THE UNIVERSITY OF CALGARY

THE FALLING RATE OF PROFIT

IN A CAPITALIST SOCIETY

By

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ABSTRACT

The historical evolution of economic thought is characterized by an attempt to identify the mechanisms through with the income of an economy is distributed among the social classes of a society - in accordance with private ownership of the means of production and labour. In this context, the objectives of this study are as follows:

Firstly, to investigate the classical theories of income distribution with particular reference to the intertemporal behaviour of the rate of profit generated in a predominantly agricultural economy;

Secondly, to develop an analytically accurate representation of an economy based upon Sraffa's model of the economy - postulating production of commodities by means of commodities and labour;

Thirdly, to investigate Georgescu - Roegen's discussion of resource scarcity in the context of the laws of thermodynamics, specifically, the Entropy Law;

Fourthly, to analyze the impact of the interaction of the material environment with the production process, upon the maximum rate of profit attainable in a predominantly industrial economy;

Finally, it is concluded that the classical prediction that the rate of profit generated in a predominantly

agricultural economy tends toward zero is reaffirmed in an industrial capitalist economy - upon recognition of resource scarcity. More specifically, it is shown that the tendency for the rate of profit to approach zero, over time, is observed in both an agricultural and industrial economy. As a result, the "dismal" classical prediction with respect to the long run unsustainability of a capitalist system remains relevant today.

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DEDICATION

To my mother, Rose White, in appreciation of her endless love, guidance and support.

and

To my husband, Marco, for his understanding, encouragement and unfailing confidence.

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CHAPTER ONE

INTRODUCTION

The historical evolution of economic thought is characterized by attempts to identify the mechanisms through which the income of an economy is distributed among the social classes of a society - in accordance with private ownership of the means of production and labour. While the theoretical foundations and models employed in this analysis have undergone transformations, over time, income distribution theories can generally be classified under two headings - classical and neoclassical.

The classical school of thought is characterized by simple, intuitive discussions of the determinants of income distribution, postulating that the production of a predominantly agricultural based society is distributed in accordance with relatively qualitative considerations such as the productive efficiency of land and the subsistence requirements of the labour force. That is, classical economists, Ricardo in particular, argue that the income of the economy is distributed to three productive sectors - landlords, labourers and capitalists - in the form of rent, wages and profits respectively. More importantly, however, classical theories suggest that the intertemporal

behaviour of these distributive shares is characterized by a gradual decline in the rate of profit - the relative return to capital employed in production - and an increase in the relative shares of rental and wage income. More specifically, Ricardo argues that, with the advance of society, diminishing returns to land make it increasingly difficult to obtain a given quantity of real output, measured in terms of corn chosen as numeraire, with the application of a fixed quantity of resources in production. As a result, as increasing quantities of land and labour are necessarily incorporated into the production process a greater proportion of total output must be distributed in the form of rent and corn wages, leaving a smaller share of income for the capitalist class.

The classical theories, while giving minimal consideration to the impact of technological progress, conclude that response to the diminishing rate of profit takes the form of expansion of the absolute scale of production via the application of more hands to more land area. However, as production expands, operation of diminishing returns at the extensive and intensive margin causes quasi - rent on higher quality land to increase which, when coupled with the growing labour force, reduces the output residual to be distributed as profits.

In summary, it is the unavoidable operation of diminishing returns at both the extensive and intensive margins which fuels the classical prediction that the rate of profit attainable within the economy has a tendency to diminish over time. The classical theorists argue, therefore, that over the long run, continuous capital accumulation and growth are not sustainable and the capitalist system - or any system operating in accordance with a profit motive - is unable to maintain itself.

The classical long - run predictions with respect to the intertemporal behaviour of the rate of profit generated in the economy are dismissed by the neoclassical school of thought for the following reasons. Firstly, the arguments put forth by Ricardo do not fit neatly into the myopic, mechanical and isolated models which characterize neoclassical economics and, hence, lack empirical verifiability. Secondly, the operation of these predictions is often perceived to be too far in the future to merit further consideration. Furthermore, the advance of industrial society has brought with it new , more interesting theoretical challenges, forcing the perceived importance of theories based on agricultural societies into the background.

The neoclassical theories of income distribution reject the classical arguments and propose that the distribution of income within an "industrial" capitalist society is

determined by the marginal productivity of factors employed in production - specifically labour and capital. However, the operation of the neoclassical models in isolation from the material environment results in policy recommendations which condone continuous and unharnessed growth and capital accumulation. Furthermore, the static and mechanical underpinnings of these theories suggest that their accuracy and validity is questionable.

Neither the classical nor neoclassical schools of thought provide analytically accurate representations of the economy. While the classical school fails to provide an analytical framework within which to perform the analysis, the neoclassical school erroneously dismisses the relevance of the material environment to the production process and discounts the importance of long run analyses. As a result, the extant income distribution theories must be perceived only as a stepping stone to the development of an analytically superior representation of the capitalist economy - particularly the production system - which recognizes both the role of the material environment and the long run implications of the model.

Sraffa's model of the economy - postulating the production of commodities by means of commodities and labour - adapted so as to conform to existing data techniques, provides the framework within which a superior analytical

representation of the economy and income distribution theories are developed. It is shown that the classical economist's prediction that, in the progress of society, the rate of profit generated in the capitalist economic system declines, remains relevant in the modern industrial economy.

While the catalyst for the classical forecasts rests in the operation of the principle of diminishing returns to agriculture, the industrial analogy is found in the operation of the laws of thermodynamics - particularly the Entropy Law. More specifically, the laws of thermodynamics provide the mechanism through which the interaction between the production process and the material environment can be incorporated into an accurate representation of the production system. The Entropy Law dictates that all existence is characterized by a continuous, irrevocable and unavoidable qualitative degradation of the finite store of matter and energy. Consequently, Georgescu - Roegen's postulate that the economic process is entropic leads to the conclusion that the natural and production induced operation of the Entropy Law results in a gradual increase in the material and labour intensity of the production process. Finally, the incorporation of these occurrences into the revised Sraffian model, leads to the conclusion that the maximum rate of profit attainable within a production

system - consistent with a given technique of production and relative pricing solution - declines over time.

In summary, therefore, although the income distribution theories of the classical economists presuppose a predominantly agricultural society, the inter-temporal predictions with respect to the profit share of income remain applicable in an industrial society - upon the development of an analytically accurate representation of the production process.

The object of this thesis is threefold. Firstly, the investigation of classical theories of income distribution with emphasis on the determinants of the relative shares of rent, wages and profits. Secondly, the development of an accurate representation of the economy which is conducive to the incorporation of the role of the material environment with the production process. Finally, the investigation of the role of the material environment in the production process and the analysis of the distribution of income as determined by this model. These objectives are achieved in the following manner.

Chapter Two discusses Ricardo's theory of income distribution with particular reference to the determinants of the distributive shares of rent, wages and profits, as well as, the Classical perception of the intertemporal behaviour of these shares. Furthermore, it is shown that

the qualitative nature of the material environment, through the operation of the principle of diminishing returns to agriculture, is the determinant of the falling rate of profit.

The first part of Chapter Three outlines Sraffa's representation of the production process as an alternate to the unidimensional models of neoclassical economics. However, Sraffa's model is only a stepping stone to an accurate analytical model of the economy, which is both theoretically valid and suited to application. Consequently, further consideration is given to the requirements of the analytical specification of the production system with particular reference to the inadequacies of Sraffa's model. The second part of Chapter Three, therefore, modifies Sraffa's representation of the production processes of the economy so as to increase the theoretical validity and set the foundation for later analysis.

In Chapter Four, the analytical model of the production system - as an aggregation of individual production processes - and the implicit wage - profit function - specifying the relationship between the rates of profit and wages simultaneously attainable in the system - are derived.

Chapter Five introduces the laws of thermodynamics as discussed by Georgescu - Roegen, as the underlying indicators of the qualitative nature of the material environment.

Secondly, the effect of the operation of the Entropy Law on the production system developed in Chapter Four - with particular reference to the parameters of wage - profit function - is investigated. Thirdly, it is shown that the entropic process results in the need for increasingly labour and material intensive techniques of production merely to maintain a given absolute level of production. Finally, it is concluded that the unavoidable operation of the entropic process causes the maximum rate of profit attainable within the capitalist system to decline. The implications of this conclusion are then discussed.

CHAPTER TWO

THE CLASSICAL THEORY OF DISTRIBUTION

The valuation and distribution of the production of a capitalist economy are questions which have occupied the thoughts of intellectuals throughout the history of economic analysis. Both their determinants and role in the long run operation and sustainability of the system have, however, received varying degrees of emphasis. As early as the 1800's, classical economists such as West, Ricardo and Malthus investigated the returns of production to the three sectors or classes of society - labourers, landlords, and capitalists. Although it is agreed that in a agriculturally based capitalist economy production is divided among these sectors in the form of wages, rent and profits , the measurement of these income forms is not universally agreed upon.[1] However, the main focus of classical teachings is on the analysis and explanation of the distribution of the income of an economy and the behaviour of the relative shares of rent, wages, and profits over time. The growth of the neoclassical and

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[1] O'Brien suggests that classical theorists employ five different theories of wage determination, four theories of profit determination and disagreed on the measurement and source of rent. (D. P. O'Brien, The Classical Economists, Oxford: Clarendon Press, 1975, pp. 111 - 124.)

Keynesian schools has led to a dismissal of many of the classical school's arguments and a shifting theoretical emphasis to continuous and unconstrained growth with the distribution of the economy's produce being determined by marginal productivity theories and the free market forces.

Although the theories of the 18th and 19th century economists may have lacked empirical validity at the time, it appears that their teachings are rapidly regaining relevance as the economy approaches the limits of it's sustainability. As a result, unlike our predecessors, we can no longer ignore the concepts of diminishing returns and theories of distribution as taught by David Ricardo.[1] The future success of economics as a science rests in its adaptability to changing world conditions and its ability to modify the theoretical foundation so as to acknowledge the rapid, continual and potentially devastating depletion of our resource base. However, before we can modernize the classical teachings, we must develop an understanding of the relevant issues as taught by David Ricardo in his theory of income distribution.

