Chapter 2
The IV Theory

Abstract The IV theory is a new theory that focuses on the quality and intensity of socioeconomic development and the substitutability and structure of factors. With the IV theory, we are now able to abstract complex social activities into simple mathematical functions. We set up the models of IV theory based on the definition, and explain the hypotheses of the theory. Then the IV functions are created on two different scenarios of resource conditions. In the end of this chapter, we obtain the IV curve based on the LDR diagram.

Keywords Intensive Variable theory · IV models · IV curve

2.1 IV

People receive benefits, value, or utility through exploitation of natural resources. In other words, natural resources would not have any value for human society without human involvement. Furthermore, resources first became valuable to mankind after the emergence of human society, when people started to "process" natural resources using labor; thus, LDR is similar. Human society, from its primitive versions of fishing and hunting to the agrarian and then the industrialized societies, has been continuously evolving from extensive to intensive natural resource use. However, it was not until the 19th century that the concept of intensive use was invented. Without human exploitation, natural resources would not have socioeconomic value. In other words, the socioeconomic value or utility of natural resources are realized only through the production activities of people, and human activities have added value to natural resources. Having realized that extensive use would only exhaust the natural resources available, people eventually adopted intensive use—a concept invented based on consumption of natural resources by human society. Obviously, intensive use is closely related to human activities and natural resources.

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The word “intensive” means involving great effort or work and enhanced farming in agriculture. In other words, an intensive process is one with steady enhancement, and IV is a variable that reflect continued incremental changes or the process of intensification.

By definition, an IV is a variable that results in an increase of value, benefits, or utility of natural resources through human activities. It is expressed in the value, benefits, or utility per unit of natural resources. IV is the capable of reflecting the status or extent of intensification of a particular region in a particular period. The IV theory is a new theory that focuses on the quality and intensity of socioeconomic development and the substitutability and structure of factors.

With the IV theory, we are now able to abstract complex social activities into simple mathematical functions. Then, we can summarize the general laws of social production by analyzing and studying the attributes of these functions. We can predict the development trends of specific regions by modeling future intensive use to support socioeconomic development and resource planning.

2.2 Models of IV Theory

As previously mentioned, IV is based on activities related to natural resources. The relationships between human activities, and natural resources can be expressed using the following function:

$$I = f(R, H) \tag{2.1}$$

where I is the IV, R represents resource conditions, and H indicates human activities. Natural resources have always been available on Earth, but human activities appeared significantly later. Without human activities, natural resources would not have any value or benefit, and the concept of IV would not exist. In other words, if $H = 0$ and $R = r$ (where r is a constant), $I = 0$. As mankind started to exploit natural resources, they produced value, benefits, and utility, and hence, IV appeared. Therefore, IV can be expressed as a function with human activities and natural resource conditions:

$$I = R \times H \tag{2.2}$$

Human activities can be further detailed. In general, human activities include inputs that can help increase the value, benefits, and utility of natural resources, including capital input (K), labor input (L) and overall technological advancement (T). They can be expressed using the following equation:

$$H = K \times L \times e^{T} \tag{2.3}$$

where the overall technological advancement is an enhancer. IV exists with or without technology, which serves only to provide additional improvements. Therefore, $T \geq 0$. Similarly, without additional cost, optimization or resource allocation through better management could also help increase resource value, benefits, and utility. If this factor is considered, it overshadows the intensity of overall technology advancement. Management improvements could help optimize the combination of labor, capital, and equipment, which, while relevant to technology, would be helpful to list separately given the actual situation. Therefore, optimized management (M) is included in Eq. (2.3), obtaining:

$$H = K \times L \times e^{(T+M)} \tag{2.4}$$

Then, the elasticity coefficient is incorporated and additional adjustments are made to change the function of the IV theory as follows:

$$I = R \times L^{\alpha} \times K^{\beta} \times e^{(T+M)} + \delta \tag{2.5}$$

where α and β are elasticity coefficients of capital input (K) and labor input (L), respectively, and $0 \leq \alpha \leq 1$ and $0 \leq \beta \leq 1$. No elasticity coefficient is identified for resource conditions (R), an index variable, and δ is the error coefficient.

Set $\mu = e^{(T+M)}$, where the function resembles a Cobb-Douglas (C-D) production function proposed by C. W. Cobb and P. H. Douglas in 1928 in an attempt to address the relations between input and output [1, 2]. The C-D production function improves the general production function and holds an important position in theoretical research and practice in quantitative economics or econometrics [3, 4]. Holding other conditions constant, its mathematical model is as follows:

$$Y = A_0 L^{\alpha} K^{\beta} \mu \tag{2.6}$$

where Y is total yield, A_0 is overall technology level of year 0, L is labor input, K is capital input, α is the elasticity coefficient of labor output, β is the elasticity coefficient of capital output, μ represents random interference, and $\mu \geq 0$.

