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Returns to scale in the production of selected manufacturing sectors in China

Liu Anguo[a*], Gao Ge[a], Yang Kaizhong[b]

[a]*School of Economics and Management, Beijing University of Chemical Technology, Beijing, China, 100029*
[b]*School of Government, Peking University, Beijing, China, 100871*

Abstract

In the study on economic growth, international trade and economic geography, making different assumption on returns to scale may lead to stark difference in both theoretic conclusion and policy implication. A very important assumption supporting literatures in New Economic Geography is that production of manufacturing sector is characterized by increasing returns to scale. Around this assumption, much debate exists. There is no predominant conclusion from empirical study either. This study begins with a brief survey of the study on the assumption of returns to scale. Based on data from 17 selected sectors in manufacturing industry in China and using Diewert-Fox Model[1], returns to scale in the production of selected sectors in manufacturing industry in China is investigated. It is found that all of the selected sectors in manufacturing industry in China show increasing returns to scale, and most of those sectors experience modest negative or zero technical change, which implies that economic growth in Chinese manufacturing industry over the recent two decades has largely been driven by increasing returns to scale rather than technical progress.

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Keywords: Manufacturing industry; returns to scale; New Economic Geography; Economic growth; Törnqvist index

1. Introduction

The study of returns to scale has a long history in the pursuit of theoretic economics. Different assumption on returns to scale may lead to stark difference in both theoretic conclusion and policy implications in the field of research on economic growth, international trade and economic geography. As the traditional assumption of constant returns to scale is not sufficient in explaining patterns of both international trade and worldwide economic growth, a new assumption of increasing returns to scale emerges, and on basis of which as well as the assumption of imperfect competition, a number of new theories are developed in recent 30 years or so, with the New Trade Theory, New Growth Theory (or

* Corresponding author. Tel.: 010-62529590;
E-mail: ykz@pku.edu.cn

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Endogenous Growth Theory) and New Economic Geography as the most prominent. All of the "Three New" theories introduce both novel perspectives and debate within their respective field. For example, under the assumption of increasing returns and imperfect competition, the New Trade Theory as developed by Krugman[2, 3], Ethier[4], Helpman[5], Helpman and Krugman[6] provides a partial explanation to intra-industry trade and the rationale of strategic trade and industrial policy; the New Growth Theory (or Endogenous Growth Theory) as developed by Romer[7], Grossman and Helpman[8], Aghion and Howitt[9] offers new perspectives in explaining the driving forces of long-run economic growth and the increasing divergence in the economic performance between the South and the North; the New Economic Geography with an explicit assumption of the existence of an manufacturing sector characterized by increasing returns as developed by Krugman[10], Fujita[11], Fujita and Thisse [12], Fujita, Krugman and Venables [13] provides a theoretic framework for analyzing location decision of business and industrial agglomeration in space. The rationale and policy implications of all these strands of economic theory offer useful instruments and reference for WTO, World Bank, governments and other organizations.

Despite of the apparent strength of the above mentioned "Three New" theories, much debate exists. In fact, over the past half century, much work has been done in empirical study with respect to the returns to scale of various economic sectors, for which a brief survey will be given in the following section. Our work follows this line of research, with the focus on the empirical study of returns to scale of manufacturing sectors based on data from China, partly because that the manufacturing industry characterized by heavy investment in fixed capital serves a good representative for analyzing returns to scale, and partly because that models in New Economic Geography particularly assume the existence of a manufacturing sector characterized by increasing returns. The structure of the paper is as follows: first, we give a introduction to the background and rationale of the study of returns to scale; second, a brief survey is carried out with respect of both theoretic and empirical studies of returns to scale; the third, returns to scale of selected manufacturing sectors in China are investigated with the approach developed by Diewert and Fox[1]; the fourth, we come out with our tentative conclusion as well as an analysis of the drawbacks of this study and future improvement that may be possibly made.

2. Related Studies on Returns to Scale

2.1. Theoretical Background

The study of returns to scale can be well dated back to Adam Smith [14], who wrote in his first chapter of *The Wealth of Nations* that "The greatest improvements in the productive powers of labour, and the greater part of the skill, dexterity, and judgment, with which it is anywhere directed, or applied, seem to have been the effects of the division of labour." In his well-cited example of a pin-maker, he noted that through division of labour, an average worker can make 4800 pins in a day compared to less than 20 pins by a worker working separately and independently. He further pointed out that the division of labor is limited by the extent of the market.

