005	−0.503	0.473*
	(0.301)	(0.834)	(0.221)
Per capita income 1976	0.01	−0.1	0.03
($'000/per capita)	(0.02)	(0.1)	(0.03)
Human capital:			
Median years of schooling 1976	−0.152	1.170	−0.234
	(0.207)	(0.427)	(0.345)
Externalities:			
Diversity (HHI) 1976	−0.050	2.858	−0.908
	(0.626)	(2.732)	(0.840)
Localization 1976	0.641	−2.046	−0.694
	(0.466)	(2.821)	(0.823)
Geographical dummies			
North	−0.106	0.846	0.333
	(0.522)	(0.932)	(1.188)
Central	−0.034	1.201	0.147
	(0.528)	(0.982)	(1.191)
South	−0.058	1.037	−0.112
	(0.532)	(1.089)	(1.200)
N	21	21	21

Note: Numbers in parentheses are standard errors.
Diversity: Hirschman-Herfindahl index.
Localization: Share of the city employment in localized industries, 10%.
* Significant at the 5% level.

Moran's I. There are only 21 observations in Taiwan, and the contiguity of the observations within the spatial weights matrix W is derived from a visual inspection of the boundaries on the map (see Isard et al. 1998; Anselin and Hudak 1992). The estimated spatial weights matrix W is reported in the appendix. *Moran's I* index reveals that there is weak spatial dependence in both Regressions (1) and (3). No spatial autocorrelation is found in Regression (2). We rerun the regressions using the MLE procedure, and the results are presented in Table 3.

Table 2 presents the growth of the cities between 1986 and 1996. The results indicate that city income grows more slowly in larger cities. Initial city income positively influences population growth, however, initial city income negatively affects the growth of income within the city. Furthermore, the higher the median years of schooling, the slower the population growth and the faster the output growth. This indicates that there is a significant influence of human capital on the growth of city output. However, the geographic externalities do not exhibit a significant impact on city growth as recent studies have predicted. Based on *Moran's I* test, the spatial autocorrelation problem does not manifest itself in Table 2.

Table 3 depicts the MLE results using the same regressions as in Table 1. It is seen that the initial population has a significant effect on city income

Table 4. City-industry employment growth and externalities (1976–1986) by OLS (Dependent variable: Growth in city-industry variable)

Dependent variable (logs)	City-industry employment growth 1976–1986			
	(1)	(2)	(3)	(4)
Intercept	1.093	0.752	1.941	1.570
	(0.027)	(0.372)	(0.507)	(0.533)
City-industry employment 1976 (Log)	−0.259*	−0.237*	−0.294*	−0.255*
	(0.027)	(0.027)	(0.026)	(0.032)
Wage in city-industry 1976 (Log)	−0.054	−0.04	−0.077	−0.067
	(0.082)	(0.081)	(0.082)	(0.082)
Geographical dummies:				
North	0.739*	0.763*	0.710*	0.692*
	(0.214)	(0.211)	(0.213)	(0.214)
Central	0.443*	0.450*	0.350	0.318
	(0.209)	(0.206)	(0.212)	(0.214)
South	0.485*	0.492*	0.374*	0.347*
	(0.208)	(0.205)	(0.214)	(0.215)
City-industry externalities:				
Specialization 1976	−0.048			−0.05
	(0.056)			(0.056)
Competition 1976		0.05*		0.046*
		(0.020)		(0.020)
Diversity 1976			−7.863*	−7.308*
			(3.435)	(3.437)
N	662	662	662	662
Adjusted R^2	0.16	0.17	0.17	0.17
Moran's I	−0.0130*	−0.0128*	−0.0115**	−0.0110

Note: Numbers in parentheses are standard errors.
* Significant at the 5% level.
** Significant at the 10% level.

growth. However, the noticeable impact of citywide externalities on city growth as was observed in Tables 1 and 2 is not significant in this table. This shows that the OLS estimator overestimates both the diversity effect in relation to city income growth and the localization effect in relation to city output growth.

The empirical results of the city growth regressions in Tables 1 to 3 do not support the citywide externalities in explaining city growth. The empirical estimation of industrial development is as follows. Table 4 reports the relationships for employment growth across city-industries in Taiwan over the 1976–1986 period. We include the log of the initial wage and the log of initial city-industry employment, as well as dummy variables indicating city location, as control variables in the regressions. Various city-industry externalities are included in the explanatory variables: specialization, competition and diversity within the environment. *Moran's I* statistic shows weak spatial autocorrelation in Regressions (1), (2) and (3). The MLE results for the same regressions in Table 4 are presented in Table 5.

