AN EVALUATION OF THE EFFICIENCY OF CONSTRUCTION INDUSTRY IN HONG KONG USING THE DEA APPROACH

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The construction industry of Hong Kong has been undergoing a fast development since 1970's. This paper evaluates the efficiency of the industry using DEA (data envelopment analysis) approach based on the statistical data during the period of 1981 to 1994. DEA is a mathematical programming technique belonging to nonparametric approaches that have been applied to measure the efficiency of decision making units (DMUs) like firms, enterprises as well as industries in which outputs are produced. The results indicate that the efficiency of the construction industry was improving although the rate of productivity growth varies over different sub-periods. The reasons for differential growth in the efficiency of the construction industry is analysed. The technical efficiency ratios of the sub-trade groups in the industry are also evaluated. The authors have attempted to explain the sources of efficiency growth over time and variations in the efficiency ratios across different trade groups.

Keywords: Construction industry, DEA approach, efficiency, Hong Kong.

INTRODUCTION

The overall economy of Hong Kong has been undergoing a rapid development since 1970's. Its achievement is appraised as a miracle in the world. Construction industry and the real estate sector contribute approximately one fifth of the GDP of Hong Kong, a lot higher than most other economies in the region. This paper attempts to assess economic performance of the industry for the period of 1981 - 1994 using the DEA (data envelopment analysis).

DEA is a nonparametric approach using mathematical programming technique to measure the efficiency of decision making units (DMUs). Here a DMU can represent any economic entity like a firm, an enterprise, a sub-sector of an industry as well as an industry in which inputs are converted into outputs. The DEA approach was first introduced by Charnes, Cooper and Rhodes (CCR, 1978). The basic conception, i.e. efficient frontier estimation, can be traced back to Farrell (1957). The Farrell's frontier represents the best practice of production technology and is regarded as a non-parametric estimation of the production function. The distiguishing disadvantage of production function is the assumption of an explicit functional form for technology. DEA method can remedy the weakness. The efficiency of a DMU is measured relative to all other DMUs with the simple restriction that all DMUs lie on or below the efficient frontier based on the observed data. Moreover, the DEA approach does not required that weights be assigned to any of inputs or outputs to reflect their relative importance on an a priori basis.

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Since the introduction of the work by CCR, the strength and applicability of the DEA approach for empirical analysis of productive efficiency has been widely recognised by researchers. This study also adopted the same approach to evaluate the efficiency of the construction industry of Hong Kong.

DEA MODEL

There are different variations of the DEA model. We have employed the CCR ratio model in this study. The fundamental characteristic of the CCR model is the reduction of the multiple-output / multiple-input situation for each DMU to that of a single 'virtual' output and 'virtual' input. For a particular DMU the ratio of this single virtual output to single virtual input provides a measure of efficiency. The model can be expressed as the following dual pair of linear programming forms.

$$\max_{u,v} z = u^T Y_o \quad \text{s.t.} \quad \begin{aligned} & v^T X_o = 1 \\ & u^T Y - v^T X \le 0 \\ & u^T \ge 0 \\ & v^T \ge 0 \end{aligned} \qquad (1)$$

$$\min_{\theta,\lambda} \theta \quad \text{s.t.} \quad \begin{aligned} & Y\lambda \ge Y_o \\ & \theta X_o - X\lambda \ge 0 \\ & \lambda \ge 0 \end{aligned} \qquad (2)$$

where, X_o and Y_o are vectors with components x_{io} and y_{ro}, representing observed values of inputs $(i = 1,2,\ldots,m)$ and outputs $(r = 1,2,\ldots,k)$ for DMU_o, the DMU being evaluated. Using x_{ij} and y_{rj} to represent the corresponding inputs and outputs for each DMU_j, $j = 1,2,\ldots,n$, we array these observations in the form of the associated $k \times n$ matrix of output values, Y, and the $m \times n$ matrix of input values, X.

Model (2) is chosen in our application since resource minimization is more consistent with contractors' decision making process than output maximization. The vector λ and θ are variables in the model to be estimated. Let e^T represent a unit vector, returns to scale for the DMU can be measured using the following criteria.