Alfred Marshall[15] ran parallel with Smith in his analysis of returns to scale by arguing that specialization reduces the action of the workers to routine, which opened the possibility for the machinery to take over some of the works previously done by workers. Improvement in machinery and division of labor go side by side，which contributes to the increased efficiency in production. For Marshall, large firms can afford to buy large and complex machinery which needs a lot of workers - skilled and unskilled alike, which drives division of labour further. Large business buys in great quantities and therefore cheaply. The increase of scale of firms and industries leads to a very complex industrial organization which generates great opportunities for both technical and managerial workers. Marshall viewed increasing returns as a phenomenon primarily associated with man-made inputs and made a further distinction between increasing, decreasing and constant returns to scale.

In elaborating the mechanism that generates increasing returns, Allyn Young [16] further extended Smith's notion of division of labour as to cover the growth of roundabout or capitalistic methods of production and division of labour among industries. By emphasizing that “the economies of roundabout methods, even more than the economies of other forms of the division of labour, depend upon the extent of the market”, his assertion that “the division of labour depends in large part upon the division of labour” made the best explication of the mechanism that generates increasing returns: with roundabout methods and division of labour, complex production processes are made into simpler and simpler sub-processes through the use of machinery which gives rise to further division of labor. However, if the roundabout or indirect way of production generates with improved efficiency a large unit of output for a firm, the firm by buying inputs creates a comparable demand upon the market, which stimulates the output of other firms, which leads to the expansion of the aggregate market, and which in turn leads to further division of labor. Decreasing costs or increasing returns come as a result of output increase in the roundabout production processes.

2.2. Implications from Different Assumptions on Returns to Scale

Different assumptions on returns to scale and market structure lead to a dichotomy between traditional theory and new theory of trade, growth and economic geography, from which different theoretical implications can be drawn. While the traditional theory of trade, growth and economic geography retains the assumption of constant retains to scale, the new theory of trade, growth and economic geography assumes that increasing returns to scale exist at the plant level. Major points of difference in the theoretical implications are well documented in literature of both traditional and new trade theory[2, 3, 4, 5, 6], growth theory[7, 8, 9] and economic geography[10, 11, 12, 13], some of which are summarized in Table 1.

2.3. Formal Characterization of Returns to Scale

Mathematically, the term **returns to scale** is defined in the context of a firm's production function. A production function $f(x)$ is said to have:

- constant returns to scale at the global level if (for any constant λ greater than or equal to 1) $f(\lambda x) = \lambda f(x)$;
- increasing returns to scale at the global level if (for any constant λ greater than 1) $f(\lambda x) > \lambda f(x)$;
- decreasing returns to scale at the global level if (for any constant λ greater than 1) $f(\lambda x) < \lambda f(x)$;

where *x* refers to vector of inputs. Then constant returns to scale (CRS) at the global level occur if output increases by the same proportional change of the inputs. If output increases by less than that proportional change, then we have decreasing returns to scale (DRS) at the global level. If output increases by more than that proportional change, then we have increasing returns to scale (IRS) at the global level. Therefore, the returns to scale faced by a firm are purely determined by technologies rather than by economic forces.

However, a technology may well exhibits increasing returns to scale over some range of the inputs and decreasing returns to scale over other range of the inputs. Therefore, the elasticity of scale defined below is used as a local measure of returns to scale, which measures the percentage change in output due to a one percent change in all inputs.