Table 5 shows that higher initial employment in a city-industry leads to slower growth of that industry's employment. Employment within industries located in the northern region tends to grow faster. Moreover, competition

Table 5. City-industry employment growth and externalities (1976–1986) by MLE (Dependent variable: Growth in city-industry variable)

Dependent variable (logs)	City-industry employment growth 1976–1986			
	(1)	(2)	(3)	(4)
Intercept	1.019*	0.694*	1.747*	1.392*
	(0.301)	(0.337)	(0.509)	(0.548)
City-industry employment 1976 (Log)	−0.264*	−0.242*	−0.293*	−0.255*
	(0.028)	(0.025)	(0.025)	(0.032)
Wage in city-industry 1976 (Log)	−0.060	−0.047	−0.079	−0.069
	(0.069)	(0.071)	(0.070)	(0.073)
Geographical dummies:				
North	0.767*	0.785*	0.739*	0.724*
	(0.193)	(0.192)	(0.198)	(0.202)
Central	0.392*	0.395*	0.315	0.290
	(0.190)	(0.190)	(0.202)	(0.206)
South	0.551*	0.552*	−6.706*	0.425*
	(0.193)	(0.192)	(3.393)	(0.213)
City-industry externalities:				
Specialization 1976	−0.038			−0.036
	(0.075)			(0.075)
Competition 1976		0.047*		0.044*
		(0.017)		(0.017)
Diversity 1976			−6.706*	−6.200**
			(3.393)	(3.442)
N	662	662	662	662

Note: Numbers in parentheses are standard errors.
* Significant at the 5% level.
** Significant at the 10% level.

and diversity help the growth of industry employment. Both effects are statistically significant, especially the diversity externality. This result indicates that more firms per worker in a city-industry relative to the national average leads to higher growth within that city-industry; and a greater variety of neighbors rather than dominant industries as neighbors help a city's own growth. The overall results favor Jacobs' theory that knowledge spillovers outside the industry are important.

Table 6 presents the MLE results relating to wage growth across city-industries. The results show that high initial city-employment in industries helps wage growth; conversely, high initial wages in the city-industries reduce the growth rate of the wage. Both influences are significant. The effect of the initial employment is statistically significant but quantitatively small. All of the regional dummies exhibit positive significant effects in relation to the growth of city-industry wages. Equation 1 tells us that city-industry specialization has no significant effect on wage growth. This result does not support the predictions of the MAR model. In Eq. 2, the effect of the competition variable is positive and statistically significant. Equation 3 indicates that wages in city-industries with environments that are more diversified increase more rapidly. This finding suggests that a greater variety of neighbors rather than dominant industries as neighbors helps promote wage growth, and is consistent with Jacobs' theory that knowledge spillovers outside the industry are important. Equation 4 uses all of the measures of externalities simultaneously.

Table 6. City-industry wage growth and externalities (1976–1986) by MLE (Dependent variable: Growth in city-industry variable)

Dependent variable (logs)	City-industry wage growth 1976–1986			
	(1)	(2)	(3)	(4)
Intercept	4.890*	4.848*	5.290*	5.253*
	(0.086)	(0.095)	(0.149)	(0.157)
City-industry employment 1976 (log)	0.055*	0.059*	0.042*	0.046*
	(0.009)	(0.009)	(0.009)	(0.010)
Wage in city-industry 1976 (log)	−1.292*	−1.290*	−1.300*	−1.299*
	(0.016)	(0.016)	(0.016)	(0.016)
Geographical dummies:				
North	0.174*	0.175*	0.147*	0.146*
	(0.060)	(0.059)	(0.059)	(0.059)
Central	0.199*	0.198*	0.148*	0.146*
	(0.060)	(0.059)	(0.060)	(0.060)
South	0.172*	0.172*	0.113*	0.112*
	(0.058)	(0.057)	(0.058)	(0.057)
City-industry externalities:				
Specialization 1976	−0.003			−0.002
	(0.018)			(0.017)
Competition 1976		0.007*		0.006
		(0.007)		(0.007)
Diversity 1976			−3.631*	−3.573*
			(0.982)	(0.986)
N	997	997	997	997

Note: Numbers in parentheses are standard errors.
* Significant at the 5% level.

