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Testing the scale effect predicted by the Fujita–Krugman urbanization model

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Abstract

This paper tests the scale effect predicted by the Fujita–Krugman [Fujita, M., Krugman, P., 1995. When is the economy monocentric? von Thűnen and Chamberlin unified. Regional Science & Urban Economics 25, 505–528] urbanization model, which implies a monotonically positive relationship between the average firm size and the degree of urbanization, given that population and fixed cost do not decrease. Empirical data from seven OECD countries are examined, and the Fujita–Krugman model is tested. The results suggest that the prediction in the Fujita–Krugman model is incompatible with empirical observation. The evidence in the paper seems to support the alternative classical urbanization theory proposed by Xenophon [Gordon, B., 1975. Economic Analysis Before Adam Smith. Macmillan, London] and William Petty [Petty, W., 1683. Another essay on political arithmetics. In: Hull, C.H. (Ed.), Economic Writings of Sir William Petty. Augustus, M-kelly, New York, p. 947 (Reissued in 1963)] and formalized by Yang [Yang, X., 1991. Development, structure change, and urbanization. Journal of Development Economics 34, 199–222], Yang and Rice [Yang, X., Rice, R., 1994. An equilibrium model endogenizing the emergence of a dual structure between the urban and rural sectors. Journal of Urban Economics 25, 346–368], and Sun and Yang [Sun, G., Yang, X., 2002. Agglomeration economies, division of labor and the urban land-rent escalation: a general equilibrium analysis of urbanization. Australian Economic Papers 41, 164–183].

JEL classification: R00; C22; D50

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1. Introduction

In the literature of the theory of urbanization, there are two different research lines, the neoclassical and the classical (see Yang, 2001). The former treats economies of scale as the driving force behind urbanization. This line is influential and widely accepted by most economists. Along this line the Fujita and Krugman (1995) model is one of the most important. In contrast, the classical line, as represented by Xenophon (see Gordon, 1975, p. 41) and Willaim Petty (1683, p. 947), stresses the intrinsic connection between the division of labor and the emergence of cities. According to the classical theory, it is the economies of specialization and the economies of division of labor, rather than the economies of scale, that play an essential role in the process of urbanization. Yang (1991), Yang and Rice (1994) and Sun and Yang (2002) have formalized the classical insights by using general equilibrium models.

It is the difference between the two lines that motivates us to turn to empirical evidence. The purpose of the paper is to test a hypothesis predicted by the Fujita–Krugman model (the FK model hereafter) of a monotonically positive correlation between the average size of manufacturing firms and both the total population and the degree of urbanization, which we refer to as the scale effect in this paper. We examine data from seven OECD countries. They are, among developed economies, Australia, the UK, Iceland, The Netherlands and Sweden, a newly industrialized country, Korea, and a developing economy, Mexico. The data from these countries show that the FK hypothesis is not supported by empirical evidence.

The paper is organized as follows. Section 2 outlines the derivation of the empirical implications of the FK model. Section 3 reports the empirical evidence against the FK model, with graphical illustration and more formal econometric tests. Section 4 concludes the paper.

2. The Fujita–Krugman model and its empirical implications

The story behind the FK model runs as follows. There are trade offs between global economies of scale, the utility benefit of the consumption variety of manufactured goods, and transaction costs. Since farming is land intensive, farmers must have dispersed residences in the rural area. Manufactured goods are not land intensive, so manufacturers can reside together in the city. In addition, as the residences of manufacturers are concentrated in a city, there is a trade off between the reduction of transaction costs between urban residents and the increase in transaction costs between rural farmers and urban manufacturers. An increase in population size or in the transaction efficiency of agricultural goods will increase the scope for individuals to trade off these conflicting forces, thereby increasing productivity, per capita real income, the average size of industrial firms, and consumption variety. The increase in the number of manufactured goods will move the efficient balance of the trade offs towards a more concentrated residential pattern of manufacturers, making a city more likely to emerge. Hence, holding other parameters constant, the FK model predicts a monotonically positive correlation between the degree of urbanization and average size of industrial firms, which is referred to as the scale effect in this paper.

Now we turn to the algebra of a simplified version of the Fujita–Krugman model (see also Yang, 2001, pp. 379–381). Consider an economy with N identical consumers, an agricultural good, and n manufactured goods, where n is endogenous. It is assumed that the manufacturing activity needs no land. Hence, the central point of the geographic area is a city where all N_B manufacturers reside. Suppose that $N_A = N - N_B$ farmers' residences are evenly located around the city. The area of land employed is endogenously determined in this model. Each rural resident has the following decision problem:

$$\begin{aligned} &\max: \quad u_A = z_A^{\alpha}[n(kx_A)^{\rho}]^{(1-\alpha)/\rho} \quad \text{(utility function)}, \\ &\text{s.t.} \quad pz_A + nqx_A = w_A \quad \text{(budget constraint)}, \end{aligned} \tag{1}$$

where p is the price of the agricultural good, q the price of the manufactured goods, z_A the quantity of the agricultural good consumed by each rural resident, n the number of different types of manufactured goods, and x_A the amount of each manufactured good consumed by the rural resident. Each consumer is endowed with one unit of labor, so that the income of a rural resident equals the rural wage rate w_A. Coefficient k ($k \in (0, 1)$) is the transaction efficiency for the manufactured goods. We assume that there is no transaction cost for a rural resident to buy the agricultural good from the local rural market. Hence, transaction costs are incurred only in buying the manufactured goods. Note that we have used symmetry conditions to justify equal prices and equal quantities of all manufactured goods consumed.