Let $y=f(x)$ be the production function, let t be a positive scalar, and consider the function $y(t)=f(tx)$. The elasticity of scale is defined by

$$e(x) = \frac{dy(t)/y(t)}{dt/t}$$

evaluated at $t=1$, or

$$e(x) = \left. \frac{df(tx)/f(tx)}{dt/t} \right|_{t=1} .$$

Table 1. Major Points of Difference in Theoretical Implications Arising from Different Assumption on Returns to Scale

Traditional trade theory	New trade theory
(1).Basis of trade: differences in endowment or technology etc.	(1).Basis of trade: increasing returns to scale in production.
(2).Direction of trade: A nation will export the commodity whose production requires the intensive use of the nation's relatively abundant and cheap factor. The Nation of relatively higher demand for a product tends to become an importer of the product.	(2). A nation does not necessarily export the commodity whose production requires the intensive use of the nation's relatively abundant and cheap factor. The Nation of relatively higher demand for a product tends to become an exporter of the product.
(3). Policy implication: free trade policy is promoted.	(3). Policy implication: strategic trade and industrial policy is somehow justified.
Traditional Growth Theory	**New Growth Theory**
(1). Economic convergence with a long-run growth rate of zero is predicted.	(1). Non-zero long-run growth rate leads to economic divergence.
(2). Change in saving behavior and population growth has no effect on long-run growth rate of the economy, but it affects the level of income per capita.	(2). Investment in both physical and human capital, population policy and government regulations affect long-run growth rate of the economy.
(3) Long-run economic growth is driven by exogenously evolved technology.	(3) Long-run economic growth is driven by technical change arising from intentional investment decisions made by profit-maximizing agents.
Traditional Economic Geography	**New Economic Geography**
(1). Transportation cost affects location decision-making of business in a linear and monotonous way, which leads to dispersion of economic activities in space.	(1). Transportation cost affects location decision-making of business in a nonlinear way, which explains the coexistence of both dispersion and agglomeration of economic activities in space.
(2). Circular causation in agglomeration of economic activities in space is explained by way of external economy, whose source is left unknown.	(2) Circular causation in agglomeration of economic activities in space is explained by way of pecuniary externality arising from cost saving out of increasing returns to scale technology.
(3). Path dependence and lock-in do not occur owing to the negative feedback mechanism arising from diminishing returns to a single input and intensified competition.	(3). Path dependence and lock-in set in: Once economic activities randomly select a specific path, they will keep running along such a path unless a significantly large disturbance toward the opposite direction occurs. "A small initial asymmetry can be amplified by circular causation and give rise to large differences between regions" [17].

The technology is said to exhibit locally increasing, constant, or decreasing returns to scale as *e(x)* is greater than, equal to, or less than 1.

2.4. Empirical Investigation on Returns to Scale

As the study on returns to scale has important implications both theoretically and empirically, various investigations have been done with both parametric and non-parametric approaches and at micro, regional or macro level. Baro and Sala-i-Martin [18] find evidence of unconditional convergence using data for regional total output for the USA and the Japanese Prefectures, which is compatible with the assumption of constant returns to scale. However, by testing the Verdoorn Law using maximum likelihood method and with data of growth and output for 178 European Union regions over 1979-1989, Fingleton and McCombie's finding [19]suggested large increasing returns to scale. Using a general equilibrium growth accounting framework that features increasing returns to scale and imperfect competition and, with the US stock market data during 1953-1995, Laitner and Stolyarov[20]suggested a 1.09-1.11 range for returns to scale at the macro level in terms of aggregate output elasticity.

Empirical investigation in returns to scale focused on manufacturing industry looks more revealing. Using data on 34 industries constituting the U.S. private business economy, Basu and Fernald[21]found that "[A]lthough estimates of returns to scale vary widely across relatively disaggregated industries, the average industry appears to produce with constant or even decreasing returns." An interesting contrast is found between durable and non-durable industries: While the former shows evidence of increasing returns, the latter shows evidence of decreasing returns. Using a general equilibrium model of international trade and, with a database covering all internationally traded, goods-producing industries (27 in manufacturing and 7 outside of manufacturing) for 71countries over the period 1972-1992, Antweiler and Trefler [22] obtained a scale elasticity of 1.05 at aggregate level and a scale elasticity of 1.10-1.20 for a third of industries (including pharmaceuticals and machinery) in question.