$\sum e^T \lambda < 1$, increase returns to scale
$\sum e^T \lambda = 1$, constant returns to scale
$\sum e^T \lambda > 1$, decrease returns to scale

The solution $\theta^*, (0 \le \theta^* \le 1)$, of the linear programming problem is the efficiency ratio of the DMU. Let vectors $s^+, s^- \ge 0$ represent slacks of Y and X respectively. The DMU is efficient if and only if $\theta^* = 1$, and all slacks are zero (for cross-section comparison). The hypothetical technically efficient inputs and outputs for all the DMU's can be derived by projecting the variables onto the efficient frontier using the following equations.

$$\begin{aligned} X_o' &= \theta^* X_o - s^- \\ Y_o' &= Y_o + s^+ \end{aligned} \qquad (3)$$

DATA AND DEFINITIONS

The data source is the Census and Statistics Department of Hong Kong. The government has assembled input/output statistics since 1979. The data provide information for a basic understanding of the structural chracteristics and performance as well as economic analysis of the construction industry.

The set of observations began in 1981 (The 1979 data was ignored as the 1980 data is less comprehensive. The methodology and frequency of the survey became stable in 1981) which was selected as the base year of the study. All monetary variables were deflated to the base year with the appropriate price deflators.

We have used an one-output / two-input model. Output (Q) is defined in terms of value added concept. It is calculated as gross value of construction work performed (GV) less the value of work rendered by fee subcontractors (FSC) and intermediate inputs which include consumption of materials and supplies, feul, electricity and water, and maintenance services (MC). The values of GV and FSC are deflated by output price index (OPI) which was derived from the tender price indexes and other statistics (see Chau, 1990). The index of materials (MCI) constructed by the Architectural Services Department is used to deflate MC.

Labour (L) is defined as number of persons employed during the period. However, such data are not readily obtained from the statistics of Census and Statistics Department, since the number of workers working as labour only subcontractors (LOS) are not recorded. Therefore it is assumed that the average remunerations and working days of the direct employees are the same as those of indirect employees (LOS) within the same trade group. The number of workers working as LOS is deduced from the total payment to them.

Capital (K) is defined as the sum of rents and rates for land & buildings (RLB) and rentals for hiring machinery & equipment (RME), interest payments (INT) on project construction loans, and depreciation of fixed assets (DFA). The "flow" concept is adopted here. All terms are deflated to the base year (1981) also. RME and DFA are deflated by capital rental price index (PEI) which is constructed from the capital price index and interest rate movement (see Chau and Walker, 1988). RLB and INT are deflated by office rental index constructed by the Rating Valuation Department and GDP deflator (GDPI) respectively.

Trade classifications were developed according to the recommendations in International Standard Industrial Classification (ISIC) of the United Nations before 1990. Of the construction industry, establishments are grouped into eight 3-digit sub-trades. The trade classifications were changed from 9 trades to 8 within the period of our observation (1981-1994). From 1990, the Hongkong Standard Industrial Classification (HSIC) was adopted to classify the trade groups. Nevertheless, they are equivalent in the eight 3-digit trades during the observed period.

Table 1. The Classification of 3-digit Groups of Construction Industry in HK

Trade code	Construction activities
511	**New construction works - pre-erection works at building and construction sites**
511	*New construction works - pre-erection works at building and construction sites*
521	**New construction works - architectural and civil engineering works at building and construction sites**
521	*New construction works - architectural and civil engineering works at construction sites*
531	**New construction works - demolition and minor construction works**
529	*New construction works - miscellaneous new construction works*
541	**Renovation and maintenance at erected buildings and structures**
531	*Decoration, repair and maintenance*
551&552	**Special trades - erection and general finishing**
541&542	*Special trades - erection and general finishing*
561	**Special trades - electrical and mechanical fitting**
551	*Special trades - electrical and mechanical fitting*
571	**Special trades - gas and water fitting**
561	*Special trades - gas and water fitting*
581	**Special trades - other fitting**
591	**Special trades - not elsewhere classified**
591	*Special trades - miscellaneous*

Note: From 1990, the Hong Kong Standard Industrial Classification (HSIC) was adopted to classify the trade groups (in italic). The International Standard Industrial Classification (ISIC) was used before 1990 (in boldface).