Each urban resident has the following decision problem:

$$\begin{aligned} &\max: \quad u_B = (tz_B)^{\alpha}[nx_B^{\rho}]^{(1-\alpha)/\rho} \quad \text{(utility function)}, \\ &\text{s.t.} \quad pz_B + nqx_B = w_B \quad \text{(budget constraint)}, \end{aligned} \tag{2}$$

where subscript B stands for variables for an urban resident and $t \in (0, 1)$ is the transaction efficiency coefficient for the agricultural good. If we assume that labor in the city is the numeraire, then $w_B = 1$. We assume that there is no transaction cost for an urban resident to buy manufactured goods from the local urban market. Hence, transaction costs are incurred for the urban resident only in buying the agricultural good.

The demand functions, the own price elasticity of demand for manufactured goods, and the indirect utility functions are:

$$\begin{aligned} z_i &= \frac{\alpha w_i}{p} \quad (i = \text{A}, \text{B}), \\ x_i &= \frac{(1-\alpha)w_i}{qn} \quad (i = A, B), \\ E &= -\left[\frac{1}{1-\rho}\right] + \left[\frac{\rho}{(1-\rho)n}\right] = \frac{-(n-\rho)}{(1-\rho)n}, \\ u_A &= \frac{\alpha^{\alpha}(1-\alpha)^{1-\alpha}n^{(1-\alpha)(1-\rho)/\rho}k^{1-\alpha}w_A}{p^{\alpha}q^{1-\alpha}}, \\ u_B &= \frac{\alpha^{\alpha}(1-\alpha)^{1-\alpha}n^{(1-\alpha)(1-\rho)/\rho}t^{\alpha}w_B}{p^{\alpha}q^{1-\alpha}}, \end{aligned} \tag{3}$$

where the own price elasticity of demand E is calculated using the Yang and Heijdra (1993) formula.[1]

A simple Leontief production function is assumed for the agricultural sector, so a units of labor and one unit of land are required to produce one unit of z. The zero profit condition in the agricultural sector yields:

$$p = aw_{\mathrm{A}}. \tag{4}$$

Free migration between the urban and rural areas will establish utility equalization between the two areas. The condition $u_{\mathrm{A}} = u_{\mathrm{B}}$, together with the Eq. (4), gives:

$$w_{\mathrm{A}} = \frac{t^{\alpha}}{k^{1-\alpha}} \quad \text{and} \quad w_{\mathrm{B}} = 1. \tag{5}$$

A linear production function with fixed cost, $Q = (L - f)/b$ is assumed for manufacturing a non-agricultural good. Hence, the amount of labor required to produce output Q is $L = f + bQ$. A monopolistically competitive regime prevails in the market for any manufactured good. The Yang–Heijdra formula for own price elasticity in Eq. (3), and the condition that marginal revenue equals marginal cost, that is, $\mathrm{MR} = q(1 + 1/E) = \mathrm{MC} = b$, gives:

$$nq(1-\rho) = (n-\rho)(q-b) \quad \text{and} \quad (1-\alpha)(q-b)(N_{\mathrm{A}}w_{\mathrm{A}} + N - N_{\mathrm{A}}) = fnq, \tag{6}$$

where N_{A} is the number of farmers, $N_{\mathrm{B}} = N - N_{\mathrm{A}}$ the number of urban residents, and the equilibrium value of w_{A} is given in (5).

Eqs. (5) and (6), together with the market clearing condition for labor or for the manufactured goods, can then be used to determine N_{A}, q, w_{A} and n. The equilibrium level of total output of the agricultural good, $Z = N_{\mathrm{A}}z_{\mathrm{A}} + N_{\mathrm{B}}z_{\mathrm{B}}$, can be obtained by inserting the equilibrium price into the demand function, $z_i = \alpha w_i/p$ (i = A, B), where w_i is given in (5). Therefore, the demand for labor from the agricultural sector is given by:

$$N_{\mathrm{A}} = aZ = a\left[\frac{\alpha N_{\mathrm{A}}}{a} + \frac{\alpha(N-N_{\mathrm{A}})}{aw_{\mathrm{A}}}\right], \quad \text{or} \quad N_{\mathrm{A}} = \frac{\alpha k^{1-\alpha}N}{(1-\alpha)t^{\alpha} + \alpha k^{1-\alpha}}, \quad \text{and}$$
$$N_{\mathrm{B}} = N - N_{\mathrm{A}} = \frac{N(1-\alpha)t^{\alpha}}{(1-\alpha)t^{\alpha} + \alpha k^{1-\alpha}} \quad \left(\frac{\mathrm{d}N_{\mathrm{B}}}{\mathrm{d}N} > 0\right), \tag{7}$$

where $w_{\mathrm{A}} = t^{\alpha}/k^{1-\alpha}$ is given in (5). Inserting (7) into (6) yields the equilibrium value for the number of manufactured goods, n, which can be considered as the degree of industrialization, and the equilibrium value of q:

$$n = \rho + \frac{(1-\alpha)(1-\rho)t^{\alpha}N}{[(1-\alpha)t^{\alpha} + \alpha k^{1-\alpha}]f} \quad \left(\frac{\mathrm{d}n}{\mathrm{d}N} > 0 \quad \text{and} \quad \frac{\mathrm{d}n}{\mathrm{d}t} > 0\right), \quad \text{and}$$