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[1] Giovanni A. Caravale and Domenico A. Tosato, Ricardo and the Theory of Value, Distribution, and Growth, London: Routledge and Kegan Paul, 1980, p. 3.

THE PRINCIPLE OF DIMINISHING RETURNS

Ricardo is often credited with the independent discovery of the principle of diminishing returns.[1] However, the use of the term "Ricardian land" to describe or imply diminishing returns at both the extensive and intensive margins is a misnomer. The concept itself does not originate within Ricardo's works, but rather, is discussed in varying degrees of detail by writers such as Sir Edward West, Trotter, Torrens, and Malthus. West, in his "Essay on the Application of Capital to Land" provides an extensive analysis of the concept - to which Ricardo does not give credit, but rather acknowledges as being in agreement with his position.[2] Therefore, it is somewhat misleading if not erroneous, to credit Ricardo for the discovery of a theory which actually pervaded the thought and teachings of the time. In his introduction to

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[1] William D. Grampp. "Ricardo and Malthus." The Journal of Economic History, vol. 41, no. 2, 1981, p. 421.

[2] Ricardo, in a letter to Malthus, suggests that "Mr. Edward West ... speaks in favour of my opinions ... because they are similar to his own ... I find his views agree very much with my own" (Piero Sraffa. The Works and Correspondence of David Ricardo, Cambridge: Cambridge at the University Press, 1951, vol. vi, pp. 179 - 180.)

Ricardo's "Essay on Profits", Sraffa suggests that :

> pamphlets by Ricardo, West, Malthus, and Torrens all had in common the principle of rent based on diminishing returns ... 1

Similarly, Jacob Hollander in his introduction to West's "Essay" quotes Cannan as follows:

> ... it is impossible to read West's pamphlet without seeing the form in which the law of diminishing returns ... are far more due to (Sir Edward West) than is imagined.2

Finally, Hollander suggests that:

> Sir Edward West's pamphlet of February 1815 is famous for its formulation of the principle of diminishing returns (allowing for both extensive and intensive margins) ... 3

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1 Piero Sraffa. The Works and Correspondence of David Ricardo, vol. IV, p. 6.

2 Sir Edward West. The Application of Capital to Land, ed. Jacob H. Hollander, Baltimore: John Hopkins Press, 1903, p. 6.

3 Samuel Hollander. The Economics of David Ricardo, (Toronto: University of Toronto Press, 1979, pp. 60 - 61.)

SIR EDWARD WEST AND THE PRINCIPLE OF DIMINISHING RETURNS

Sir Edward West describes the "chief object" of his Essay on the Application of Capital to Land as the presentation of the principle of diminishing returns, which he defines as follows:

> in the progress of the improvement of cultivation the raising of rude produce becomes progressively more expensive or, in other words, the ratio of the net produce of land to its gross produce is continually diminishing.[1]

In general terms, these diminishing returns are argued to be a result of the need to resort to land of lesser quality and to more intensively cultivate land which is currently employed in production.[2] There are a number of West's arguments, however, which merit further discussion.

Firstly, West argues that "in the progress of cultivation" capital employed must necessarily generate a positive return in the form of profits, or there will be no incentive to

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[1] Where gross produce is defined as the whole produce without any reference to the expense of production. Net produce is defined as that which remains of the gross produce after replacing the expense of production. (Sir Edward West, The Application of Capital, p. 90.)

[2] George J. Stigler. "The Ricardian Theory of Value and Distribution," The Journal of Political Economy, vol. 60, no. 3, June 1952, p. 196.

cultivate in a market economy where production decisions are made in accordance with profit maximizing criteria. The essential argument is, however, that the rate of return on capital employed diminishes as the absolute produce generated by a constant application of capital declines.[1] In order to acknowledge that both labour and capital are employed in agricultural production, West generalizes his argument as follows:

> Each additional quantity of work[2] bestowed on agriculture, yields an actually diminished return and ... the whole of work bestowed on agriculture in the progress of improvement yields an actually diminished proportionate return.[3]

Secondly, it is the fertility of the soil which provides the impetus for West's principle of diminishing returns in agriculture. West distinguishes between two forms of

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[1] In keeping with Adam Smith, Edward West argues that although division of labour can have a positive impact on agricultural productivity, specialization of labour and the introduction of machinery can not be carried as far in an agricultural setting as in a manufacturing environment. (Sir Edward West, The Application of Capital, p. 14.)

[2] West comments that labour's productive powers should be measured by the final product or "effect produced" rather than the effort expended in production so as to eliminate qualitative differences in both labour skill and land fertility.

[3] Sir Edward West, The Application of Capital, p. 12.

diminishing returns - those at the intensive margin and those at the extensive margin. The former, diminishing returns at the intensive margin, are experienced when the same piece of land is more intensively cultivated, while the latter, diminishing returns at the extensive margin, occur as lower grades of land are incorporated into the cultivation process. Each of these are discussed below.

As the scale of the economy expands, the most fertile and conveniently located pieces of land are the first to be cultivated.[1] However, as population pressures increase, land of lower quality and poorer location is necessarily incorporated into the production process. As a result, even though the same quantity of work is expended on both qualities of land, the less fertile land provides a lower absolute return.[2]

Diminishing returns at the intensive margin, however, refers to the situation where "a quantity of work extracts from the soil a gradually diminishing return".[3] West suggests that the existence of diminishing returns at the intensive margin is verified by the natural tendency to resort to

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[1] West, however, does not rule out the possibility of "artificial regulations of society" interfering with the adoption of the most fertile land first. (Sir Edward West, Application of Capital, p. 14.)

[2] Sir Edward West, Application of Capital, p. 13-14.

[3] Sir Edward West, Application of Capital, p. 15.

cultivating land which is lesser in quality. For example, he concludes that:

> ... the very fact that in ... the progress of society new land is brought into cultivation, proves that additional work cannot be bestowed with the same advantage as before on the old land.1

Furthermore, it is only when the returns to cultivation at the intensive margin - i. e. increasing cultivation of the same piece of land - fall below the returns to cultivation at the extensive margin - i. e. adopting a new, lower quality, piece of land for cultivation - that the new piece of land will be adopted into the production process. More specifically, West argues:

> ... generally, if the best land already in cultivation will not return so much to the additional capital as to the capital already bestowed on it, by any great difference, such additional capital will not be expended on the best land, but on that next in quality to the best, and which from the infinite number of gradations of the quality of the soil, must be removed at the least possible distance from the best.2

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1 Sir Edward West, Application of Capital, p. 14.

2 Sir Edward West, Application of Capital, p. 15

RICARDO AND THE PRINCIPLE OF DIMINISHING RETURNS

David Ricardo devotes little time to the discussion of the principle of diminishing returns to land, but, rather, chooses to accept the prevailing opinions as being similar to own. In both his Essay on Profits and Principles of Political Economy Ricardo makes reference to the concept, the main purpose of which is to employ it in his definition of rent and as justification for his theory of distribution particularly, the falling rate of profit and other conclusions emanating from this theory.

Ricardo alludes to the principle of diminishing returns as early as 1811 in his analysis of Bentham's currency papers as follows:

> ... the same labour employed on double the quantity of equally good land ... will produce a greater return ... founded on the decreasing power of the land to produce in proportion to the labour and capital employed on it.1

However, this is only a passing comment which does not receive further formal explanation until 1815 with the publication of the Essay on Profits. Ricardo argues that

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1 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. III, p. 287.

in order to analyze the rate of profit it is necessary to discuss "the principles which regulate the rise and fall of rent; as rent and profits ... have an intimate connexion."[1] Therefore, Ricardo hardly refers to diminishing returns as such, but rather, discusses reductions in productivity in the context of rent generation. More specifically, Ricardo argues that:

> In the first settling of a country rich in fertile land, and which may be had by anyone who chooses to take it, the whole produce, after deducting the belongings to cultivation, will be the profits of capital and belong to the owner of such capital without any deduction whatever for rent ... after all the fertile land in the immediate neighbourhood of the first settlers are cultivated, if ... more food will be required, and it can only be procured from land not so advantageously situated ... by bringing successively land of a worse quality into cultivation, rent will rise on land previously cultivated.[2]

Ricardo's use of the principle of diminishing returns is much more obvious in his Principles where he

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[1] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. III, p. 9.

[2] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. III, pp. 13 - 14.

recognizes and refers to the inequality of produce which can be obtained from successive applications of capital and labour on existing or newly adopted pieces of land. More specifically, Ricardo suggests that it is the variable quantity and quality of land which generates a payment for its use. Furthermore, Ricardo argues the following

> ... it is only ... because ... in the progress of population, land of an inferior quality, or less advantageously situated, is called into cultivation, that rent is ever paid for the use of it.1

Finally, like West, Ricardo's writing alludes to the ability to cultivate land at both the intensive and extensive margins. However, he does not distinguish between diminishing returns at these margins in as clear a manner as West does. More specifically, Ricardo discusses two types of margins as follows:2

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1 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, pp. 70 - 71.

2 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. III, p. 71.

> It is often, and, indeed, commonly happens that before No. 2, 3, 4, or 5, of the inferior lands are cultivated,[1] capital can be employed more productively on those lands which are already in cultivation.[2] It may, perhaps be found that by doubling the original capital employed on No. 1, though the produce will not be doubled,[3] will not be increased by 100 quarters, it may be increased by eighty five quarters, what can be obtained by employing the same capital on land No. 3.[4]

In summary, the principle of diminishing returns plays a prominent role in the teachings of David Ricardo. However, it is analyzed only to the extent that it facilitates the explanation and analysis of rent generation. It is not emphasized in either Ricardo's Essay or Principles as a concept which is important in its own right, but rather as a stepping stone to the more stimulating and relevant issue of income distribution. Ricardo appears to view the concept as an empirical phenomenon which can be used as a tool of reflection. Nevertheless, the magnitude of Ricardo's predictions requires that the principle of diminishing returns and the prominence of its role in classical distribution theory be given full recognition.