The C-D production function assumes that changes to total yield are the result of changes only to labor and capital, and that labor and capital are used at the same intensities each year. Therefore, cyclical fluctuations in yields are not considered in this function [5]. There are flaws in the C-D production function, including the following: (1) Production is the result of scale expansion, without considering the effect of technological advancement. In addition, knowledge, skills, and experience of workers and managers are expected to improve, and the use of plant houses, equipment, capital, and technologies is expected to become increasingly rational; thus, total yield changes over time given that advancements in technology vary over periods. (2) It does not consider the effect of natural conditions or social and political factors on production activities. Many improvements have been proposed to address this issue, for example, by incorporating the missing factors into the function. Many production functions are based on the C-D function [6, 7], such as the constant elasticity of substitution (CES) production function developed by Arrow et al. [8]. This function appears to be more complex but is theoretically better than the C-D production function, described as follows:

$$y = A[\alpha L^{\rho} + \beta K^{\rho}]^{1/\rho} \tag{2.7}$$

where α is the labor distribution ratio indicating the labor intensity of a specific technology; β is capital distribution ratio indicating the capital intensity of a specific technology; $\alpha + \beta = 1$; and ρ is the elasticity of substitution.

Taking into consideration changes to the elasticity of substitution, all other production functions can be regarded as variations of a CES production function, which therefore has a much wider scope of applications [9]. Furthermore, it is possible to prove that the C-D production function is a special case of the CES production function [10]. For CES production functions, the elasticity of substitution for labor α and capital β are correlated with the technology coefficient *K/L* as follows:

$$L \cdot K = \left[\frac{\beta P_K}{\alpha P_L}\right]^{1/(1+\rho)} = \left[\frac{\beta P_K}{\alpha P_L}\right]^{\sigma} \tag{2.8}$$

The results of CES calculations are more accurate than those of the variable elasticity of substitution (VES) and therefore better reflect the size of the elasticity [11, 12]. In addition, the production function changes along with technological advancements. In order to more accurately reflect the substitutability of the factors, Revanka proposed the VES production function in 1971. Both CES and VES are monotonic functions. To provide an elasticity of substitution that is a non-monotonic function, Fare and Yoon argued the WDI production function. However, measuring the parameters of the WDI production function proves to be an obstacle to its application [13].

The production function theories show that in the process of using land to produce products and services necessary for human society, certain relations of substitutability between land, capital, and labor exist. By increasing capital and labor inputs, less land could be consumed for given products to satisfy the growing physical and cultural demands of human society. People have been using labor and capital as substitutes of land; in other words, we have been trying to increase total product per unit of land to satisfy the growing physical and cultural demands of human society by increasing the variable inputs. Essentially, this is a process of intensive land use.

As a matter of fact, intensification is the increase of intensity through a number of approaches, such as improving technology and management, increasing labor and capital inputs, and optimizing structures and spatial distributions. These factors are inter-substitutable, meaning that the substitution of one with another could help achieve intensive use.

With statistics-based regression analysis, we can obtain the optimal labor input (L*) and optimal capital input (K*) per unit of land [14]:

$$L^* = \sqrt[\alpha+\beta-1]{\alpha^{\beta-1} K^{\beta} / \beta^{\beta} A L^{\beta-1} Y} \tag{2.9}$$

$$K^* = \frac{\alpha L}{\beta K} L^* \tag{2.10}$$

The extent of intensive land use can be reflected with intensive land use coefficient E:

$$E = \frac{A L_0^{\alpha} K_0^{\beta}}{A L^{*\alpha} K^{*\beta}} = \left(\frac{L_0}{L^*}\right)^{\alpha} \left(\frac{K_0}{L^*}\right)^{\beta} \times 100\,\% \tag{2.11}$$

where K_0 and L_0 represent capital and labor inputs per unit of land with a given purpose. E is positively correlated with capital and labor inputs and, hence, the extent of intensive land use [15, 16].