The definitions and contents of the first seven 3-digit trades in both ISIC and HSIC classification systems are the same although there are some minor differences in the terminologies and trade codes (see Table 1). However, the last 3-digit group in HSIC contains the last two groups in ISIC. So it is necessary to merge the last two trade groups in ISIC used before 1990 into one so that the data set is consistent over the entire period of observation. Therefore, we have altogether eight 3-digit trade groups in the observation period for analysis.

RESULTS AND EXLANATION

Our focus in this paper is on relative technical efficiency, or also called Pareto - Koopmans efficiency (see Charnes et al, 1985). We can, therefore, concentrate on possible technical productive efficiency without using relative prices of the relavant inputs and outputs.

The study analyses the data at two different levels of aggregation. The first is on industry level. The second is on 3-digit trade sub-groups.

Table 2. General Results of Construction Industry in HK (1981~1994)

Year	**In puts**		**Output**	**Efficiency ratio**	$\sum e^T \lambda$	
	L (persons)	K ($000')	Q ($000')			
1981	238798	1104831	13256393	0.7235	0.5599	IRS
1982	221010	1246320	14169555	0.6856	0.5984	
1983	180338	1297988	15067908	0.7848	0.6177	
1984	186144	1277629	16939565	0.8631	0.7016	
1985	187202	1395252	17068923	0.8502	0.6942	
1986	207804	1474464	18839509	0.8541	0.7747	
1987	224814	1522546	21460224	0.9078	0.8914	
1988	228716	1427776	23677805	1	1	CRS
1989	238003	1634120	23593676	0.9402	0.9772	IRS
1990	235472	1767029	22802907	0.9016	0.9260	
1991	241576	2243114	24014341	0.8807	0.9248	
1992	248880	3444616	25814798	0.8175	0.8766	
1993	246453	4972537	33739964	0.9417	0.9882	
1994	234843	4664426	34142034	1	1	CRS
Aver.	**222961**	**2105189**	**21756257**	**0.8679**	**0.8236**	

Table 2 shows the results of the analysis at industry level. The DMU here refers to the whole construction industry. The figures in the second to the fourth columns show the input-output data derived from the procedure described above. The efficiency ratios shown in the fifth column of Table 2 are derived using linear programming technique (equation 2). The efficiency ratios of 1988 and 1994 reach one, that means they are on the efficient frontier. All the other years are less efficient compared with these two years. The efficiency ratios are the lowest for the first 3 years. The average efficiency ratios for the fourteen years is 0.8679. In general, the efficiency ratios show an upward sloping trend.

Returns to scale can be indicated by the value of $\sum e^T \lambda$ in the model. The results are presented in the second last column of Table 2. Except for 1988 and 1994, all years show increasing returns to scale (IRS) because their values are less than one. The smaller the value of $\sum e^T \lambda$, the stronger the scale effect. The industry exhibits constant returns to scale (CRS) in 1988 and 1994. During these two years, the efficiency ratios were also the highest. This suggests that returns to scale are exhausted when productive efficiency is peaked. This is not surprising as part of the growth in efficiency may come from larger scale of operation.

Since all values $\sum e^T \lambda$ of are less than or equal to one, there is no sign of decreasing returns to scale (DRS). If DRS is a result of the industry operating a scale beyond its capacity, it seems that the industry can adjust its capacity quickly to changing demand for construction work.

Table 3 shows the relative efficiency ratios for the 3-digit trade groups within each year, i.e. cross-section comparison of the trade groups. The last column in Table 3 shows the coefficient of variance of efficiency ratios. This measure indicates the spread of the relative efficiency across trade groups.

A value of 1 means that trade group is on the efficient frontier (most efficient). It can be seen that the more labour intensive trade groups (HSIC 529, 531, 541&542 and 591) seldom appear on the efficient frontiers. This suggests that mechanization or substitution of capital for labour has played an important role in determining the technical efficiency of the trade groups.

Table 4 shows the relative efficiency ratio for all the 3-digit trade groups based on the pooled time series and cross section data (comparison across different trade groups and over time). The last column in Table 4 gives the average efficiency ratios of all trade groups weighted by the volume of output. The most efficient years being 1994, the average efficiency ratio of this year is 1.96 times of that of 1981, representing an annual growth rate of 5.3%.