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[1] Cultivation at the extensive margin.

[2] Cultivation at the intensive margin.

[3] Diminishing returns at the intensive margin.

[4] Diminishing returns at the extensive margin.

RICARDO'S THEORY OF DISTRIBUTION

As briefly mentioned in the introductory comments to this chapter, the focus of the classical economists, Ricardo in particular, is to explain the determination of the distribution of the income of a capitalist system among the various classes of the society. The analytical discussion, however, does not stop at this point, but, rather, extends to an analysis of the intertemporal behaviour and distribution of the relative shares of production. Ricardo prefaced his Principles of Political Economy and Taxation by stating that:

> ... in different stages of society the proportion of the whole produce of the earth which will be allotted to each of (its) classes, will be essentially different ... To determine the laws which regulate this distribution is the principle problem in Political Economy.[1]

Ricardo's theory of distribution is the subject of a great deal of criticism and debate since its publication in Principles. It is suggested that the inability of Ricardo's interpreters to reach agreement upon many of the relevant issues is due to "the peculiarity of some of the concepts which he used which are not always defined in an unambiguous

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[1] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I , p. 5.

way"[1] Hollander introduces his extensive analysis of "The Economics of David Ricardo" as follows:

> Unfortunately, in many cases ... it is with 'Ricardo-like' models rather than with 'the economics of Ricardo' that the interest lies ... amongst historians of economics, who are of course profoundly concerned with the historical Ricardo, there is a lack of consensus regarding the distinguishing features of Ricardo's theoretical structure.[2]

A complete presentation of the various arguments surrounding the issue of distribution is beyond the scope of this work. Rather, a discussion of Ricardo's general theory of distribution and some of the more interesting conclusions is presented. As stated by Samuelson, "the reader should of course be warned that any simple codification of the classical economists' discursive writings must be an oversimplification."[3]

David Ricardo provides both a clear and extensive discussion of the distribution question in Principles of

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[1] Luigi Pasinetti, "A Mathematical Formulation of the Ricardian System", The Review of Economic Studies, vol. 27, no. 74, 1960, p. 78.

[2] Samuel Hollander, The Economics of David Ricardo, (Toronto: University of Toronto Press, 1979, p. 3.)

[3] Paul A. Samuelson, "The Canonical Classical Model of Political Economy", Journal of Economic Literature, vol. 16, no. 4, December 1978, p. 1415.

Political Economy and Taxation which is an aggregation and extension of his earlier writings. Although Ricardo's arguments are proposed in the context of an agricultural setting, he does extend his conclusions to the relationship between the rate of profit generated in both the agricultural and manufacturing sectors. The main assumptions and conclusions made with respect to the question of income distribution are located within three chapters of his text - "On Rent", "On Wages", and "On Profits". Generally, Ricardo argues that the produce of the earth is both derived from the efforts of and distributed among three different classes of the economy - labourers, landlords, and capitalists - in the form of wages, rents and profits, respectively.1

Kaldor suggests that this theory of distribution rests upon the application of two principles - a marginal principle and a surplus principle. Firstly, payments to landowners in the form of rent are solely attributable to the marginal principle - diminishing returns to agriculture. Secondly, the surplus principle serves to define the share of profits as the residual after landlords and labour have received

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1 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 5.

their share of production. The determinants of each of the income forms are discussed below.[2]

The Ricardian Theory of Rent

Ricardo defines rent as that "portion of the earth's produce which is paid to the landlord for the use of the original and indestructible powers of the soil".[1] As previously mentioned, the payment of rent necessarily flows from the operation of diminishing returns to agriculture and should not include any payment of interest or profit on capital employed in production. Ricardo argues that in the early stages of society, when the most fertile pieces of land are readily available and accessible for cultivation, rent is not generated. This is due to the fact that additional quantities of capital and labour can be applied in production yielding equal returns in the form of total product. Consequently, Ricardo postulates that the payment made for the use of a particular piece of land necessarily increases as cultivation is extended at either the intensive or extensive margins. The magnitude of this payment is argued to be

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Review of Economic Studies, vol. 7, no. 3 , 1955 - 1957, p. 85.

[1] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 67.

equal to the difference in produce obtained from the "employment of two equal quantities of capital and labour".1 Therefore, if we assume that in the progress of society, land is successively incorporated into production in order of quality2 - from superior to inferior - the rent payment to higher quality lands must continually increase as the difference in productivity expands.

It must be emphasized, however, that the productivity of labour and capital employed in production remains constant. As a result, it is the varying qualities of land which causes the net productivity of the system as a whole to diminish.

The Ricardian Theory of Wages

The second form of income distribution, as put forth by Ricardo, is the payment to labour in the form of wages. It is important to note that Ricardo distinguishes between two forms of wage payments: the natural price of labour and the market price of labour, both of which are expressed

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1 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, pp. 71 - 72.

2 Jeffrey T. Young, "Entropy, Scarcity and Neo-Ricardianism", Journal of Post Keynesian Economics, vol. 6, no. 1, Fall, 1983, p. 83.

in terms of "food, necessaries and conveniences essential from habit which money will purchase."[1]

Firstly, the natural price of labour is defined as "that which is necessary to enable labourers to subsist and perpetuate their race".[2] More specifically, Ricardo assumes that the subsistence wage rate is dependent upon the price of "food, necessaries and conveniences, (which are) essential to him from habit"[3] and therefore represents a culturally determined level of subsistence rather than a biologically or physiologically determined absolute minimum. The market price of labour, however, is defined as the actual payment received for effort expended in the production process and is determined by the natural operation of the forces of demand and supply.[4] Ricardo argues that, in the long run, the market price of labour tends toward the natural price of labour. However, during the progress of society, the market price will not always coincide with the long run equilibrium or subsistence level. The magnitude of the

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[1] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 93.

[2] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 93.

[3] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 93.

[4] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, pp. 93 - 96.

deviation is argued to be a function of the forces of demand and supply and a determining factor in the growth rate of the population. That is, when the market price of labour exceeds its natural price, as a result of an excess demand for labour, the condition of the labourer is such so as to enable him to support a growing family. On the other hand, a surplus of labour will tend to force the market price toward its long run equilibrium at the subsistence wage, thereby increasing poverty and reducing the population's ability to maintain itself.1

As for the behaviour of this income share over time, Ricardo extends a number of conclusions. Firstly, it is argued that the natural price of labour will have a tendency to increase during the advance of society due to the increased cost of producing food and necessaries. The natural increase in the price of these commodities arises from the operation of the principle of diminishing returns in agriculture requiring increasing quantities of capital and labour inputs in order to obtain equal quantities of output. More specifically, Ricardo argues that "the same cause which raises rent, namely, the increasing difficulty of providing an

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1 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 94.

additional quantity of food with the same proportional quantity of labour, will also raise wages".1

Secondly, in the short run, the market price of labour is expected to fluctuate around the natural price of labour as a result of capital accumulation which generates a demand for labour. Ricardo argues that although the long run tendency for the market price of labour is toward some non - physiologically determined level of subsistence, capital accumulation, especially during the early stages of society2 can cause the market price to exceed the natural price of labour for an extended period of time. The length of time over which this surplus can be sustained is dependent upon the responsiveness of the population to greater than subsistence wages. As society advances however, capital accumulation diminishes, leading to a reduction in the excess demand for labour and forcing the market price of labour downward.3

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1 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 102.

2 During the initial stages of society, labour employed in agricultural is highly productive as a result of the abundance of fertile soil. Therefore, incentive exists for capital accumulation at a rate whereby the growth of the demand for labour exceeds the growth rate of the labour supply. (Piero Sraffa, The Works and Correspondence of David Ricardo, vol. 1, p. 98).

3 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, pp. 94 - 101.

The Ricardian Theory of Profits

Ricardo defines profits as the payment made for the use of capital employed in agricultural production. Ricardo concludes that rent is assumed to be the intramarginal surplus generated in the progress of society, and labour's share of production, i.e. wages, are determined by some socially specified level of subsistence combined with the forces of demand and supply. Therefore, the capitalist's share of income, in the form of profits, is determined as the residual of produce after payment is made to labour and landlords. More specifically, Ricardo defines the profits of stock in agriculture as "the remaining quantity of produce of the land, after the landlord and labourer are paid (which) necessarily belongs to the farmer (capitalists)."[1]

It is obvious that the determination of the share of profits in accordance with Ricardian theory, is a relatively simple and unchallenging procedure. However, it is the behaviour of the profit rate over time which is perhaps the most interesting aspect of Ricardo's theory of distribution. Given that diminishing returns to land cause both the shares of rent and wages in production to increase, as society

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[1] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 112.

advances the relative share of profit must necessarily decline.[1]

Perhaps the most controversial aspect of Ricardo's analysis of distribution, is the proposed relationship between the rates of profit earned in the agricultural and manufacturing sectors of the economy. Although Ricardo's theory of distribution focuses on an agricultural setting, he does argue that the rate of profit in the manufacturing sector is determined by the distribution of income, particularly in the form of wages and profits, in the agricultural sector.[2] The degree to which these two rates of profits are related is the subject of extended discussions and debates.

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[1] An important assumption underlying the theory of a falling rate of profit is that the farmer can not pass on the increased cost of production to the consumer by raising the price of his product. If the commodity is a major component of the wage basket, any increase in the price at which the commodity is sold will cause labour to demand higher money wages in an attempt to maintain their real incomes. As a result, the farmer will still earn the same real value of profits. (Piero Sraffa, The Works and Correspondence of David Ricardo vol. I, pp. 113 - 114.)