The effect of diversity remains statistically significant. The overall results indicate that industrial diversity within a city helps promote the wage growth of the industry. In ways similar to the results in Table 5, these findings favor Jacobs' theory.

Table 7 presents the results of regressions similar to those in Table 5 except for the different time period data used. As in the case of Table 5, high initial employment in city-industries leads to the slower growth of the industry's employment. The negative influence of this initial employment is stronger during this later decade than it is during the earlier decade. Furthermore, industries in the northern region are seen to have grown significantly as compared with industries in other regions. The positive effect of the competition variable is significant but quantitatively small as in Table 5. The effect of diversity remains statistically significant. Industries in cities with more diversified environments grow more rapidly. This finding suggests that a greater variety of neighbors rather than dominant industries as neighbors during this period helps cities with their own growth as was the case during the previous decade. The overall results favor Jacobs as in Table 5. The influence of the diversity externality on employment growth has increased when compared with the previous decade. On the contrary, the effect of the competition externality on employment growth has decreased as compared with the previous decade.

Table 8 presents the results of regressions similar to those in Table 6 using

Table 7. City-industry employment growth and externalities (1986–1996) by MLE (Dependent variable: Growth in city-industry variable)

Dependent variable (logs)	City-industry employment growth 1986–1996			
	(1)	(2)	(3)	(4)
Intercept	3.610*	2.443*	6.171*	5.066*
	(0.745)	(1.009)	(0.926)	(1.161)
City-industry employment 1986 (Log)	−0.507*	−0.490*	−0.572*	−0.558*
	(0.037)	(0.032)	(0.033)	(0.038)
Wage in city-industry 1986 (Log)	−0.060	0.159	−0.096	0.081
	(0.157)	(0.209)	(0.168)	(0.210)
Geographical dummies:				
North	0.639*	0.581*	0.604*	0.571*
	(0.261)	(0.254)	(0.250)	(0.249)
Central	0.492**	0.426**	0.106	0.085
	(0.264)	(0.259)	(0.269)	(0.267)
South	0.348	0.281	−0.215	−0.231
	(0.263)	(0.258)	(0.283)	(0.281)
City-industry externalities:				
Specialization 1986	−0.0006			0.025
	(0.122)			(0.117)
Competition 1986		0.024*		0.019*
		(0.009)		(0.009)
Diversity 1986			−25.638*	−24.015*
			(5.432)	(5.467)
N	598	598	598	598

Note: Numbers in parentheses are standard errors.
* Significant at the 5% level.
** Significant at the 10% level.

data for the later time period. As in the case of the results in Table 6, high initial wages at the city-industry level correspond to lower wage growth rates. The effect is statistically significant as in the previous decade. Moreover, the wages of industries in the northern region are still seen to grow significantly faster than in the other regions as was the case during the previous decade. The overall results indicate that diversity within a city helps wages grow within the industry. The effect of diversity is statistically significant. This finding is consistent with the results of the previous decade, and favorable to Jacobs' theory.

Overall, in the cases of employment growth and wage growth during the two different time periods (Tables 5–8), we find that a high initial wage at the city-industry level corresponds to significantly lower wage growth rates for both decades. Similarly, high initial employment corresponds to a significantly lower employment growth rate in both decades. On the contrary, initial employment at the city-industry level helps wages grow during the early decade. Moreover, the regression results indicate that both competition and diversity externalities promote the growth of wages and employment significantly. In particular, the diversity externalities are not only statistically significant, but also consistently exhibit relatively large influences on both wage growth and employment growth at the city-industry level. According to our empirical results, the effect of diversity on employment growth becomes increasingly important. We use the standard definition to identify the outliers

Table 8. City-industry wage growth and externalities (1986–1996) by MLE (Dependent variable: Growth in city-industry variable)