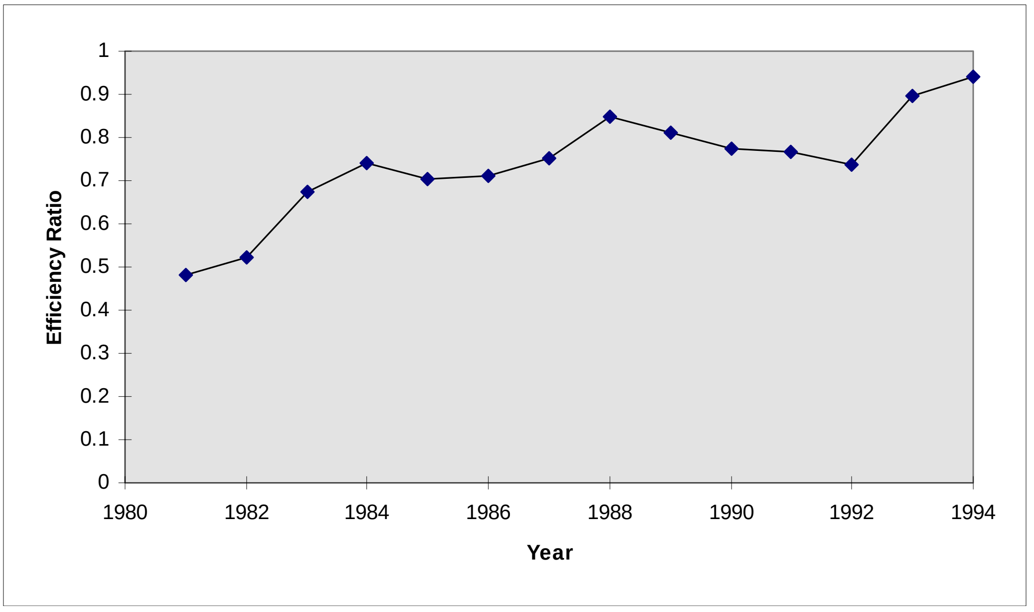

Figure 1. The trend of output-weighted average efficiency ratios by pooled computation of 3-digit trade groups.

Table 3. Efficiency Ratios For 3-digit Trade Groups (Annual, 1981-1994)

Year	**511 (511)**	**521 (521)**	**531 (529)**	**541 (531)**	**551&2 (541&2)**	**561 (551)**	**571 (561)**	**581&591 (591)**	**Aver.**	**Coefficient of Variance**
1981	0.7743	0.8308	1	0.5789	0.6503	0.6232	0.8297	0.5763	**0.7329**	**0.1924**
1982	1	1	0.9570	0.8462	0.7842	0.9754	1	0.8180	**0.9226**	**0.0922**
1983	0.8649	1	0.8017	0.8161	0.8078	0.8893	0.8438	1	**0.8780**	**0.0862**
1984	0.7640	1	0.8345	0.8133	0.9603	0.9871	1	0.7741	**0.8917**	**0.1099**
1985	0.8589	1	0.7060	0.7426	0.8230	1	1	0.7334	**0.8580**	**0.1389**
1986	1	1	0.7918	0.8367	0.7827	1	1	0.7161	**0.8909**	**0.1271**
1987	1	1	0.8338	0.8627	0.8635	1	1	0.7873	**0.9184**	**0.0920**
1988	1	1	0.7778	0.7657	0.8580	1	1	0.8574	**0.9074**	**0.1075**
1989	0.9915	1	0.8040	0.8649	0.8884	1	1	0.6781	**0.9034**	**0.1226**
1990	0.9480	1	0.6925	0.9833	0.9370	1	1	0.8385	**0.9249**	**0.1098**
1991	1	1	0.8478	0.7843	0.8711	1	1	0.8088	**0.9140**	**0.0976**
1992	0.9531	1	0.9342	0.8191	0.8352	1	1	0.8039	**0.9182**	**0.0872**
1993	1	0.9707	0.8448	0.8447	0.7334	1	0.8080	0.7285	**0.8663**	**0.1208**
1994	1	1	0.8414	0.9462	0.7315	1	0.8242	0.7613	**0.8881**	**0.1180**
Aver.	**0.9396**	**0.9858**	**0.8334**	**0.8218**	**0.8233**	**0.9625**	**0.9504**	**0.7773**		
CV	**0.0894**	**0.0443**	**0.0996**	**0.1109**	**0.0979**	**0.1021**	**0.0828**	**0.1200**		