[2] This relationship is discussed by Sraffa in terms of basic and non basic commodities. More specifically, it is only those commodities which enter directly or indirectly into the production of all other commodities which are determinants of the relative pricing solution. Consequently, the production of agricultural sector is analagous to Sraffa's basic commodities while the manufacturing sector produces nonbasic commodities.

Hollander has distinguished between three Ricardian theories of profit, each of which differs only with respect to the degree to which the agricultural rate of profit determines the rate of profit in other sectors. The first, 'strong proposition' is contained within Ricardo's earlier writings. The main argument proposed by Ricardo is that "it is the profits of the farmer which regulates profits of all other trades".[1] Secondly, a more 'sophisticated variation' of Ricardian profit theory, as proposed by Hollander, is that "the state of agricultural productivity on the margin of cultivation is the unique determinant of the general profit rate - insofar as corn is the sole wage good".[2] Finally, the 'weaker proposition' is contained within the "Principles" in the following form : "the state of agricultural productivity exerts the influence on the general profit rate, but not to the exclusion of other forces".[3]

Regardless of which of the above propositions are accepted, there are three mechanisms by which the rate of profit in agriculture can influence the rate of profit in other sectors of the economy - increasing wages, increasing costs of inputs into the production process, and as a result

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[1] Piero Sraffa, The Works and Correspondence of David Ricardo vol. VI, pp. 103 - 104.

[2] Samuel Hollander, The Economics of David Ricardo, p. 138.

[3] Samuel Hollander, The Economics of David Ricardo, p. 138.

of capital flows across sectors. Firstly, Ricardo argues that as the cost of production increases in agriculture - in consequence of the operation of the principle of diminishing returns - the money wage of labour increases, in order for labour to maintain it's real wage at subsistence. More specifically, Ricardo argues that as society progresses, diminishing returns to agriculture require that more labour be employed in the production of an equal quantity of corn, causing corn to increase in price. Given that the natural price of labour is dependent upon the price of necessaries, wages in all sectors of the economy should increase.[1] Just as this reduces the rate of profit in agriculture, the rate of profit in manufacturing is also expected to decline.[2] Furthermore, Ricardo suggests that there are

> few commodities which (are) not more or less affected in their price by the rise of raw produce; because some raw material from the land enters into the composition of most commodities.[3]

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[1] The degree to which wages incease in response to higher prices depends upon its importance in the wage basket.

[2] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 110.

[3] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 117.

Therefore, it is suggested there are two ways in which diminishing returns in agriculture can cause the cost of production in manufacturing to increase - increased wages and an increased cost of raw materials or inputs.

In summary, profits in both the agricultural and manufacturing sectors of the economy are argued to decrease as labour demands compensation, in the form of higher wages, for higher food prices and higher prices of necessaries other than food which are contained in the wage basket.[1]

The third mechanism through which the rate of profit in agriculture is believed to influence the rate of profit in manufacturing is analagous to the concept of entry and exit in a neoclassical perfect competition setting. More specifically, Ricardo suggests that "it (is) through the inequality of profits that capital moves from one employment to another".[2] Therefore, any substantial difference in profit rates across the sectors of the economy will give rise to a flow of capital from the sector which is earning a relatively lower rate of profit to that which earns a relatively higher rate of profit. The flow of capital between sectors in this manner is argued to continue until the profit rates in

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[1] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 118.

[2] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 119.

all sectors are in conformance. For example, if the rate of profit earned in the manufacturing sector exceeds that in the agricultural sector, there will be a flow of capital from the latter to the former. However, as applications of capital are removed from land, the operation of diminishing returns - in reverse - will cause the rate of profit in the agricultural sector to increase. Similarly, the addition of capital to the manufacturing sector may cause the rate of profit to decline. This flow of capital will only continue until the rates of profit earned in all sectors "conform to some general level."[1]

In summary, Ricardo employs the principle of diminishing returns so as to perform his analysis of the general profit rate. In doing so, he concludes that in the advance of society, it is inevitable that the general rate of profit - not only that in the agricultural sector - will decline. As a result, continuous capital accumulation and growth are not sustainable.

A GRAPHICAL REPRESENTATION OF RICARDIAN DISTRIBUTION THEORY

Numerous authors have attempted to graphically depict the relationships between the profit rate, rent and wages,

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[1] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 119.

as well as Ricardo's general solution to the distribution problem. Samuelson's "Canonical Classical Model of Political Economy" presents the theory of distribution and growth as discussed by Adam Smith, David Ricardo, Robert Malthus, and John Stuart Mill. The Samuelson model of classical distribution theory presupposes the following:

Firstly, output is derived from "a production function involving land input and a dose of labor-cum-capital input".1 Secondly, this output is distributed between rent and the "combined return to the composite dose of labour-capital".2 Thirdly, there is both a short run and long run solution to the problem. The long run equilibrium is consistent with the minimum required returns to labour and capital- which are just enough to allow the population and capital stock to be maintained but not promote any net growth. Samuelson proposes that the classical distribution theories can be graphically represented in the following manner.

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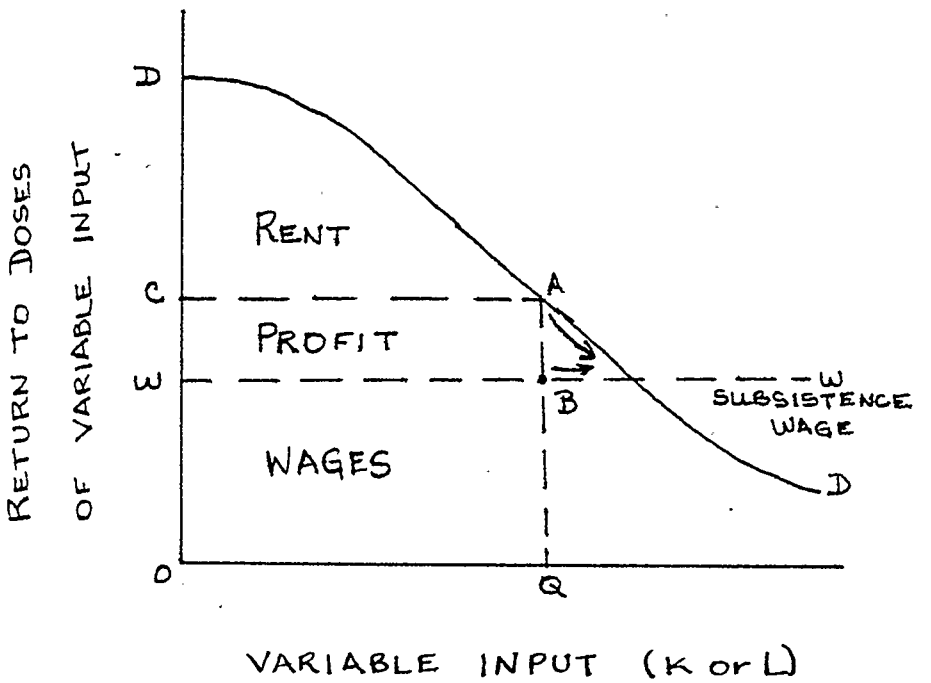
1 Paul A. Samuelson, The Canonical Classical Model, p. 1416.

2 Paul A. Samuelson, The Canonical Classical Model, p. 1416.

FIGURE 1

THE CLASSICAL DISTRIBUTION OF INCOME



As shown in Figure 1, the graphical representation of income distribution in two dimensional space requires that product per unit of combined capital/labour input be measured on the vertical axis while the horizontal axis measures units of combined capital/labour input to a fixed "land profile".[1] It can be argued that two dimensional representations of the production process oversimplify the

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[1] Kaldor, et al, have oversimplified this analysis by considering labour as the only variable input to land.

analysis as they obscure the concept of varying qualities of land, therefore, confusing the issue of diminishing returns at the extensive and intensive margins. For example, if the graph is intended to represent application of successive doses of capital/labour input to a single piece of land, the declining product curve, DD, is representative of diminishing returns at the intensive margin. On the other hand, if the analysis is applied to land in a more general and all encompassing sense, the product curve, DD, is indicative of diminishing returns at both the intensive and extensive margins. Samuelson defends this analysis by arguing that at low levels of capital/labour application a surplus of high grade (quality) land exists, and therefore, less favourably situated plots of lower quality land will not be cultivated. Rather, existing plots of land will be cultivated more intensively. However, as the capital/labour doses increase, less favourable grades of land will be incorporated into the prouction process.1

For any quantity of work such as Q, we can readily determine the distribution of total output, OQAD, among landlords, labour and capitalists. Firstly, in accordance with Ricardian theory, landlords' share of output in the form of rent is determined by the productivity of the last

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1 Paul A. Samuelson, The Canonical Classical Model, pp. 1417 - 1418..

application of the capital/labour input to land, area ACD. Secondly, the distribution of the remaining output between labourers and capitalists (farmers) depends upon the assumptions made with regard to the speed at which the population adjusts or responds to an excess of market wages over their long run subsistence level. Samuelson, for simplicity, assumes instantaneous adjustment, thereby concluding that the distribution of income to labour does not deviate from the subsistence level. In accordance with this assumption, labour's share of total product will be equal to area OQBW. Finally, the residual of total output, therefore, will be distributed to the owners of capital in the form of profits equal to area WBCA.[1]

The short run generation of profits in excess of that required to maintain the existing capital stock, provides incentive for capital accumulation, growth, and the employment of additional units of the variable input to land. As indicated by the arrows in Figure 1, the principle of diminishing returns causes the distribution of total output to change as an increasing share of income is distributed in the form

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[1] The reader should note that the magnitude of this residual is dependent upon our previous assumptions regarding the short run wage rate. If the short run market price of labour exceeds the natural or subsistence price, as a result of the market forces of supply and demand, a larger portion of output will be distributed to labour. (Paul A. Samuelson, The Canonical Classical Model, pp. 1426 - 1427.)

of rent, and the shares of profit and wages to approach their long run minimum levels.