[1] The own price elasticity of demand in the Dixit and Stiglitz model (1977) and the FK model is $1/(1-\rho)$, which ignores the term $\rho/(1-\rho)n$ in the Yang–Heijdra (1993) formula. Therefore, according to the DS formula of the own price elasticity of demand, the average of firm size does not change as urban population size increases. However, as Yang and Heijdra argue, since the number of goods is endogenized in the DS model, it is not legitimate to make such an ad hoc assumption that the number of consumption goods is large enough. The ad hoc assumption is inconsistent with another assumption that a firm can perceive the effect of the own price through the price index on the quantity that it can sell.

$$q = \frac{b(1-\alpha)t^{\alpha}N}{\rho\{(1-\alpha)t^{\alpha}N - f[(1-\alpha)t^{\alpha} + \alpha k^{1-\alpha}]\}}. \tag{8}$$

Following the method to solve for the output level of each firm in the Dixit and Stiglitz (1977) model, we can find the output level for each industrial firm:

$$X = N_{\mathrm{A}}x_{\mathrm{A}} + N_{\mathrm{B}}x_{\mathrm{B}} = \frac{f\rho[(1-\alpha)\gamma(N-f) - \alpha f]}{b\{(1-\rho)(1-\alpha)\gamma N + \rho f[(1-\alpha)\gamma + \alpha]\}} \quad \left(\frac{\mathrm{d}X}{\mathrm{d}N} > 0\right), \tag{9}$$

where $\gamma = t^{\alpha}/k^{1-\alpha}$.

The average firm size L in terms of employment is given by:

$$L = \frac{N_{\mathrm{B}}}{n} = \frac{1}{(\rho/N)[1 + \alpha k^{1-\alpha}/(1-\alpha)t^{\alpha}] + (1-\rho)/f}. \tag{10}$$

Let $\theta = \alpha k^{1-\alpha}/(1-\alpha)t^{\alpha}$, we have:

$$L = \frac{1}{(\rho/N)(1+\theta) + (1-\rho)/f}. \tag{11}$$

The level of urbanization is measured by the urbanization ratio:

$$R = \frac{N_{\mathrm{B}}}{N} = \frac{1}{1 + \alpha k^{1-\alpha}/(1-\alpha)t^{\alpha}} = \frac{1}{1+\theta}. \tag{12}$$

From (11) and (12), we can then establish a direct relationship between L and R:

$$L = \frac{1}{\rho/NR + (1-\rho)/f}, \tag{13}$$

where

$$\frac{\partial L}{\partial N} > 0, \quad \frac{\partial L}{\partial f} > 0, \quad \text{and} \quad \frac{\partial L}{\partial R} > 0. \tag{14}$$

Assuming ρ remains constant, we explore the empirical implications of the Fujita–Krugman model as follows:

$$\mathrm{d}L = \frac{\partial L}{\partial N}\mathrm{d}N + \frac{\partial L}{\partial f}\mathrm{d}f + \frac{\partial L}{\partial R}\mathrm{d}R. \tag{15}$$

In other words, from (14), the average size of firms is positively related to the total population N, the fixed input f for producing manufactured goods, and the degree of urbanization R. That is, if both N and f have not decreased over time, we should observe a positive co-movement between L and R.

Table 1
Data for a proxy measure for the fixed labor input per firm

	Austria	Canada	Finland	Japan	UK	US
1983	204.03	207.33	51.48	65.17	20.38	14.30
1984	227.55	195.469	52.56	73.57	17.81	16.01
1985	236.16	238.507	55.46	85.13	18.26	17.70
1986	265.77	275.56	60.50	83.06	16.92	16.408
1987	266.35	297.72	71.12	73.98	17.50	15.83
1988	262.71	303.55	66.48	79.56	20.13	15.68
1989	267.05	357.07	77.77	95.38	21.29	18.36
1990	291.16	311.20	72.17	96.15	20.42	19.06

Notes: The figures in the table are calculated by dividing the gross fixed capital formation by the associated number of manufacturing establishments and the manufacturing wage rate for each country. Gross fixed capital formation relates to the expenditure on new plant and equipment only.
Sources: Data for the gross fixed capital formation and the number of establishments are from the OECD (various years) and the UNIDO (various years). Data for manufacturing wage rates are from the ILO (1969–2002).

3. Empirical evidence against the Fujita–Krugman model

3.1. *A casual observation against the Fujita–Krugman model*

A casual observation of the empirical data shows that all three right-hand side variables in Eq. (15) have either increased consistently or at least have not decreased over time. The total populations in most economies have increased. The fixed cost for establishing new manufacturing enterprises has also increased, although it is not easy to find a good proxy with readily available data for the variable f in the FK model. Increased skill requirements of human capital have meant that the fixed labor costs through education and training have increased. The depreciation period for fixed capital on average has also decreased, as old technologies become obsolete much faster due to rapidly changing technologies. This is especially the case as we observe an increasing component of information technology in all manufacturing sectors.