Dependent variable (logs)	City-industry wage growth 1986–1996			
	(1)	(2)	(3)	(4)
Intercept	6.604*	6.699*	6.909*	7.046*
	(0.258)	(0.277)	(0.307)	(0.343)
City-industry employment 1986 (Log)	−0.003	−0.006	−0.012	−0.014
	(0.011)	(0.012)	(0.011)	(0.013)
Wage in city-industry 1986 (Log)	−1.257*	−1.275*	−1.257*	−1.279*
	(0.052)	(0.055)	(0.051)	(0.055)
Geographical dummies:				
North	0.156*	0.165*	0.157*	0.161*
	(0.064)	(0.064)	(0.066)	(0.066)
Central	−0.016	−0.007	−0.060	−0.058
	(0.055)	(0.054)	(0.069)	(0.069)
South	0.007	0.015	−0.058	−0.056
	(0.060)	(0.060)	(0.078)	(0.078)
City-industry externalities:				
Specialization 1986	−0.006			−0.004
	(0.013)			(0.012)
Competition 1986		−0.003		−0.004
		(0.007)		(0.007)
Diversity 1986			−3.148*	−3.327*
			(1.487)	(1.558)
N	1055	1055	1055	1055

Note: Numbers in parentheses are standard errors.
* Significant at the 5% level.

in the regression.[3] There are not any cities that persistently appear to be outliers in the regression.

Two hypotheses are tested to examine whether the parameters in both the employment growth and wage growth regressions vary through time. We first test to see whether the parameters in the employment growth regression (Regression (4) in Table 5 and Regression (4) in Table 6) are different between the two decades (1976–1986 and 1986–1996). The *F test* statistic is found to be 17.42, which is greater than the 1% critical value. We therefore reject the hypothesis that the parameters in the regression model are the same during the two time periods.[4] These results indicate that the influences of the initial condition and the externalities on the employment growth within industries are statistically significantly different from one decade to the next. The second hypothesis is tested to see whether the parameters in the wage growth regression remain the same during the two time periods. The *F test* statistic equals

[3] An outlier is a value that is more than 1.5 times the interquartile range, and is larger than Q_3 or smaller than Q_1.

[4] The test statistics in relation to the hypotheses that the parameters of Regression (4) in Table 5 remain the same during 1976–1986 and 1986–1996 are as follows:

$$F = \frac{e_*'e_* - e'e/k}{e'e/(n-2k)} = \frac{[2601-(1028+1311)]/8}{(1028+1311)/1259-16} = 17.42 > F_{.01}(k, n-2k) = F_{.01}(8, 1243) = 2.51$$

Table 9. City-industry wage growth and externalities by MLE city-industry wage growth

Dependent variable (logs)	1976–1986		1986–1996	
	(1)	(2)	(3)	(4)
Intercept	3.888*	5.112*	5.540*	2.431*
	(0.297)	(0.247)	(0.439)	(0.286)
City-industry employment 1976 (Log)	0.044*	0.040*	0.008	0.025*
	(0.011)	(0.020)	(0.017)	(0.011)
Wage in city-industry 1976 (Log)	−0.964*	−1.062*	−1.026*	−0.329*
	(0.060)	(0.030)	(0.066)	(0.051)
Geographical dummies:				
North	0.127**	−0.040	0.235*	−0.074
	(0.068)	(0.099)	(0.076)	(0.069)
Central	0.219*	−0.118	−0.002	0.038
	(0.071)	(0.099)	(0.077)	(0.070)
South	0.176*	−0.074	0.016	0.050
	(0.066)	(0.101)	(0.091)	(0.074)
City-industry externalities:				
Specialization 1976	−0.006	−0.012	−0.044*	−0.009
	(0.014)	(0.034)	(0.022)	(0.016)
Competition 1976	0.003	0.010	−0.001	0.011*
	(0.010)	(0.014)	(0.010)	(0.002)
Diversity 1976	−2.227*	−3.454**	−4.057*	3.946*
	(1.107)	(1.837)	(1.810)	(1.721)
N	739	258	790	265

Note: Numbers in parentheses are standard errors.
* Significant at the 5% level.
** Significant at the 10% level.
Regressions (1) and (3) use city-industries with a wage growth rate lower than the top 25%.
Regressions (2) and (4) use city-industries with a wage growth rate within the top 25%.

152.3, which is greater than the 1% critical value of 2.51.[5] We therefore reject the hypothesis that the parameters remain the same during both time periods. The results of these two tests indicate that the impact of dynamic externalities on the growth of both employment and wages changes over time.