Long run equilibrium is attained and stable, or steady-state growth experienced at that level of output where capital and labour are just earning their minimum required returns. At this point land rent is maximized and both capital and labour earn only enough to maintain and reproduce themselves. Samuelson recognizes that the minimum rate of profit has been set at zero by many theorists. This is theoretically valid, however, only if allowances have been made for depreciation and replacement of the existing capital stock.[1] The assumption of a minimum profit rate greater than zero is consistent with Ricardo's theory of distribution, as he recognizes, in his Principles, that "(money) wages can never rise so high so as to leave no portion of (the total product after payment of rent) for profits."[2]

CLASSICAL DISTRIBUTION THEORY AND TECHNICAL PROGRESS

It is often suggested that the classical economists do not give adequate consideration to the impact of technical

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[1] Paul A. Samuelson, The Canonical Classical Model, pp. 1416 - 1419.

[2] Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 115.

progress and improvements in agriculture on the productive capacity of the economy. Samuelson claims that:

> the classicists earned ... Carlyle's title of the dismal science precisely because their expositions erred in overplaying the law of diminishing returns and underplaying the counterforces of technical change.1

Others have gone as far as to say that the classicists give no recognition to the possibility of technical change. This, however, is an overstatement. Sir Edward West comments on the ability to innovate or incorporate technical progress in the form of "subdivision of labour and machinery" into the agricultural process. However, he dismisses the possibility of this technical improvement to offset or more than compensate for the reduced productivity resulting from the operation of the principle of diminishing returns. West argues that if either of the aforementioned situations are experienced, the rate of profit will continually increase as society and production expands, causing population and capital accumulation to grow at an unbounded, increasing rate.2

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1 Paul A. Samuelson, The Canonical Classical Model, p. 1428.

2 Sir Edward West, Application of Capital, pp. 16 - 20.

Similarly, David Ricardo acknowledges that two types of improvements in agriculture are possible - land saving and labour saving - both of which will reduce the cost of obtaining raw produce and dampen the tendency for the share of rent in income to increase. The former type of improvements are argued to include crop rotation, better inputs such as fertilizer, and tend to improve the "productive powers of land". On the other hand, the latter refers to adoption of machinery, which improves the productive powers of labourers, allowing the same level of production to be attained with less labour inputs.1

Furthermore, in Principles, Ricardo recognizes that the rate of profits - after rent and wages are distributed - is dependent upon the productivity of resources employed on intramarginal land. This productivity is argued to be determined by soil fertility, capital accumulation, and the "skill, ingenuity and instruments employed in agriculture."2

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1 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 80.

2 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 5.

More specifically,

> The natural tendency of the profit rate ... to fall ... is checked at repeated intervals by improvements in machinery, connected with the production of necessaries, as well as by discoveries in the science of agriculture which enables us to relinquish a portion of labour before required, and, therefore, to lower the price of the prime necessary of the labourer.1

However, Ricardo is of the opinion that improvements in agriculture will only temporarily offset the natural tendency for the price of agricultural produce to increase.2 Ricardo dismisses the long run sustainability of this counteracting effect on the grounds that eventually the total output will be consumed by the share of landlords and labourers, leaving a zero profit rate and halting all capital accumulation.3

More importantly, however, the classical response to the falling rate of profit takes the form of an expansion of the absolute scale of production supported by a larger labour force. That is, rather that adopting technologies which improve the productivity of land so as to sustain an

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1 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 120.

2 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 93.

3 Piero Sraffa, The Works and Correspondence of David Ricardo, vol. I, p. 121.

absolute level of production, this goal is accomplished through the expansion of the scale of production which necessarily requires the additional employment of labour. Unlike their classical counterparts, current day economists assume that there exists an infinite supply of technological advances which will counteract the diminishing productivity of both labour and capital. However, the operation of the principle of diminishing returns naturally results in a reduction in the quantity of output obtained with a given quantity of capital and labour. Furthermore, the growing labour force and accompanying increased wage share, reduce the share of output to be distributed in the form of profits. Clearly, Neoclassical economists dismiss the conclusions of classical income distribution theories and reject the importance of a falling rate of profit on the long run sustainability of the system.

Perhaps both West and Ricardo prematurely rejected the importance of technological improvements, thereby contributing to the subsequent lack of acceptance on the part of their fellow theorists. In the early stages of society, the principle of diminishing returns is not as apparent and the ability of technological progress to increase productivity is stronger than in the later stages.

CONCLUSION

In conclusion, the classical theory of income distribution is determined solely by the qualitative nature of the material environment. The direct consequence of the operation of the principle of diminishing returns at either the extensive or intensive margin is reflected in a gradual increase in the share of income which is distributed in the form of rent. However, given that the rate of profit earned in the economy is determined as a residual after rent and wages, the implicit consequence of this phenomenon is a tendency for the rate of profit to decline toward zero. Although the principle of diminishing returns is discussed in the context of a predominantly agricultural economy, its consequences, particularly the falling profit share, extend to other sectors of the economy. More specifically, the impact of the operation of the principle of diminishing returns is manifested in sectors which do not directly employ land in the production process, as a result of rising wages in the agricultural sector, rising costs of necessaries, i. e. food, and a flow of capital across sectors in response to unequal returns to capital investment. That is, the intertemporal distribution of income in the form of profits - throughout the economy - is dictated by and

necessarily accompanies the falling rate of profit earned within the agricultural sector.

Although the analyses of these economists and the recognition of the qualitative nature of the material environment of the production process are intuitively appealing, they lack analytical substance and the "dismal" forecasts emanating from these theories have resulted in their rejection by Neoclassical economists. Although current economists ignore many of the issues which classical economists discuss,[1] there is a growing renewed interest in diminishing returns and the theoretical teachings of classical economists, David Ricardo in particular. There is a growing awareness of the relevance of Ricardian models incorporating the impact of continual application of variable inputs of capital and land to a fixed resource base. Furthermore, Georgescu - Roegen's discussion of the Entropy Law[2] in the context of the economic process, provides strong analytical support for the conclusions of Ricardo and West. Therefore, models must be developed which recognize and incorporate these environmental constraints into theories of economic growth. The problem, however, rests in the identification of an industrial analogue to the Ricardian theory of

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[1] D. P. O'Brien, The Classical Economists, p. 136.

[2] The continual transformation of free into bound energy is both unidirectional and irrevocable.

diminishing returns, as well as, the provision of an analytical model which incorporates the qualititative nature of the environment. Young, in "Entropy, Scarcity and Neo - Ricardianism", suggests that the entropy law is analagous to the classical theory of diminishing returns - in an agricultural setting - and that "Sraffa's model is ideal to bridge the gap between entropy and economics via a revised 'classical law of diminishing returns'."[1] The remainder of this thesis will focus upon the incorporation of Georgescu - Roegen's observations with respect to the Entropy Law and the Sraffa pricing system, so as to analyze the impact of the production process on the sustainability of a predominantly industrial economy.

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[1] Young, Jeffrey T., Entropy, p. 86.

CHAPTER THREE

THE ANALYTICAL REPRESENTATION OF A PRODUCTION PROCESS

Classical economist's conclusions with respect to the effect of growth, in the absence of technological change, upon the distribution of income among the productive sectors of the economy have serious implications for the sustainability of the capitalist system. The conclusion that economic expansion is unavoidably accompanied by a gradual reduction in the rate of profit attainable in the system leads us to question the appropriateness of growth and economic models which condone continual and unharnessed expansion of both the absolute level of production and the productive capacity of the economy. Unfortunately, however, the analyses of the classical economists are restricted by the knowledge of their time and although stimulating, lack analytical substance. Whether the impact of a physically based scarcity is perceived, by current economists, to be too difficult to incorporate into economic models and theories or to be operative too far in the future to merit consideration is not as important as the fact that its role and significance in the productive process is, essentially, ignored. This is unfortunate, as it reduces the applicability and reliability

of the extant Neoclassical models and the policy recommendations which flow from these models.

The analytical appeal of mechanics and mathematics is a contributing factor to the development of models of the economy based upon unidimensional production functions which operate in isolation from the material environment and do not recognize the finite and qualitative nature of the resource base. It is suggested that Neoclassical production functions implicitly incorporate the classical concept of diminishing returns at the intensive marginl through the property of diminishing marginal productivity. However, the long run validity of these models is discredited by a rejection of resource scarcity and the accompanying operation of diminishing returns at the extensive margin.[2] Schumacher argues that this omission has led to the treatment of the material environment as an "expendable" rather than an irreplacable fixed capital and the erroneous perception that the "problem of production has been solved."[3] More specifically,

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[1] Young refers to this as "crowding in a confined space". (Young, Entropy, p.83.)

[2] Young, Entropy, p. 84.

[3] E. F. Schumacher, Small is Beautiful - Economics as if People Mattered. (New York: Harper and Row Publishers, 1973, p. 13.)

> The illusion of unlimited powers, nourished by astonishing scientific and technological achievements has produced the concurrent illusion of having solved the problem of production ... (However), our current methods of production are already eating into the very substance of industrial man ... (That is), the modern industrial system, with all its intellectual sophistication, consumes the very basis on which it has been erected. To use the language of the economist, it lives on irreplacable capital which it cheerfully treats as income.1

Given that one of the goals of economics as a science is the development of an accurate representation of the production processes within the economy, the inadequacies of the existing models suggest that alternate analytical tools be investigated. However, an accurate representation of the production process requires that three conditions be satisfied. Firstly, recognition of the relevance of the material environment in any description of the economy is essential. Secondly, the identification of a framework within which both the role of the material environment and its qualitative nature can be described. Finally, the development of models which facilitate the incorporation of the qualitative nature of the material environment, as well as, the interaction between the production process and that environment.

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[1] Schumacher, Small is Beautiful, p. 14, 20.