Two proxies are used to show the trend of the fixed cost f: (i) fixed capital formation per manufacturing firm deflated by the manufacturing wage rate; and (ii) average number of years of schooling of adults.

The data for the first proxy measure in (i) for six countries are given in Table 1 and Fig. 1, which indicate an increasing trend for almost all countries and no decreasing trend for any countries.[2] The figures in Table 1 are not exactly the values of the fixed labor costs in the production function of the FK model, as we need to depreciate the fixed capital formation before we divide it by wage rate. The depreciation period has decreased significantly in the past 50 years. For example, the average life span for information technology has decreased from 15 to 2 years for some products in the past decade while we have observed an increasing component of information technology in all sectors. Consequently, if we take into account

[2] Unfortunately, we cannot find data for this fixed cost measure for the same seven countries that we use to conduct econometrics tests in the subsequent subsections.

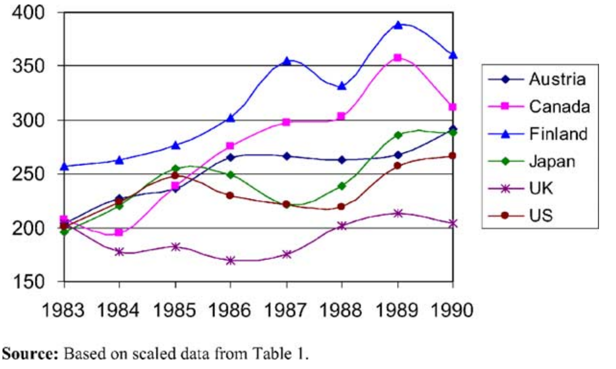

Fig. 1. Trend of fixed labor input. *Source*: based on scaled data from Table 1.

the depreciation effect, the resulting data would show an even stronger increasing trend for the fixed inputs than that indicated in Fig. 1.

Now we turn to the second proxy of *f*. The underlying assumption in the FK model is that the greater the fixed cost, the more difficult for a person to enter a sector because of a greater learning and training fixed labor cost. Therefore, we consider the average years of education and training of workers in individual countries. The argument is that as average education level increases, the proportion of labor income in each year that is used to repay the employees' education and training by firms increases. This proportion can be considered to be *f* in the FK model. Data for average years of schooling for major OECD countries across the last 30 years are given in Table 2. They have all shown an increasing trend.

Turning to the degree of urbanization *R*, which measures the proportion of urban population, a persistent trend of urbanization is observed in most countries according to data from the Global Development Network Growth Database of the World Bank (Easterly and Sewaden, 2000). For example, based on information given in this database, Fig. 2 shows the

Table 2
Average years of schooling of adults (in years)

	1970	1975	1980	1985	1990	1995	2000
Australia	10.24	10.14	10.29	10.32	10.38	10.67	10.92
Austria	7.35	7.42	7.34	7.5	7.76	8.05	8.35
Canada	9.08	9.76	10.32	10.76	10.99	11.39	11.62
Finland	6.11	6.66	7.16	7.8	9.38	9.65	9.99
Iceland	6.55	6.95	7.37	7.77	8.12	8.48	8.83
Japan	7.45	7.78	8.51	8.74	8.96	9.23	9.47
Korea	4.91	6.6	7.91	8.68	9.94	10.56	10.84
Mexico	3.68	3.93	4.77	5.2	6.72	6.96	7.23
The Netherlands	7.76	8	8.24	8.49	8.75	9.12	9.36
Singapore	5.05	5.49	5.5	6.1	5.96	6.72	7.05
Sweden	7.98	8.87	9.71	9.46	9.51	11.23	11.41
UK	7.66	8.04	8.27	8.52	8.77	9.09	9.42
US	9.53	9.69	11.87	11.57	11.74	11.89	12.05

Source: World Bank (2000).