In summary, we have identified the following identities for the IV theory:

(1) Because the IV theory is concerned with the actual intensity of resource use, the IV should be larger than 0.
(2) The IV is a variable with a changing value depending on period and location.
(3) As IV may arise from the interaction between human activities with different resources, it has a wide range of forms. In other words, IV has different meanings and forms for each resource and economic activity.
(4) The IV calculation may entail as many samples as possible, because it needs to apply probability as well as statistics knowledge.
(5) IV models are just abstract summarizations of extremely complex human activities. In practice, different conditions should be added to make sure that these conditions fit the reality of human activities. In the meantime, it is necessary to keep these conditions in mind when analyzing the intensification of human activities.
(6) The IV models reflect the LDR. Therefore, an IV reflects a continuous dynamic instead of an unchanging process of human activities.
(7) Each factor of the IV model can be divided infinitely, allowing for the use of infinitesimal analysis.

2.3 IV Hypotheses

While development and exploitation of natural resources generate economic benefits, excessive development has resulted in excessive consumption of resources, which, in turn, has caused a decline of product or yield and irreversible degradation of the ecological environment. Thus, the ideas of conservation and intensive use of natural resources have been proposed. The IV theory was developed in the background of mankind's exploitation of natural resources. In other words, IV would not exist without the development and exploitation of natural resources. Exploitation results in consumption or quality degradation of natural resources. With technology, however, people restore their ability to generate benefits. Therefore, the hypotheses of IV theory include:

(1) There are natural resources available, that is, $R > 0$;
(2) There are human activities affecting natural resources and generating benefits, value, and utility, that is, $I > 0$;
(3) There are changes to technologies that help continuously generate benefits, value, and utility from natural resources, that is, $T \geq 0$;
(4) There are changes to management ability that help continuously generate benefits, value, and utility from natural resources, that is, $M \geq 0$.

2.4 Intensive IV Functions

IV means the value, benefits, or utility per unit of natural resources. Using Q as the value, benefits, and utility of total product and S as the quantity of resources, the IV function can be expressed as follows:

$$I = \frac{Q}{S} \tag{2.12}$$

In line with the function models of IV theory, we focus our discussions on two different scenarios of resource conditions.

(1) Fixed Resource Conditions

The effect of fixed resource conditions on the IV in different stages remains the same. In this scenario, the value of R is 1, and the IV function can be simplified as follows:

$$I = L^{\alpha} \times K^{\beta} \times e^{(T+M)} + \delta \tag{2.13}$$

For example, consider a case study of intensive use in a particular region. If the total volume of resources is kept constant and no significant change occur to resource quality and other attributes, this function can be used to measure the extent of intensive use.

(2) Variable Resource Conditions

Variable resource conditions have different effects on the IV in different stages. In this scenario, different values are assigned to R for calculation. Because it is impossible to obtain quantitative resource conditions, assessments are made on the suitability of the resources, and the result is used as the value for R. Then, the IV function changes to the following equation:

$$I = RL^{\alpha}K^{\beta}e^{(T+M)} + \delta \tag{2.14}$$

Function (2.14) is referred to as the basic function of IV.

Generally, resource conditions of any region are variable. Therefore, to simulate the IV function over different periods, we can use the following:

$$I = R(\mathrm{t})L^{\alpha}K^{\beta}e^{(T(t)+\mathrm{M}(\mathrm{t}))} + \delta \tag{2.15}$$

or

$$I = R(\mathrm{t})e^{(T(t)+\mathrm{M}(\mathrm{t}))}\left(L^{\alpha} \times K^{\beta}\right)^{1/\rho} + \delta \tag{2.16}$$

In the event that more factor inputs are required, the following function is acceptable:

$$I = R(t)e^{(T(t)+M(t))}(\alpha_1 K^{\rho} + \alpha_2 L^{\rho} + \cdots + \alpha_n M^{\rho})^{1/\rho} + \delta \tag{2.17}$$

Variables in these IV models should have different values depending on specific targets of research and purposes of resource utilization. Instead of fixed values, they should have variable values depending on the actual situation and the purpose of the study. For example, a variable could be the economic value created per unit of construction land, the agricultural product generated per unit of farming land, or the aquatic breeding output per unit of water area. Resource conditions could imply any one or more land, air, water, and mineral resources. Capital and labor input are mutually substitutable depending on the specific target of evaluation. For example, metrics used for an intensive land use evaluation of one particular development zone in China could include land use status, benefits, and management performance. In this case, management performance is integrated into T, whereas land use status and benefits are categorized into capital input (K) and labor input (L), and the function is changed into a model better suited to intensive land use evaluation for development zones in China [17].