Using an index number method and based on data during 1964-1988, Nakajima, Nakamura and Yoshioka[23] estimated scale economies and technical progress in Japanese Manufacturing industry and found that most of the 18 manufacturing industries under their investigation exhibit economies of scale. "The Pottery and Food/Kindred industries have particularly high estimates (1.07 or higher) of elasticity of scale. The Precision and Transportation machinery industries, on the other hand, have modest scale elasticities (about 1.02) but very high rates of technical progress (2.5%±3% per year). The Electric machinery industry enjoys both a high rate of technical progress and a high elasticity of scale." Similarly, Diewert and Fox [1] developed a translog cost function model without assuming perfect competition， estimating returns to scale, technical progress and monopolistic markups when there are multiple outputs and/or multiple inputs. Using US data on manufacturing at the aggregate and sectoral levels over 1949-2000, they found evidence of strong increasing returns to scale and positive monopolistic markups for most sectors. "Technical progress is typically found to be insignificant implying that, contrary to previous results, US economic growth has been driven by increasing returns to scale rather than technical progress".

3. Estimation of Returns to Scale Based on Data from Selected Manufacturing Sectors in China

3.1. Description of Method Used

While there are a lot of empirical studies on returns to scale based on data from different industries and sectors in China in literature (e.g. Sheng shubin et al., 2005 [24]; Wang and Li, 2007 [25]; Cheng and Huang, 2010 [26]; Gao, 2006 [27]; Wang, 2008 [28]; Chen and Huo, 2009 [29]), such study based on industry-wide data from manufacturing industry is relatively few. Using DEA (Data Envelopment Analysis) method - one of the non-parametric approaches - and based on data from first industrial census carried out in China in 2004, Zhong Wei et al. [30] found that among 38 industrial sectors in China, there were only 6 sectors (Gas Supply; Timber Processing, Bamboo, Cane, Palm Fiber and Straw Products; Artware; Smelting and Pressing of Nonferrous Metals; Non-metal Mineral Products; Water Supply) showing increasing returns to scale and another 6 sectors (Smelting and Pressing of Ferrous Metals; Tobacco Products; Leather, Furs, Down and Related Products; Furniture Manufacturing; Cultural, Educational and Sports Goods; Wastes Recycling) showing constant returns to scale, with all the rest showing decreasing returns to scale. While their findings look similar with those of Basu and Fernald[21], there are, however, considerable distance between them and the findings of Fingleton and McCombie [19], Laitner and Stolyarov[20], Antweiler and Trefler [22], Nakajima, Nakamura and Yoshioka [23] and Diewert and Fox [1].

However, DEA as used by Zhong Wei et al. [30] is an extreme point technique, problems may arise with any noise (even symmetrical noise with zero mean) such as measurement error. In contrast to parametric approaches to measuring efficiency and returns to scale which use central tendency (or the average producer) as a benchmark, DEA compares Decision Making Unit (DMU) to the 'best unit', on the assumption that all producers should be able to achieve the same level of efficiency. As a result, DEA measures of efficiency and returns to scale are extremely sensitive to outliers. Any errors in measurement or variation in sample size may lead to severe distortion (Zhang and Bartels, 1998 [31]; Staat, 2001 [32]; Brown, 2006 [33]). In analyzing pitfalls in DEA, Dyson et al. [34] pointed out that while CRS (Constant Returns to Scale) DEA models do not allow for potential economies or diseconomies of scale, VRS (Variable Returns to Scale) DEA model "will always envelop the data more closely than the CRS model, irrespective of whether variable returns to scale exist…If the VRS model is used, where there are no inherent scale effects, small and large units will tend to be over-rated in the efficiency assessment." For similar reasons, Olesen concluded that "…both the comparison of scale economies and the marginal rates of transformation from the two models are potentially problematic. [35]"

Accordingly, it is necessary to examine the returns to scale of Chinese manufacturing sectors with a method rather than DEA. The Diewert-Fox model as elucidated in Diewert and Fox [1]provides a good candidate for this purpose. A single firm or production unit is considered in the model that produces N outputs and uses M inputs for periods $0, 1, \ldots, T$. Let $y \equiv [y_1, \ldots, y_N]$ denote the vector of positive outputs that is produced by the positive vector of inputs, $x \equiv [x_1, \ldots, x_M]$. Assume the firm faces the positive output price vector $p^t \equiv [p_1{}^t, \ldots, p_N{}^t]$ and the positive input price vector $w^t \equiv [w_1{}^t, \ldots, w_M{}^t]$. Diewert and Fox (2008) [1]deduced that the following translog cost function could be used in estimating returns to scale, technical progress and monopolistic markups without assuming perfect competition:

$$\ln Q_T^*(w^{t-1}, w^t, x^{t-1}, x^t) = -\tau + \rho \ln Q_T(p^{t-1}, p^t, y^{t-1}, y^t) \qquad t=1,\ 2,\ \ldots\ldots T \qquad (1)$$

where τ is a parameter measuring technical progress, which here is expressed as exogenous cost reduction if τ is greater than zero; ρ is the positive returns to scale parameter which exhibits constant/increasing returns to scale if ρ is equal to/less than 1; $Q_T(p^{t-1}, p^t, y^{t-1}, y^t)$ and $Q_T^*(w^{t-1}, w^t, x^{t-1}, x^t)$ are Törnqvist output quantity index and implicit input quantity indexes respectively, which can be calculated using observable data on output and input prices and quantities for periods $t-1$ and t. If $T \geq 2$, then the technical change parameter τ and the returns to scale parameter ρ can be estimated by running a linear regression using Eq. (1) after appending error terms ε as shown in equation (2):

$$\ln Q_T^*(w^{t-1}, w^t, x^{t-1}, x^t) = -\tau + \rho \ln Q_T(p^{t-1}, p^t, y^{t-1}, y^t) + \varepsilon \qquad t=1,\ 2,\ \ldots\ldots T \qquad (2)$$

Following Diewert and Fox (2008), we will use the direct rather than implicit Törnqvist quantity index for inputs in our regression below, as the direct and implicit indexes should approximate each other quite closely[1]. Definition and method of calculation of Törnqvist quantity index can be found in Coelli et al. (1998) [36]. For example, the logarithm of the Törnqvist quantity index for output is defined as follows:

$$\ln Q_T(p^{t-1}, p^t, y^{t-1}, y^t) \equiv (1/2)\sum_{n=1}^{N}[s_n^{t-1} + s_n^t][\ln y_n^t - \ln y_n^{t-1}] \qquad (3)$$

where s_n^t and s_n^{t-1} are observable output shares in period $t-1$ and t respectively. The logarithm of the Törnqvist quantity index for input can be calculated similarly.

3.2. Description of Data Used

Owing to the variation of industrial classification method, comparable data are available for only 17 sectors within manufacturing industry in China, which include：(a) Textile Industry; (b) Garments and Other Fiber Products; (c) Leather, Furs, Down and Related Products; (d) Timber Processing, Bamboo, Cane, Palm Fiber and Straw Products; (e) Furniture Manufacturing; (f) Papermaking and Paper Products; (g) Printing and Record Medium Reproduction; (h) Cultural, Educational and Sports Goods; (i) Raw

Chemical Materials and Chemical Products; (j) Medical and Pharmaceutical Products; (k) Chemical Fiber; (l) Rubber Products; (m) plastic products; (n) non-metal mineral products; (o) Smelting and Pressing of Ferrous Metals; (p) Smelting and Pressing of Nonferrous Metals and (q) Metal Products.

Here we use time series data of gross output, value added, fixed assets, number of workers at the end of year and average annual wages of these 17 sectors over 1993-2008 to estimate the technical change parameter τ and the returns to scale parameter ρ for each sector with equation (2). As data of energy, materials and purchased business services inputs as used by Diewert and Fox (2008) [1] are unavailable in our selected Chinese manufacturing sectors, we use data of intermediate inputs as Nakajima, Nakamura and Yoshioka (1998) [23]did, which can be easily derived from the difference between gross output and value added. Data for gross output, value added, and fixed assets come from China Statistical Yearbook, 1994 - 2009[37]; and data for number of workers at the end of year and average annual wages come from China Labor Statistical Yearbook, 1994 - 2009[38]. Constant prices of the year 1993 are used for the standardization of the data in various years.

3.3. Result Analysis

Results of our estimation are reported as in Table 2.