Young proposes that the movement toward the "solution of the production problem" is facilitated by consideration, in concert, of Sraffa's model of the economy outlined in Production of Commodities by Means of Commodities, and the laws of thermodynamics, in the context of Georgescu - Roegen's The Entropy Law and the Economic Process. Firstly, Young argues that the laws of thermodynamics, in analogy to the classical theories of diminishing returns, provide a structured description of the physical scarcity issue as classical diminishing returns are analagous to the entropic view of the economic process. More specifically, the laws of thermodynamics focus upon the diminishing quality of the natural resource base, a degradation process which occurs in historical time, and recognize that scarcity is a universal physically based phenomenon.[1]

Secondly, Young argues that the physical basis of the Sraffian representation of the production process of the economy - which postulates the production of commodities by means of commodities and labour - is conducive to the incorporation of both the finite and qualitative nature of the earth's resources. The relative pricing solution to the Sraffa model, modified so as to increase applicability, implicitly defines an associated wage - profit function

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[1] Young, Entropy, p. 85.

characterized by a "monotonically inverse relationship between the real wage and the rate of interest."[1] Furthermore, the operation of the Entropy Law, is reflected in increasingly material and labour intensive techniques of production which result in a contraction of the parameters of the wage - profit function for a particular technique of production and relative pricing solution. More specifically, in analogy to the classical theories of income distribution, the maximum rate of profit attainable within the system is predicted to decline over time. Consequently, it is proposed that Sraffa's model of the economy is the ideal tool to link classical theories of income distribution with the analytical description of modern industrial processes and the Entropy Law.

However, before we can investigate the impact of the operation of the Entropy law upon the sustainability of a predominantly industrial economy, we must discuss Sraffa's model of production.

PRODUCTION OF COMMODITIES BY MEANS OF COMMODITIES

Piero Sraffa, in his Production of Commodities by Means of Commodities, attempts to provide a theoretical

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[1] Cengiz Ozol, "Parable and Realism in Production Theory: The Surrogate Wage Function." Canadian Journal of Economics, vol. 17, no. 2, May 1984, p. 353.

framework in which to analyze the distribution of surplus output in the form of wages and profits, as well as, the impact of a change in the distributive shares on the relative pricing solution of the system. Some argue that the main purpose of Sraffa's book is to "show how one can construct a standard of value which is independent of the vagaries of demand and ultimately tastes."[1] However, Sraffa's discussion of a standard commodity arises from the need to find a numeraire against which commodity prices or exchange values can be compared. In fact, the only role which demand plays in Sraffa's model is to set the scale of production. In this context, the standard of value is required to be "invariant in price and value when the rate of profits and wages changes."[2]

It is often suggested that the susceptibility of Sraffa's model to misinterpretation and criticism hinders its acceptance and incorporation into economic thought. For example, Levine argues that "misinterpretation by others has played a part in impeding Sraffa's entry into the profession . . . (not to mention) his extremely compact expository

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[1] M. W. Reder, Review of "Production of Commodities by Means of Commodities: Prelude to a Critique of Economic Theory.", The American Economic Review, vol. 51, no. 4, p. 689.

[2] J. A. Kregel, Rate of Profit and Growth: Two Views., (London: MacMillan Press Ltd. , 1971, p. 18)

manner."[1] There are essentially four areas of debate, misunderstanding and contention with respect to Sraffa's model - the assumptions regarding returns to scale, the derivation of a numeraire commodity or standard of value, the role of consumer demand in the relative pricing solution, and finally, the price determining apparatus itself.[2] However, debates over these issues arise from a misunderstanding of the context of Sraffa's model and often take the form of discussion, with little, if any, analytical justification. Finally, Sraffa's model is quite narrow and is not well suited to dynamic theoretical analysis. As a result, this chapter is concluded by modifying the model so as to increase its applicability.

Sraffa's Production of Commodities by Means of Commodities presupposes an economy in which "all basic commodities appear as both inputs and outputs of the processes of production."[3] Sraffa's analysis progresses from subsistence economies characterized by single commodity producing industries, to surplus generating economies with

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[1] A. L. Levine, "This Age of Leontief ... and Who? An Interpretation." Journal of Economic Literature, vol. 12, no. 3, September 1974, p. 873.

[2] Levine, Age of Leontief, p. 877. and Edwin Burmeister, "A Comment on 'This Age of Leontief ... and Who?'." Journal of Economic Literature., June 1975, vol 13, no. 2, pp. 454 - 457.

[3] Kregel, Rate of Profit, p. 18.

"multiple - product" industries incorporating fixed capital and land. In this context, therefore, the classical "conception that production and not consumption is the primary motive force of activity is revived."[1] Furthermore, the model rests on supply - side determination of individual commodity prices and the resulting "exchange values" or relative price configurations. In keeping with classical tendencies, Sraffa postulates "interrelationships between elements of input and elements of output over the economy as a whole"[2] in such a manner that resulting price determinations would derive from production costs and supply side considerations.

In this context, therefore, consumer demand enters into the model of production and price determination only to the extent that it is

> reflected in the relative magnitudes of the scalars of the equations of production (and therefore), commodity prices are determined entirely independently of those relative weights and scalars ... provided that neither the techniques of production nor distributive shares change.[3]

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[1] P. R. Brahmananda, "Economics: The Sraffa Revolution - I." Indian Economic Journal, vol. 10, no. 3, January - March 1963, p. 267.

[2] Ronald L. Meek, "Mr. Sraffa's Rehabilitation of Classical Economics." Scottish Journal of Political Economy, no. 8, June 1961, p. 120.

[3] Levine, Age of Leontief, p. 879.

However, some critics argue that

> it is surprising that one can get a system of price determination without reference to final demand ... and (one) cannot find anything ... that justifies ignoring the influence of the commodity mix that consumers wish to have.1

Similarly, Reder argues that "a theory of price determination without demand functions ... is (not) satisfactory."2 Unfortunately, these comments are not developed into theoretically based arguments.

The Role of Returns to Scale Assumptions

Much of the misunderstanding surrounding Sraffa's arguments can be linked to the fact that there are a number of assumptions which are not explicitly mentioned within his text. It is suggested that "we plunge immediately into the argument without any preliminary discussion of assumptions and delimitations of topics."3 The "assumption" which receives the most attention from Sraffa's critics and

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1 R. F. Harrod, "Review of 'Production of Commodities by Means of Commodities'." The Economic Journal, vol. 72, no. 284, December 1961, pp. 785 - 787.

2 Reder, p. 693.

3 Joan Robinson, "Prelude to a Critique of Economic Theory." Oxford Economic Papers, vol. 13, no. 1, February 1961, p. 53.

supporters concerns the role of returns to scale within the model.

Sraffa's model is based on the analysis of an actual economic system, particularly the determination of the relative pricing structure which is generated by a given tableau of scalar inputs, producing a specific level and composition of output.[1] Furthermore, Sraffa is concerned with the analysis of the properties of an economic system which are insensitive to changes in scales or factors of production. As a result, the economic relationships discussed are only applicable to a specific time period and existing tableau of input/output data.[2]

Sraffa's model is often compared to a Leontief type of input/output analysis. However, this is slightly misleading as Sraffa does not "define the equivalent of input coefficients."[3] The generalization of Sraffa's representation of the economy is the result of modern theorists attempts to improve the applicability of the model and contributes to the debate over the role of constant returns

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[1] Levine, Age of Leontief, p. 875.

[2] G. C. Harcourt and Vincent G. Massaro, "Mr. Sraffa's Production of Commodities." The Economic Record, vol. 41, no. 91, p. 442.

[3] Richard E. Quandt, "Production of Commodities by Means of Commodities: A Review." Journal of Political Economy, vol. 69, no. 5, October 1961, p. 500.

to scale within the model. More specifically, Sraffa and others argue that any assumptions made with respect to returns to scale - whether diminishing, constant or increasing - are irrelevant to the analysis contained within Production of Commodities.[1] Furthermore, Sraffa's "snapshot" of the economy with respect to the total coefficients of production[2] is a static analysis concerned "exclusively with such properties of an economic system as do not depend on changes in the scale of production."[3] As a result, consideration of returns to scale need not enter into the analysis in any way whatsoever.

It is important to note, however, that once we attempt to transform Sraffa's system of production into a more generalized representation, based upon technical coefficients of production, returns to scale assumptions are essential so as to ensure comparability and consistency. In order to apply technical coefficients which define input requirements per unit of output in the analysis and comparison of relative price configurations and distributive shares, we necessarily

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[1] Piero Sraffa, Production of Commodities by Means of Commodities: Prelude to a Critique of Economic Theory, (Cambridge: Cambridge University Press, 1960, p. v) or Levine, Age of Leontief, p. 873.

[2] As opposed to unit coefficients of production which describe input requirements per unit of output.

[3] Sraffa, Production of Commodities, p. 5.

assume that those coefficients exhibit constant returns to scale properties. i.e. they are unchanging with respect to variations in the absolute levels of production.

NOTATION

Prior to presenting Sraffa's model of production and relative pricing solutions it is necessary to set out the relevant notation. The reader should note that the following notation is consistent with that used by Sraffa:

a, b, ... k: indicate the commodities produced within the system.

A, B, ... K: represent the quantity of commodities a, b, ... k, produced annually.

A_a, B_a, ... K_a: indicate the physical quantities of commodity inputs a,b, ... k, used annually in the production of output A of commodity a.

A_b, B_b, ... K_b: indicate the physical quantities of commodity inputs a, b, ... k, used annually in the production of output B of commodity b.

P_a, P_b, ... P_k: represent the values or prices of commmodities a, b, ... k, per unit.

L_a, L_b, ... L_k: represent the annual quantities of labour employed in each of the k industries. These values are expressed as a fraction of the total annual labour supply of the society so that:

$$L_a + L_b + \ldots + L_k = 1$$

r: represents the uniform rate of profit earned across industries.

W: represents the wage per unit of labour employed.