Note: From 1990, the Hong Kong Standard Industrial Classification (HSIC) was adopted to classify the trade groups (trade codes in brackets). The International Standard Industrial Classification (ISIC) was used before 1990

Table 4. Efficiency Ratios For 3-digit Trade Groups (Pooled, 1981-1994)

Year	**511 (511)**	**521 (521)**	**531 (529)**	**541 (531)**	**551&2 (541&2)**	**561 (551)**	**571 (561)**	**581&91 (591)**	**Output W-Aver.**
1981	0.4557	0.4914	0.7432	0.4003	0.4350	0.4435	0.4703	0.3581	**0.4814**
1982	0.5339	0.5445	0.5086	0.4351	0.3921	0.4908	0.5410	0.4309	**0.5221**
1983	0.6024	0.7693	0.4802	0.4969	0.4834	0.5310	0.5098	0.6173	**0.6745**
1984	0.5874	0.8403	0.5025	0.4960	0.5656	0.7076	0.5846	0.4811	**0.7416**
1985	0.5786	0.7537	0.4969	0.5467	0.6048	0.7457	0.6653	0.5196	**0.7052**
1986	0.7344	0.7483	0.5691	0.6094	0.5657	0.7320	0.7462	0.5276	**0.7094**
1987	0.7044	0.7599	0.6376	0.6988	0.6530	0.8021	0.9583	0.6289	**0.7528**
1988	0.8465	0.8448	0.6838	0.6942	0.7311	0.9604	1	0.7738	**0.8467**
1989	0.7983	0.8600	0.6240	0.7113	0.6825	0.8401	0.7226	0.5500	**0.8119**
1990	0.7602	0.8690	0.5603	0.6684	0.6379	0.6775	0.6918	0.5692	**0.7751**
1991	0.6970	0.8282	0.6428	0.6096	0.6639	0.7928	0.6447	0.6164	**0.7670**
1992	0.6253	0.7589	0.7002	0.6623	0.6264	0.7790	0.9197	0.6020	**0.7352**
1993	1	0.8897	0.7893	0.8226	0.6881	1	0.7873	0.6942	**0.8955**
1994	1	1	0.8414	0.8301	0.7315	1	0.7642	0.7456	**0.9418**
Aver.	**0.7089**	**0.7827**	**0.6271**	**0.6201**	**0.6044**	**0.7502**	**0.7147**	**0.5796**	0.7400

Note: From 1990, the Hong Kong Standard Industrial Classification (HSIC) was adopted to classify the trade groups (trade codes in brackets). The International Standard Industrial Classification (ISIC) was used before 1990

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From Table 4, the trend of output-weighted average efficiency ratios based on pooled data is shown in Figure 1. Four sub-periods of different characteristics can be identified.

Period 1. (1981-1984) -- a period of rapid increase in productive efficiency,

Period 2. (1984-1988) -- a relatively steady period,

Period 3. (1988-1992) -- a period of gradual declining efficiency,

Period 4. (1992-1994) -- a period of rapid increase in productive efficiency.

Table 5. Slacks and Inefficiencies at Industry Level

Year	**Efficiency ratio**		**In puts**		**Output**
			L (persons)	K ($000’)	Q ($000’)
1981	0.7235	Slack value	44724	0	0
		Value if efficient	128046	799345	13256393
1982	0.6856	Slack value	14645	0	0
		Value if efficient	136879	854477	14169555
1983	0.7848	Slack value	0	0	0
		Value if efficient	141529	1018661	15067908
1984	0.8631	Slack value	0	0	0
		Value if efficient	160661	1102722	16939565
1985	0.8502	Slack value	0	0	0
		Value if efficient	159159	1186243	17068923
1986	0.8541	Slack value	0	0	0
		Value if efficient	177485	1259340	18839509
1987	0.9078	Slack value	0	0	0
		Value if efficient	204086	1382167	21460224
1988	1	Slack value	0	0	0
		Value if efficient	228716	1427776	23677805
1989	0.9402	Slack value	0	0	0
		Value if efficient	223770	1536400	23593676
1990	0.9016	Slack value	0	0	0
		Value if efficient	212302	1593153	22802907
1991	0.8807	Slack value	0	0	0
		Value if efficient	212756	1975511	24014341
1992	0.8175	Slack value	0	0	0
		Value if efficient	203459	2815974	25814798
1993	0.9417	Slack value	0	72993	0
		Value if efficient	232085	4682638	33739964
1994	1	Slack value	0	0	0
		Value if efficient	234843	4664426	34142034