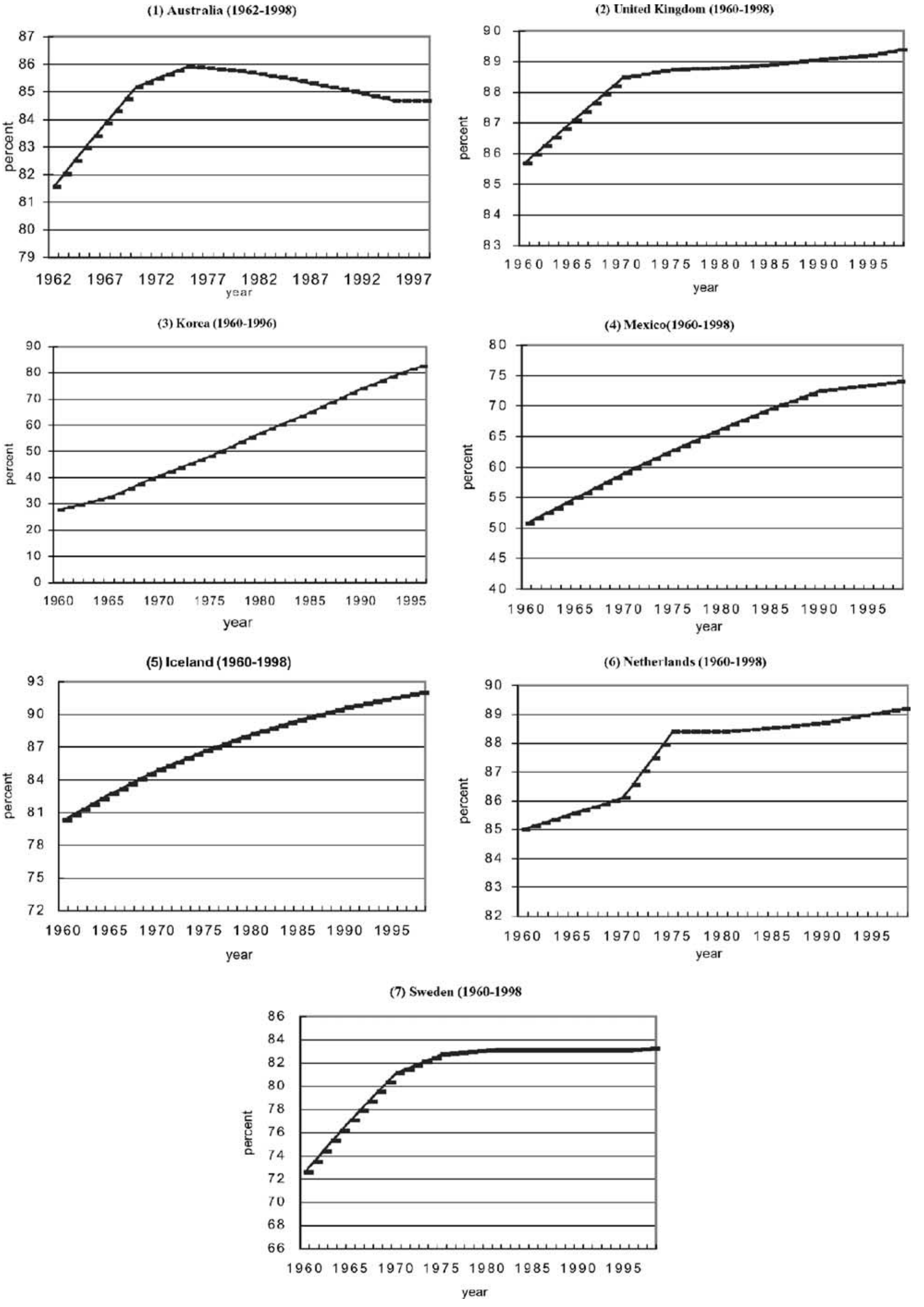

Fig. 2. Urbanization index R for seven OECD countries. *Source*: Easterly and Sewaden (2000).

urbanization ratios for seven OECD countries. They have all increased monotonically over the past 30 years. These countries are Australia, the UK, Mexico, Iceland, The Netherlands, Sweden, and Korea.

According to the Fujita–Krugman model in the form of (13), the above evidence would imply that the average size of firms in most countries would have to increase monotonically. However, this is not what we have seen in most industrialized countries. The new development phenomena, such as franchise networks, business practices of downsizing, disintegration, outsourcing, contracting out, original equipment manufacture (OEM), and focusing on core competence, have become increasingly common since the 1980s (Hart, 1995). In many countries, the average size of firms now shows a trend of declining. A research report provided by the OECD (Ark and Monnikh, 1996) examined the average firm sizes of the US, the UK, Germany, Japan and France. It shows that the average number of employees per manufacturing unit in these five OECD countries exhibits either an inverted U-shape or a declining trend over the period of the 1960–1990s. For instance, the average number of employees per enterprise of manufacture industry in Germany was 91, 93, and 86 in 1967, 1977, and 1990, respectively, showing an inverted U-shape. In the UK, the average firm size has declined significantly over time, with 85, 67, and 34 employees per firm for 1968, 1977, and 1990, respectively.

Based on data from the *Industrial Structure Statistic* by OECD and the *Yearbook of Industrial Statistics* by the United Nations (UNIDO) in various years, Fig. 3 illustrates the average numbers of employees per industrial establishment for the same seven OECD countries as in Fig. 2. They exhibit either a pattern of inverted U-shape or a monotonically downward trend. None of the countries shows a monotonically upward trend. This is obviously incompatible with the prediction of the FK model.

3.2. *Time series properties of the urbanization ratio and the average firm size*

The consistent increasing trend for the urbanization ratios of the seven OECD countries as shown in Fig. 1 can be further illustrated by a formal analysis of the time series properties of this variable. Results for testing for either a deterministic trend or a stochastic trend are given in Table 3 for each of the seven OECD countries. For each country, the best fitted deterministic trend $f(t)$ chosen from a group of simple functional forms is estimated, and the error term is corrected for serial correlation with autoregression. The LM column gives the test statistics and the associated P-values for the Breusch–Godfrey Lagrange multiplier test for serial correlation (Eviews, 2000). For all countries except for Mexico and Australia, significant and monotonically positive trends are detected. While an uprising linear trend with constant rate is significant for Korea, the other four countries have shown an increasing trend of a log-linear form, indicating a persistent increase though with a decreasing rate. The LM tests for these countries indicate that the null hypothesis of no serial correlation in the residuals after the autoregressive correlations with order p (given in the preceding column) cannot be rejected at 5 percent significance level. In other words, there is no significant serial correlation in the corrected residuals. All the inverted roots for the autoregressive process are within the unit circle for each case, which is consistent with a stationary AR(p) process. These results indicate that a persistently increasing deterministic trend is significant in the past 30 years for the urbanization ratio R for these five countries.