2.5 IV Curve

Given the limited nature of land resources, our goal is to maximize the efficiency of land use, which can be achieved with one premise—intensive use is usually connected to high performance. Intensive land use is a dynamic, relative concept specific to a particular region and a particular time, and it is the process of

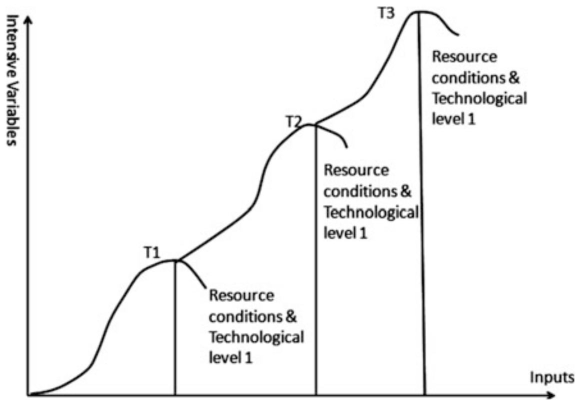

Fig. 2.1 LDR under changing technology conditions

continuously improving the efficiency of land use to obtain satisfactory economic, social, and ecological benefits through rational planning, optimization and sustainable growth, additional inputs, and better management while meeting the requirements of regional development and maximizing economies of scale and the clustering effect under current conditions. The intensities of labor, capital, and technology inputs per unit of land are metrics to measure the extent of intensive land use. Factors that affect the efficiency of land use include land supply, cost, usage and location, technology, market capacity, land-related speculation, taxation, policies, and systems. Higher intensity does not necessarily mean higher efficiency. In reality, maximal intensity is not an exclusive goal, and an adequate intensity is a better objective for ensuring maximization of land use efficiency.

One of the main theoretical bases of intensive use is the LDR, meaning that at the point of diminishing returns, additional inputs to land would result in zero MP and maximal total product. Intensity of land use reaches its peak at this critical point, which is also known as the intensity margin of land use. Throughout its history, mankind has been progressing along a journey toward this critical point. Today, LDR has become a shadow law that exists in our mind, even though in reality, it is non-existent.

LDR is a component of the IV theory, implying here that with given production technologies and all other factor inputs kept constant, the additional input of a single factor would result in increasingly less incremental product after a certain point. According to the IV theory, resource conditions and technologies are constantly changing, and the balance and substitutability among factors of production change as well. As resource conditions and technologies change, marginal returns of inputs change accordingly, as shown in Fig. 2.1.

With resource conditions and technologies kept constant, an increase of a single input would result in the same total product, MP, and LDR curves. When resource conditions and technologies change, total product peaks and continues to increase, while MP declines to a negative level before increasing again. In reality, as

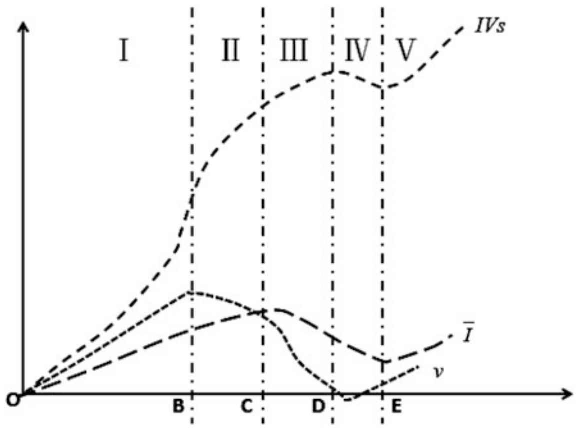

Fig. 2.2 Development stages of IV

advances in human civilization have been driving the evolvement of technologies and resource conditions, the MP curve would bottom out before it actually drops to zero.

Based on this LDR diagram, we can obtain the IV curve as shown in Fig. 2.2. Five stages for IV exist depending on the developments of MP v and AP $\bar{I}$.

(I) v increases (before reaching its peak) and $\bar{I}$ increases; this is a stage of low intensity of use;
(II) v declines and $\bar{I}$ continues to increase (before reaching its peak); this is a stage of medium intensity of use;
(III) v declines (before dropping to zero) and $\bar{I}$ declines; this is a stage of intensive use;
(IV) v is negative; regardless of the state of $\bar{I}$, this is a stage of excessively intensive use;
(V) v bottoms out and rises above zero and $\bar{I}$ increases; this is a stage of post-intensive use, after which another round of use would begin under new conditions (as shown in Fig. 2.2).

According to these classifications, the elasticity coefficient is obtained through fitting. Adjustments are made to keep technologies and other conditions constant, while capital and labor inputs increase separately to enable identification of specific stages and analysis of the status of intensive land use.

The IV curve integrates LDR and intensification into a single model, expanding static LDR to dynamic contexts and driving the development of the original theory. IV applies to all land use cases, and represents the overall land use situation within the society.

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