As briefly mentioned earlier, Sraffa's Production of Commodities by Means of Commodities can be perceived as an evolution from a simplistic and intuitively appealing representation of the economy to more realistic and abstract models. This progression is outlined below:

PRODUCTION FOR SUBSISTENCE

Sraffa begins his discussion by "considering an extremely simple society which produces just enough to maintain itself."[1] In this context, he assumes that each industry produces a single commodity from commodity inputs which it then exchanges for its input requirements at the end of the production season. Furthermore, the value of each commodity is determined by the cost of all commodities which enter into it's production.

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[1] Sraffa, Production of Commodities, p. 3.

Therefore, in general terms, this model can be represented with elementary linear algebra as follows:1

$$
\begin{aligned}
A_aP_a + BaPb + \ldots + KaPk &= APa \\
A_bP_a + BbPb + \ldots + KbPk &= BP_b \\
- - - - - - - - - - - - - - - - - - & \qquad (Ia) \\
A_kP_a + BkPb + \ldots + KkPk &= KP_k
\end{aligned}
$$

It should be noted that Sraffa recognizes that each commodity, a, b, ... k, does not necessarily enter into the production of every other commodity. Consequently, it is possible for one or more of the inputs represented by the left hand side of the production equations (means of production) to be equal to zero. For example, commodity 'a' need not directly enter into the production of final output B of commodity 'b', i. e. $A_b=0$. However, it may enter indirectly through its use as an input into the remaining means of production, (C_b, D_b, , ... K_b), of commodity 'b'.[2] Furthermore, as the system is only self - replacing, and no net product is generated, the final output or each commodity must not

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1 Sraffa, Production of Commodities, p. 4.

2 Sraffa, Production of Commodities, pp. 4 - 5.

exceed its total use as an input into each industry. As a result, we have the following condition on the system:[1]

$$\begin{aligned} A_a + A_b + \ldots + A_k &\equiv A \\ B_a + B_b + \ldots + B_k &\equiv B \\ - - - - - - - - - - - - - - - - & \qquad \text{(IIa)} \\ K_a + K_b + \ldots + K_k &\equiv K \end{aligned}$$

Therefore, the production equation for any specific industry, i.e. the k'th industry can be deduced from the sum of the k - 1 commodity producing industries. Furthermore, so as to make the above equation system determinate, Sraffa suggests that one commodity be "chosen as a standard of value and its price made equal to unity."[2] This has the further consequence of allowing the pricing solution to the system to be expressed in terms of relative prices or "exchange values". Finally, the simplest version of Sraffa's model is a determinate system with k - 1 independent equations and k - 1 unknown prices.

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[1] Sraffa, Production of Commodities, p. 4.

[2] Sraffa, Production of Commodities, p. 5.

PRODUCTION WITH A SURPLUS

The second, more realistic version of this model replaces the subsistence economy with one in which a surplus of products over means of production - commodities used up in the production process - is generated. In this case, the value of the total output of each commodity includes both the value of its inputs as well as a share of the value of the surplus product. The generalized version of an economy which produces in excess of "the minimum necessary for replacement"[1] is as follows:

$$\begin{aligned}
(A_aP_a + B_aP_b + \ldots + K_aP_k)(1+r) &= AP_a \\
(A_bP_a + B_bP_b + \ldots + K_bP_k)(1+r) &= BP_b \\
- & \qquad \text{(Ib)} \\
(A_kP_a + B_kP_b + \ldots + K_kP_k)(1+r) &= KP_k
\end{aligned}$$

At this point it is important to note that Sraffa assumes the existence of a uniform rate of profit across all industries. Although some argue that this is an oversimplifying assumption, it is supported as "a result toward which an actual economic system tends with the operation of long run competitive

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[1] Sraffa, Production of Commodities, p. 6.

forces."[1] Furthermore, failure to make such an assumption increases the number of unknowns and therefore complicates the analysis of the system in this form. However, if estimates of the rates of profit are known, they can be accepted as exogenous to the system, thereby reducing these analytical difficulties.

Finally, the dependence of the exchange value of each commodity on the exchange value of its means of production, imposes a restriction on the determination of relative prices without knowledge of the rate of profit generated in the system. More specifically, Sraffa argues that the surplus product can not be allocated across industries prior to the determination of the relative pricing solution of the system.[2] Similarly, the relative exchange value of each commodity can not be determined without knowledge of the uniform rate of profit generated in the production of that commodity and that which is incorporated into the price of its means of production. Consequently, "the distribution of surplus (across industries) must be determined through the same mechanism and at the same time as are the prices of commodities."[3]

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[1] Harcourt and Massaro, Mr. Sraffa's Production, p. 444.

[2] Harcourt and Massaro, Mr. Sraffa's Production, p. 444.

[3] Sraffa, Production of Commodities, p. 6,

Returning to the generalized form of Sraffa's second model of production. Unlike the simplest version, the final quantity of each commodity produced is no longer equal to the total physical units which are used up in production . Therefore, the equations (IIa) in the previously outlined system are replaced by the following conditions of production:[1]

$$\begin{aligned} A_a + A_b + \ldots + A_k &\leqslant A \\ B_a + B_b + \ldots + B_k &\leqslant B \\ - - - - - - - - - - - - - - - & \quad \text{(IIb)} \\ K_a + K_b + \ldots + K_k &\leqslant K \end{aligned}$$

It is apparent that it is no longer possible to deduce the production equation of any one industry from the sum of the inputs and outputs of the remaining industries. As a result, the system is comprised of k independent equations which determine k unknowns, specifically, k - 1 relative prices and the rate of profit.

At this point in the development of Sraffa's model of production, we must distinguish between two different types of commodities - basics and nonbasics. Sraffa defines basic commodities as those which enter directly or indirectly into the production of all other commodities. The prices of

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[1] Sraffa, Production of Commodities, p. 6

these commodities simultaneously determine and are determined by the price of their means of production. As a result, these commodities "play an essential role"[1] in the process of price determination. The emergence of nonbasic commodities on the other hand, is argued to be a direct consequence of the production of a surplus over replacement requirements . Sraffa tends to classify these commodities as "luxury items" and their identifying characteristic is that they do not enter into the production of all other commodities - either directly or indirectly. More specifically, Sraffa suggests that non - basic commodities "do not enter into production either as instruments of production or articles of subsistence."[2] As a result, these commodities do not impact on the determination of prices within the system.[3]

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[1] Sraffa, Production of Commodities, p. 7.

[2] Sraffa, Production of Commodities, p. 7.

[3] This distinction between commodity types is analagous to Ricardo's discussion of the relation between the agricultural and manufacturing sectors of the economy. More specifically, the agricultural sector's role in the determination of the general rate of profit is similar to the role of basic commodities in the determination of the relative pricing solution. Similarly, the rate of profit experienced in the manufacturing sector, being dependent upon it's counterpart in the agricultural sector is analagous to the Sraffa's concept of nonbasic commodites. This distinction is incorporated in the model developed at the end of this chapter throught the irreducibility requirement of the technology matrix A and the capital fund matrix B. (Ozol, Parable and Realism, p. 356.)

THE ROLE OF LABOUR IN THE PRODUCTION PROCESS

The third phase in the evolution of Sraffa's model of the economy involves an analysis of labour's role in the production process. Up until this point, it has been implicitly assumed that the wage paid to labour is set at some subsistence level, thereby incorporating labour as a means of production rather than a recipient of surplus production.[1] A more accurate definition of wages, however, recognizes that the payment to labour may exceed some predetermined minimum physical and social requirement,[2] thereby including both an element of subsistence and a share of the surplus generated in production.[3] The ideal generalized model, therefore, should incorporate labour into the production process at two separate stages. Firstly, as a constant component of the means of production and secondly, as a variable proportion of surplus output.[4] However, Sraffa

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[1] Sraffa assumes that the labour required in the production of commodities a, b, ... ,k (is) uniform in quality or that we can assume that "any differences in quality ... have previously (been) reduced to equivalent differences in quantity so that each unit of labour receives the same wage." (Sraffa, Production of Commodities, p. 10.)

[2] Sraffa, Production of Commodities, p. 33.

[3] Sraffa, Production of Commodities, p. 9. The reader should note the similarity to Ricardo's discussion of actual versus natural wage rates.

[4] Sraffa, Production of Commodities, pp. 9 - 10.

suggests this over complicates the analysis of the system and therefore assumes that "the whole of the wage (is) variable ... (and) paid post factum as a share of the annual product."[1]

The third generalized version of Sraffa's representation of the productive process is as follows:[2]

$$(A_aP_a + B_aP_b + \ldots + K_aP_k)(1+r) + L_aW = AP_a$$
$$(A_bP_a + B_bP_b + \ldots + K_bP_k)(1+r) + L_bW = BP_b$$
$$- \quad \text{(Ic)}$$
$$(A_kP_a + B_kP_b + \ldots + K_kP_k)(1+r) + L_kW = KP_k$$

It should be noted that the means of production in this model are no longer identical to those which are discussed in versions 1 and 2. Isolation of the subsistence wage and its combination with the variable portion of surplus production has the effect of reducing the absolute size of the means of production. More specifically, the absolute scale of inputs, $(A_a, A_b, \ldots, A_k;\ B_a,\ B_b, \ldots, B_k;\ \ldots\ldots;\ K_a, K_b, \ldots, K_k)$, employed in the first two versions of Sraffa's production model, exceed those in this, more

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[1] Sraffa, Production of Commodities, p. 10.

[2] Sraffa, Production of Commodities, p. 10.

comprehensive, version by an amount representative of the subsistence wage.

Consistent with versions one and two of the model, this third version is both self - replacing and surplus generating so that the following condition on production also holds:

$$
\begin{aligned}
A_a + A_b + \ldots + A_k &\leqslant A \\
B_a + B_b + \ldots + B_k &\leqslant B \\
- - - - - - - - - - - - - - - & \qquad \text{(IIc)} \\
K_a + K_b + \ldots + K_k &\leqslant K
\end{aligned}
$$

At this stage of the analysis Sraffa replaces the previously defined standard of value or numeraire commodity by a "composite commodity"[1] in terms of which both prices and the wage payment to labour are expressed. More specifically, Sraffa argues that national income can be defined as a "composite commodity" composed of the

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[1] Sraffa provides an extensive discussion of the derivation of this standard commodity. The most significant requirement being that its price by invariant with respect to changes in the distribution of national income in the form of profits and wages.