Table 9 presents the regressions in relation to wage growth across city-industries over the two decades for two different groups of city-industries. We group the city-industries into "fast-growing" industries and "other" industries. The "fast-growing" industries are defined as those industries whose wage growth rates fall within the top 25 percentiles, while the "other" industries are those industries whose wage growth rates fall outside the top 25 percentiles. We find that a high initial wage reduces wage growth in both industry groups. The effect is statistically significant, and also demonstrates the weak influence of initial employment on the growth of wages. Wages for "other" industries in the northern region increase significantly more than wages for "other" industries located outside the northern region. The northern region dummy

[5] The test statistics in relation to the hypotheses that the parameters of Regression (4) in Table 6 remain the same during 1976–1986 and 1986–1996 are:

$$F = \frac{e_*'e_* - e'e/k}{e'e/(n-2k)} = 152.3 > F_{.01}(k, n-2k) = F_{.01}(8, 2035) = 2.51$$

variable does not exhibit a significant effect in "fast-growing" industries. As with the previous results, the effects of diversity externalities are significant in both "faster-growing" industries and "other" industries. Furthermore, it can be seen that diversity helps promote wage growth in both groups of industries and within each time period.

4. Conclusion

It would have been the first best choice to use metropolitan areas as the unit of observation. However, there are only seven metropolitan areas in Taiwan, and this number of observations is too small for the regressions. Due to the limitations of the data, we have adopted the second best alternative, namely, the "city" as the unit of observation in this study.

The results have shown that, at the city-industry level, high initial employment within a city-industry leads to slower growth in terms of that industry's employment in both decade-long time periods under study. Similarly, a high initial wage within a city-industry reduces wage growth significantly in both periods.

As for the effect of externalities, industry specialization does not exert a significant impact on either employment growth or wage growth in both decades. Our results in this regard do not support the predictions of the MAR model. The competition variable has a positive influence on employment growth in both decades, the effect being significant but quantitatively small. This indicates that more firms per worker within a city-industry relative to the national average leads to a higher growth of that city-industry. This result tells us that the existence of more relatively small-scale industries within a city helps industries grow in that city. This is consistent with both Porter's and Jacobs' hypothesis that local competition fosters innovation. Moreover, the diversity among city-industries improves both employment growth and wage growth in both decades. This positive effect of diversity is not only statistically significant but also quantitatively large relative to the effect of competition. Besides, the effect of diversity has increased from one decade to the next. The diversity externalities exhibit an increasingly greater impact on employment growth over time. Both competition and diversification among industries stimulate employment growth. Our results suggest that knowledge spillovers are mostly derived among industries. It is geographical diversity of proximate industries rather than specialization that encourages innovation and growth. Overall, we find that specialization hurts, competition helps, and city diversity helps both employment growth and wage growth in both periods under study. Urban variety and local competition are more important for the growth of industries than is regional specialization. This result is consistent with the theories of Jacobs. We also find that the extent of the effects of the initial conditions and externalities on employment growth and wage growth vary through time.

In relation to the city-level evidence, the regression results do not provide strong evidence of externality effects and the size effect. This may be due to the limitations on the number of observations in our data. In addition, the median years of schooling (human capital) helps city output growth.

To sum up, we find that the effects of local competition and urban variety are becoming more and more important in the growth of employment and wages in Taiwan. The results provide evidence that knowledge spillovers

across industries, but not spillovers within industries, encourage employment growth in industries. As is the case with the study by Glaeser (1992), our findings favor Jacobs' theory that local competition and the cross-fertilization of ideas across industries helps industries grow.

References

Anselin L, Hudak S (1992) Spatial econometrics in practice: A review of software options. Regional Science and Urban Economics 22:509–536

Bostic RW et al. (1997) Urban productivity and factor growth in the late 19th century. Journal of Urban Economics 4(1):38–55

Eaton J, Eckstein Z (1997) Cities and growth: Theory and evidence from France and Japan. Regional Science and Urban Economics 27:443–474

Garcia-Mila T, McGuire TJ (1993) Industrial mix as a factor in the growth and variability of states' economies. Regional Science and Urban Economics 23(6):731–748

Glaeser EL et al. (1992) Growth in cities. Journal of Political Economy 100(6):1126–1152

Glaeser EL et al. (1995) Economic growth in a cross section of cities. Journal of Monetary Economics 36(1):117–143

Henderson VJ (1974) The sizes and types of cities. American Economic Review 64(4):640–656

Henderson VJ (1986) Efficiency of resource use and city size. Journal of Urban Economics 19:47–70

Henderson VJ et al. (1995) Industrial development in cities. Journal of Political Economy 103(5):1067–1090