Table 2 Estimates of Returns to Scale and Technical Change of Selected Manufacturing Sectors

Sector	Coeff. (ρ)	Std. Error	*t*-Statistic	Coeff. (τ)	Std. Error	*t*-Statistic
(a) Textile Industry	0.5948	0.1432	4.1526	-0.0120	0.0092	-1.3042
(b)Garments & Other Fiber Products	0.8649	0.1028	8.4074	-0.0059	0.0067	-0.8786
(c)Leather, Furs, Down & Related Products	0.7966	0.0913	8.7211	-0.0064	0.0056	-1.1521
(d) Timber Processing, Bamboo, Cane, etc.	0.6554	0.0514	12.7376	-0.0191	0.0055	-3.4839
(e) Furniture Manufacturing	0.7706	0.0426	18.0512	-0.0130	0.0044	-2.9508
(f) Papermaking & Paper Products	0.4727	0.0944	5.0078	-0.0285	0.0066	-4.2672
(g) Printing & Record Medium Reproduction	0.5029	0.0447	11.2507	-0.0206	0.0036	-5.6498
(h) Cultural, Educational & Sports Goods	0.8057	0.1064	7.5675	-0.0090	0.0069	-1.2927
(i) Raw Chemical Materials & Chemical Products	0.4368	0.0918	4.7553	-0.0301	0.0065	-4.5898
(j) Medical & Pharmaceutical Products	0.4469	0.0814	5.4859	-0.0283	0.0049	-5.7046
(k) Chemical Fiber	0.6953	0.1042	6.6684	-0.0079	0.0076	-1.0315
(l) Rubber Products	0.5816	0.0698	8.3314	-0.0207	0.0047	-4.4156
(m) Plastic products	0.6211	0.0711	8.7304	-0.0196	0.0055	-3.5158
(n) Nonmetal Mineral Products	0.5276	0.0830	6.3558	-0.0220	0.0067	-3.2556
(o) Smelting and Pressing of Ferrous Metals	0.4892	0.0517	9.4526	-0.0278	0.0049	-5.5961
(p) Smelting and Pressing of Nonferrous Metals	0.6298	0.0745	8.4476	-0.0225	0.0073	-3.0691
(q) Metal Products	0.7818	0.0868	9.0050	-0.0078	0.0067	-1.1679

The returns to scale parameter ρ for each sector is found to be between 0 and 1, showing that each of the 17 manufacturing sectors is characterized by increasing returns to scale. While the finding exhibits quite a difference from that of Wei Zhong et al. [23] , it seems to go well along with those of Fingleton and McCombie (1998) [12], Laitner and Stolyarov（2004）[13], Antweiler（2002）and Trefler [15], Nakajima, Nakamura and Kanji (1998) [16] and Diewert and Fox (2008) [1]. In contrast to the returns to scale estimates, the estimates of technical progress in Table 2 all exhibit negative values, some of which are insignificantly different from zero at standard levels of significance, which can be seen from the relative small absolute value of each t-Statistic. This implies that most of the 17 manufacturing sectors experience zero or even modest negaive technical change.

4. Conclusion

This paper gives a very brief introduction to the theoretical background and conceptualization of returns to scale. In addition, differences in theoretical and policy implications arising from different assumption of returns to scale are briefly discussed. As the existence of increasing returns to scale in the production of manufacturing sectors is a very important assumption adopted by New Economic Geography approach, we use data of 17 selected sectors within manufacturing industry in China for the purpose of an empirical investigation. Our finding reveals that each of the 17 selected manufacturing sectors is characterized by increasing returns to scale, which lends empirical support for inclusion of the assumption of increasing returns to scale in the production of manufacturing sectors within the New Economic Geography framework. In contrast, it is found that most of the 17 selected manufacturing sectors experience zero or even modest negaive technical change. A tentative conclusion seems to be that economic growth in Chinese manufacturing industry over the recent two decades has largely been driven by increasing returns to scale rather than technical progress.

However, as our empirical study is only concentrated on the sector-level manufacturing activities, our findings may well be subject to certain limitations (e.g. the loss of precision owing to the use of data of general intermediate input in place of data for energy, materials and purchased business services inputs as used by Diewert and Fox[1]), and improvements may be expected from a number of ways. For example, plant-level data for energy, materials and purchased business services inputs etc. may be collected to provide better estimation; or comparison can be made between findings from manufacturing sectors and those from agricultural or tertiary sectors. In addition, dummies for firm size, town size, location variable (e.g. coastal or non-coastal) etc. may well be introduced into the econometric model for identification of the ranges within which different returns to scale apply, just to mention a few.

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