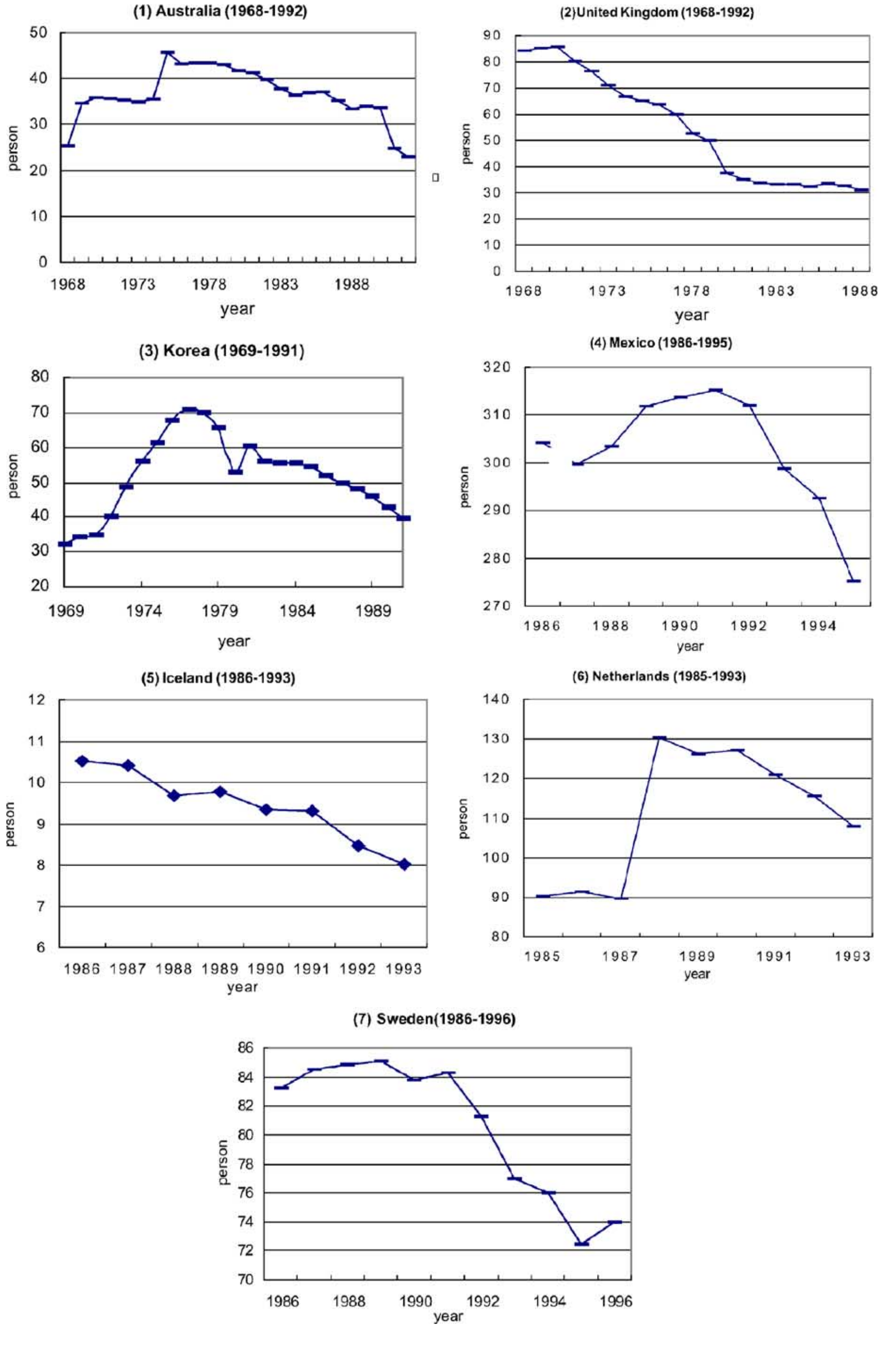

Fig. 3. Firm size: average number of employees per industrial firm. *Source*: OECD (various years) and UNIDO (various years).

Table 3
Time series properties for urbanization ratio R

	Deterministic time trend $f(t)$[a]	α_0	α_1	α_2	R^2	p	Roots <1?	LM
Australia (1962–1998)	$\alpha_0 + \alpha_1 t + \alpha_2 t^2$	112.5 (0.10)	−1.14 (0.60)	0.013 (0.54)	0.99	2	Y	1.111 (0.34)
UK (1960–1998)	$\alpha_0 + \alpha_1 \log(t)$	86.49* (0.00)	0.77* (0.00)		0.99	2	Y	0.628 (0.54)
Korea (1960–1996)	$\alpha_0 + \alpha_1 t$	23.04* (0.00)	1.61* (0.00)		0.99	2	Y	0.012 (0.988)
Mexico (1960–1998)	$\alpha_0 + \alpha_1 \log(t)$	54.96* (0.00)	1.136* (0.02)		0.99	2	N	0.385 (0.683)
Iceland (1960–1993)	$\alpha_0 + \alpha_1 \log(t)$	69.22* (0.00)	6.212* (0.00)		0.99	2	Y	0.244 (0.785)
The Netherlands (1960–1993)	$\alpha_0 + \alpha_1 \log(t)$	84.46* (0.00)	1.266* (0.00)		0.99	2	Y	0.028 (0.972)
Sweden (1960–1998)	$\alpha_0 + \alpha_1 \log(t)$	79.6* (0.00)	1.03 (0.10)		0.99	0	Y	1.73 (0.19)