It can be seen that a majority of the growth took place in the early 80’s and the early 90’s. During these periods, the dispensions of the efficiency ratios among the trade groups were also lower. This seems to refute the hypothesis of intra-industry technological diffusion, which suggests that technological progress took place initially at some hi-tech sub-sectors (during which period there is a rapid growth in the technical frontier and a large dispersion of technical efficiency ratios among trade groups) followed by a diffusion process where the efficiency growth would slow down and the dispersion of the efficiency ratios also decrease. However, more empirical evidence is required to support our results.

By solving the linear programming problem of the DEA model, the slacks of every variables can be obtained. The amounts of 'inefficiency' can be analysed using equation (3). The inefficiencies discussed here are called "technical inefficiencies". The results based on industry level data in Table 2. are shown in Table 5. All the slacks are zero except for the L variable in 1981 and 1982. After projection of all variables onto the relative efficient frontier, a set of new values are derived. It can be seen that all new output values are unchanged because of the all corresponding zero slacks. However, the input values are different mainly due to the influence of θ^* in the equation. In Table 5, we know that all input values could have been decreased, more or less depending on the efficiency ratios and slacks, to achieve the very same output aims if technical efficiency of every observation year reached the level of those in 1988 and 1994.

The reasons and sources of productivity growth of construction industry in Hong Kong was studied by Chau in his research (1993, 1997). The efficiency of the construction industry of Hong Kong experienced an obviously increasing period in our observation also. Three main sources of efficiency improvement could explain the results.

- Enhancement of labour quality

The natural resource is quite scarce in Hong Kong. So the government has been paying a lot of efforts to train the professionals, management people and construction workers. Education is the most effective means to improving the productivity of human resources as well as to speeding up diffusion of technology.

Besides tertiary education in local universities and colleges, Vocational Training Council (VTC) and Construction Industry Training Authority (CITA) organized by the government have also provided trains and apprentices for the people in the industry at different levels. Furthermore, overseas education and training in local companies have offered inneglectable supplement to it. Large number of qualified professionals and skilled labours after these education and training can therefore improve the overall efficiency of the construction labour force.

- Advances in production knowledge

Although construction techniques in Hong Kong have improved a lot over the decades, construction industry is relatively slow in technological progress compared with other hi-tech industries. Improvement in production technology in the construction industry within a short period of time is often difficult to be observed.

In Hong Kong, most enhancement of construction techniques are gained from abroad because there is very little research and development done locally. This is mainly due to the policy of laissez-faire in the economy. Hong Kong's construction industry is one of the most open and freest in the world. All contractors, both local and overseas, have the equal opportunity to compete for construction projects. Many advanced construction methods, new materials and machinery are brought into Hong Kong by foreign contractors with their execution of a large number of infrastructure projects.

At the same time, local contractors are forced to learn the advanced technology for a better fit of the competition. The efficiency has been improved as a result.

- Economies of scale

The efficiency of an industry will increase as output volume rises. The ouptut volumes in our observation period present an almost monotonically increasing trend over time. The output in 1994 is about 2.6 times of that in 1981. Specialization is supported by the increasing of demand resulting in increasing efficiency.

CONCLUDING REMARKS

This paper reports the results of research on technical efficiency of construction industry of Hong Kong for the period from 1981 - 1994 by using DEA approach. The results of the analysis suggest that there is technical efficiency increasing of the construction industry over the observation period although there are some fluctuations in the sub-periods. The analysis shows that there is no sign of intra-industry technology diffusion. The lower technical efficiency of the labour-intensive sub-sectors also suggests that mechanization has played an important role in determining the efficiency of the industry. DEA approach is identified as a powerful tool to analyse technical efficiency at different levels. More comprehensive research on this problem is expected as more data are available in the future.

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