Jacobs J (1969) Economy of cities. Vintage, New York

Jacobs J (1984) Cities and the wealth of nations: Principles of economic life. Random House, New York

Jaffe AB et al. (1993) Geographic localization of knowledge spillovers as evidenced by patent citations. Quarterly Journal of Economics 108:557–598

Lucas RE (1988) On the mechanics of economic development. Journal of Monetary Economics 12:3–42

Marshall A (1890) Principles of economics. Macmillan, London

Mills ES (1967) An aggregative model of resource allocation in a metropolitan area. American Economic Review 57:197–211

Miracky WF (1992) Technological spillovers, the product cycle and regional growth. Manuscript. Massachusetts Inst. Tech., Cambridge

Mumy GE, Niskanen E (1993) The impact of distributional objectives on the toll and capacity of a congestible facility. Journal of Urban Economics 34:401–413

Nakamura R (1985) Agglomeration economies in urban manufacturing industries: A case of Japanese cities. Journal of Urban Economics 17(1):108–124

O'Regan KM, Quigley JM (1996) Teenage employment and the spatial isolation of minority and poverty households. Journal of Human Resources 31(3):692–702

Porter M (1990) The comparative advantage of nations. Free Press, New York, NY

Quigley JM (1998) Urban diversity and economic growth. Journal of Economic Perspectives 12(2):127–138

Romer P (1986) Increasing returns and long-run growth. Journal of Political Economy 94:1002–1037

Segal D (1976) Are there returns to scale in city size? Review of Economics and Statistics 58(3):339–350

Shefer D (1973) Localization economies in SMSAs: A production function analysis. Journal of Regional Science 13:55–64

Sveikauskas L (1975) The productivity of cities. Quarterly Journal of Economics 89(3):393–413

Appendix: Description and sources of variables

The spatial weights matrix (W): There are only 21 observations in Taiwan, so that the contiguity of the observations of the spatial weights matrix W is

derived from visual inspection of boundaries on the map. The entry in cell i, j is 0 if spatial unit i and j are not contiguous, and 1 if they are contiguous.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
3	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
5	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0
9	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1
14	0	1	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	1
15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
17	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0

The number of cities:

Number	Cities
1	Taipei City
2	Kaohsiung City
3	Taipei County
4	Ilan County
5	Taoyuan County
6	Hsinchu County
7	Miaoli County
8	Taichung County
9	Changhua County
10	Nantou County
11	Yunlin County
12	Chiayi County
13	Tainan County
14	Kaohsiung County
15	Pingtung County
16	Taitung County
17	Hualien County
18	Penghu City
19	Keelung County
20	Taichung City
21	Tainan City

Population (City). This variable is the number of persons living within the political unit of the city, and comes from the Taiwan-Fukien Demographic Fact Book, Republic of China.

Income (per capita). This variable is obtained from the Report on the Survey of Personal Income Distribution in the Taiwan Area, Republic of China. It is the distributed factor income, which is the sum of the compensation of employees, entrepreneurial income, and net property income. It does not include transfer payment income.

Median years of schooling. This variable is the median of schooling years within the city. It is from the Taiwan-Fukien Demographic Fact Book, Republic of China.

Employment (City-industry). This is the number of people employed in the city-industry, and is obtained from the Report on the Industrial and Commercial Census, Taiwan-Fukien Area, Republic of China.

Wage (City-industry). This variable is obtained from the Report on the Industrial and Commercial Census, Taiwan-Fukien Area, Republic of China.

Output (per capita). This variable is derived from dividing the total industrial output by the total number of industrial employees in the city. The total industrial output is derived from the summation of various industries' output. The output of each industry is mainly derived from deducting production cost from the sum of production revenue and inventory. This variable is obtained from the Report on the Industrial and Commercial Census, Taiwan-Fukien Area, the Republic of China.

Regions in Taiwan. Northern region: The major city in this region is Taipei, and most of the industries are concentrated in this region; especially service and high-tech industries. There are two airports (one international and one domestic) in this region.

Central region: The major city in this region is Taichung. The major industries are services and manufacturing.

Southern region: The major city in this region is Kaohsiung. The major industries are mining and manufacturing. The mining industry is mostly concentrated in this region.

Eastern region: The major city in this region is Hualien. The major industries are service industries, especially tourism. This is the least-developed region in Taiwan.