Stochastic trend[b]	γ_0	γ_1	p	ADF-stat	P-value
Australia (1962–1998)	7.12	−0.084	6	−2.721	0.082
Mexico (1962–1998)	0.46	−0.0058	1	−2.092	0.249

[a] The deterministic trend model estimated is $R_t = f(t) + u_t$, where the error term is AR(p) corrected with $u_t = \rho_1 u_{t-1} + \cdots + \rho_p u_{t-p} + \varepsilon_t$. The second last column indicates whether the stationarity condition for the AR(p) process (that requires that all inverted roots of the lagged polynomial, whether real or imaginary, lie inside the unit circle) is satisfied. The LM column gives the test statistics for the Breusch–Godfrey Lagrange multiplier test for serial correlation for the autoregressive corrected residuals up to the second order (Eviews, 2000). Values in the parentheses are the P-values for the associated tests. Figures in the brackets are the P-values associated with the significance of the relevant coefficients, and the asterisks (*) indicate significance at the 5% significance level.

[b] The stochastic trend model estimated is $\Delta R_t = \gamma_0 + \gamma_1 R_{t-1} + \sum_{i=1}^{p} \delta_i \, \Delta R_{t-i} + \varepsilon_t$, where the lag order of p is chosen based on Swartz Information Criterion (SIC). The last two columns present the test statistic and the P-value for the augmented Dickey–Fuller (ADF) test for a null hypothesis of unit root H_0: $\gamma_1 = 0$.

For the case of Mexico, although a significant and increasing log-linear trend is estimated, one of the inverted roots for the autoregressive error correction process has a value of 1.04. This implies that the AR(p) process is non-stationary, which invalidates the regression results. This suggests that the deterministic trend model may be misspecified and a stochastic trend may better describe the series. Indeed, the augmented Dickey–Fuller (ADF) test for Mexico as shown in the lower part of Table 3 indicates that a unit root with a positive drift cannot be rejected. Thus, the data is consistent with an increasing stochastic trend for the urbanization ratio for Mexico.

The urbanization trend in Australia is slightly different. Examining the Australia data as illustrated in Fig. 1, the proportion of total population living in the cities has stabilized since the seventies after a slight increase during the 1960s. In fact, there has been a very slight decrease in the urbanization ratio since the 1980s, due to the non-economic lifestyle choices of many people and, more recently, the trend of moving away from the cities of a retired 'baby boomer' generation. Test for a quadratic deterministic trend for Australia has shown insignificant coefficients for both linear and quadratic terms. A further test for a stochastic trend, as presented in the second part of Table 3, shows that although the urbanization proportion for Australia has exhibited a slight decrease since the early eighties, a unit root with positive drift cannot be rejected at the 10 percent significant level. This suggests that over the whole period since the beginning of the 1960s, the data are not inconsistent with an increasing stochastic trend.

However, turning to the time series properties for the average firm sizes as presented in Table 4, the assumption of a monotonically increasing trend is rejected for all countries. The UK, Iceland, and Sweden have shown a persistently decreasing deterministic trend over the observed time period, in either a linear or a quadratic functional form. The other four countries (i.e., Australia, Korea, Mexico, and The Netherlands) have shown a significant deterministic trend of the inverted U-shape. All models are estimated with an autoregressive correction for the error term and no further serial correlation is significant in the corrected residuals as indicated by the LM test statistics. All the inverted roots for the autoregressive process are within the unit circle for each case, suggesting a stationary AR(p) process. This is obviously inconsistent with the increasing trends shown for the urbanization ratios according to the FK model.

3.3. A regression analysis for the FK model

Finally, we attempt to use the data from the seven countries empirically to estimate the FK relationship as presented in (15). As we do not have data for the fixed inputs variable f for the same seven countries, we treat f as an omitted variable and estimate a regression relationship between the average firm size L and the total population N and urbanization ratio R.[3] According to the FK model in (15), both of variables N and R should be positively related to the L variable. Table 5 shows the results of the regressions with autoregressive error corrections. As expected, none of the countries show significant and positive correlations between the average firm size L with both the total population N and the urbanization ratio

[3] Because we can speculate that the fixed input shows a monotonically increasing trend based on data from some other countries as in Table 1, we know the direction of bias for the misspecified models.

Table 4
Time series properties for average firm size L[a]

	Deterministic time trend $f(t)$	α_0	α_1	α_2	R^2	p	LM
Australia (1968–1992)	$\alpha_0 + \alpha_1 t + \alpha_2 t^2$	26.83* (0.00)	2.529* (0.00)	−0.105* (0.00)	0.816	0	0.864 (0.437)
UK (1968–1992)	$\alpha_0 + \alpha_1 t$	93.93* (0.00)	−2.782* (0.00)		0.985	2	1.694 (0.213)
Korea (1969–1991)	$\alpha_0 + \alpha_1 t + \alpha_2 t^2$	26.53* (0.00)	5.797* (0.00)	−0.233* (0.001)	0.864	1	1.515 (0.249)
Mexico (1986–1995)	$\alpha_0 + \alpha_1 t + \alpha_2 t^2$	286.4* (0.00)	11.65* (0.002)	−1.241* (0.001)	0.862	0	0.153 (0.862)
Iceland (1986–1993)	$\alpha_0 + \alpha_1 t$	10.98* (0.00)	−0.343* (0.00)		0.936	0	0.199 (0.827)
The Netherlands (1985–1993)	$\alpha_0 + \alpha_1 t + \alpha_2 t^2$	62.67* (0.003)	20.58* (0.016)	−1.722* (0.029)	0.703	0	0.721 (0.54)
Sweden (1986–1996)	$\alpha_0 + \alpha_1 t + \alpha_2 t^2$	85.6* (0.00)		−0.11* (0.00)	0.88	0	0.205 (0.820)

[a] The deterministic trend model estimated is $R_t = f(t) + u_t$, where the error term is AR(p) corrected with $u_t = \rho_1 u_{t-1} + \cdots + \rho_p u_{t-p} + \varepsilon_t$. LM column gives the F-test statistics for the Breusch–Godfrey Lagrange multiplier test for serial correlation of up to the second order for the autoregressive corrected residuals. Values in the parentheses are the P-values for the associated tests. Figures in the brackets are the P-values associated with the significance of the relevant coefficients, and the asterisks (*) indicate significance at the 5% significance level.

Table 5
Regression for the FK model[a]

	α	β	γ	R^2	p	LM
Australia (1968–1992)	−1221.65* (0.04)	−0.755 (0.55)	14.85* (0.03)	0.79	1	0.286 (0.75)
UK (1968–1992)	3428.7* (0.03)	−15.56* (0.03)	−28.08 (0.11)	0.98	2	2.595 (0.11)
Korea (1969–1991)	−181.46 (0.47)	13.72 (0.205)	−4.95 (0.103)	0.86	1	0.396 (0.67)
Mexico (1986–1995)	−1171.3* (0.00)	−7.88* (0.00)	29.59* (0.00)	0.83	0	0.089 (0.92)
Iceland (1986–1993)	54.43 (0.13)	−106.7* (0.00)	−0.203 (0.63)	0.94	0	0.03 (0.96)
The Netherlands (1985–1993)	65630.6* (0.02)	389.11* (0.01)	−804.02* (0.02)	0.72	0	3.864 (0.11)
Sweden (1986–1996)	2656.9 (0.66)	−23.87* (0.00)	−28.52 (0.69)	0.79	0	1.43 (0.31)

[a] The regression model estimated is $L_t = \alpha + \beta N_t + \gamma R_t + u_t$, where the error term u_t is AR(p) corrected with $u_t = \rho_1 u_{t-1} + \cdots + \rho_p u_{t-p} + \varepsilon_t$. LM column gives the F-test statistics for the Breusch–Godfrey Lagrange multiplier test for serial correlation for the autoregressive corrected residuals. Values in the parentheses are the P-values for the associated tests. Figures in the brackets are the P-values associated with the significance of the relevant coefficients, and the asterisks (*) indicate significance at the 5% significance level.

R. In fact, there seems to be a significant negative relationship between L and at least one of the two variables of N and R at 10 percent significance level for all countries except for Australia. This is obviously inconsistent with the FK prediction. Without testing for the non-stationarity for the variables concerned and their orders of integration where necessary, the results in Table 5 show that a positive cointegration relationship among the three variables is not possible.

4. Conclusions

We have found that the empirical evidence is inconsistent with the prediction of a monotonically positive relationship between the average size of industrial firms and the degree of urbanization in the Fujita–Krugman model. It seems that the conventional neoclassical wisdom that attributes the driving force behind urbanization to the economies of scale is inconsistent with empirical evidence. However, empirical evidence seems to be consistent with the classical theory of urbanization that considers economies of division of labor as a driving force of urbanization. The theory is represented by Xenopnon and Petty, and formalized by Yang (1991), Yang and Rice (1994), Sun (2000), and Sun and Yang (2002).[4] The latter literature uses general equilibrium models with endogenous network size of division of labor and endogenous urbanization. Their models show that the economic development and urbanization occur regardless of whether the average firm size increases or decreases as long as the transaction efficiency increases and thereby the equilibrium level of division of labor increases. If division of labor develops within each firm, then the equilibrium degree of urbanization and the average size of firms increase side by side. If division of labor develops between a greater number of more specialized firms, there is a negative correlation between the equilibrium degree of urbanization and the average size of firms. This theory is in line with the theory of irrelevance of the size of the firm that was proposed by Adam

[4] For instance, according to Baumgardner (1988), physicians in large cities are much more specialized than those in small towns. This empirical evidence is consistent with the conjecture of classical economists.

Smith (1776), Allyn Young (1928), George Stigler (1951), Coase (1937), Cheung (1983), Yang and Ng (1995) and Liu and Yang (2001).

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