> set of commodities which are left over when from the gross national product we have removed item by item the articles which go to replace the means of production used up in all the industries.[1]

More specifically, Sraffa argues that the national income generated in the system should be set equal to unity and expressed as follows:

$$[A-(A_a+A_b+\ldots A_k)] \quad P_a$$
$$+ [B-(B_a+B_b+ \ldots +B_k)] \quad P_b$$
$$+ (K_a+K_b+\ldots K_k)] \quad P_b = 1$$

As a result, of the above mentioned modifications to the system of equations, the system is no longer determinate, moving with one degree of freedom. More specifically, the above production system possesses k + 1 equations describing the production process of each of the k industries and the national income, which determin k + 2 unknowns, specifically, k prices, the rate of profit - r, and the wage per unit of labour - W.

The solution to the system, therefore, can take the following two forms:[2]

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[1] Sraffa, Production of Commodities, p. 11.

[2] Levine, Age of Leontief, p. 874.

(1) Determination of a set of commodity prices and uniform profit rate which are consistent with the given scale and composition of output and a given wage rate.

(2) Determination of a set of commodity prices and wage rate which are consistent with the given scale and composition of output and a specified uniform rate of profit.

Although Sraffa initially chooses the wage rate as given he later concludes that the rate of profit is "susceptible of being determined from outside the system of production, in particular by the level of money rates of interest."[1]

THE EFFECT OF A CHANGE IN DISTRIBUTIVE SHARES

Sraffa extends his analysis to the investigation of the effect of reducing labour's share of national income on the pricing solution and the rate of profit - r. His conclusions are as follows:

1) The Rate of Profit

Firstly, when the total surplus production is distributed in the form of wages, i. e. W = 1, the rate of profit generated in the system is zero and the "relative values of commodities are in proportion to ... the quantities of labour which

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[1] Sraffa, Production of Commodities, p. 33.

(have) directly and indirectly entered into their production."[1] As a result, the system reduces to a pure labour theory of value as discussed by Marx. Alternately, when labour's share of surplus production is set at zero, i. e. W = 0, the rate of profit will be at a maximum - receiving the total share of national income. In this case, commodity prices are influenced by "their ratios of labour to means of production"[2] and no longer directly reflect the value of labour employed in their production. However, it is argued that

> it is always possible 'in principle', (to reduce commodity prices to labour values) provided that we know (the rate of profit) and the direct and indirect labour components of the commodity.[3]

Clearly, for a given level of surplus production or national income, the rate of profit generated in the system is inversely related to the share distributed in the form of wages. That is, as a greater (smaller) percentage of the national income is distributed to labour in the form of wages, less (more)is left to be distributed as profits. In Sraffa's derivation of a standard commodity, he concludes

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[1] Sraffa, Production of Commodities, p. 12.

[2] Harcourt and Massaro, Mr. Sraffa, p. 445.

[3] Harcourt and Massaro, Mr. Sraffa, p. 453.

that this relationship is linear and can be represented as follows:1

$$r = R(1-W)$$

where:

r = the uniform rate of profit across industries.

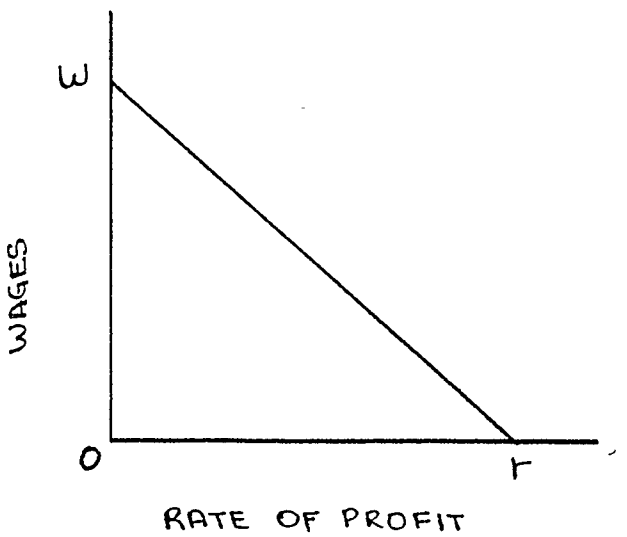
W = The wage rate.

R = The ratio of the value of net product to the value of the commodity means of prouction. The maximum rate of profit obtained when W =0.

This relationship can be shown graphically as follows:

FIGURE 2

THE SRAFFIAN WAGE - PROFIT RELATION



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1 Levine, Age of Leontief , p. 876.

2) The Relative Pricing Solution

Unfortunately, the relationship between distributive shares and the relative pricing solution to the system is not as clear cut. More specifically, as the wage share of national income changes, commodity prices must also change so as to maintain a uniform rate of profit across industries. Sraffa provides an extensive discussion of the impact of a change in the distribution of income between wages and profits on the relative pricing solution. Although we intuitively expect that as labour's share of income, in the form of wages , declines (increases), the relative price of commodities which are produced with a high degree of labour intensity will tend to decline (increase) as well. However, Sraffa argues that the direction of the price change is not so readily ascertainable, but, rather, is dependent upon the relative means of production in the industry in question, as well as the means of production of those commodity inputs. For example, a particular commodity may experience a drop in its relative price subsequent to a decline in the wage rate even though its means of production are relatively capital intensive. This situation occurs when the means of production of these commodity inputs are relatively labour

intensive.[1] Harcourt and Massaro discuss this problem as follows:

> When W is given a value less than unity, the entire national income no longer goes to wages, and exchange ratios are now influenced by a uniform rate of profits. Prices then vary according to the different ratios of labour to the means of production, with the modification that we must take into account the different ratios producing the means of production at each remove. For instance, in comparing the relative price movements of commodities 'a' and 'b', where 'a' is apparently more labour - intensive than 'b', we cannot immediately conclude that the price of 'a' will decrease relative to 'b' (following a decline in w) since the means of production producing commodity 'a' (and the means of production producing those means of production, and so on) may be highly commodity intensive; whereas the means of production producing commodity 'b' (and again the various means of production producing those means of production, and so on) may be of such a labour intensive nature as to offset or reverse the price movements initially expected.[2]

MODIFICATIONS TO SRAFFA'S MODEL

As mentioned previously, Sraffa extends and adapts his analysis to incorporate "further important characteristics

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[1] Sraffa, Production of Commodities, p. 13.

[2] Harcourt and Massaro, Mr. Sraffa, p. 445.

of actual economic systems"1 These modifications include the reduction of the means of production to their direct labour equivalents, consideration of industries of processes which produce more than one commodity as a final output, and, finally, the incorporation of fixed capital and land in the production process. Although each of these issues increase the reality of Sraffa's model, they also require increasing degrees of abstraction and are often characterized by theoretical errors.2

We are concerned with the investigation of the behaviour of the maximum rate of profit and wages attainable within the system over time. As a result, we will use Sraffa's simple model of single commodity producing industries outlined. However, in order to employ this model in general theorizing, it is necessary to impose some modifications. Firstly, "in order to facilitate mathematical exposition, it is convenient to rewrite Mr. Sraffa's model in the notation familiar from input output literature."3 More importantly, however, the theoretical base of the model must be defined and modified so as to ensure greater analytical accuracy. Georgescu-Roegen 's discussion of the analytical

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1 Harcourt and Massaro, Mr. Sraffa, p. 447.

2 Sraffa, Production of Commodities, p. 43n.

3 Edwin Burmeister, "On a Theorem of Sraffa." Economica, vol. 35, no. 137, February 1968, pp. 83 - 87.

representation of the production process provides the framework for this revision of Sraffa's model.

THE DEVELOPMENT OF AN ANALYTICAL REPRESENTATION OF A PRODUCTION PROCESS

In keeping with Georgescu-Roegen, it is necessary to define the qualities which must characterize an analytical representation of the production process.[1] Although economic theory is overloaded with models of production processes, the term "process" is not explicitly defined which results in a great deal of confusion. Consequently, it is essential that we lay our theoretical foundations firmly so as to ensure both accurate understanding and application of the subsequently developed models. This requires that we give consideration to the following issues.

Firstly, Change is the basis of all existence and its description and analysis are the driving forces behind any scientific investigation. To this date, economics as a science has chosen to recognize and investigate only those aspects of Change which fit neatly into the existing mechanical representation of the economy. The analytical representation

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[1] The reader should refer to Nicholas Georgescu-Roegen, The Entropy Law and the Economic Process, (Cambridge, Mass.: Harvard University Press, 1971), Chapter IX, pp. 211 - 275.

of the production process developed in Chapter 4 will allow for the incorporation of the underlying basis of Change - The Entropy Law. However, before we can do this, we must look more closely at the concept of Change.

The discovery and analysis of Change requires that we make some type of comparison between alternate states of existence. That is, we need something against which to compare the object of investigation, be it some type of control group or its nature in a previous time period. For the universe as a whole, there is no such comparative "other" and, therefore, in order to investigate Change we must look at individual components of the totality. Unfortunately, this immediately causes difficulty as there is no guide by which we can divide actuality and, in principle, there is no restriction as to where or how we define these partial processes. However, ad hoc division has little, if any, relevance to the issue at hand.[1] Consequently, each field of study defines partial processes in accordance with its own phenomenal domain. For economics, the "natural boundary of the economic process" is defined so as to facilitate the

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[1] Georgescu-Roegen, The Entropy Law, pp. 212 - 213.

analysis of production, consumption and income distribution.[1] As a result, "at any one time, the boundaries of the processes in which the economist is interested are drawn where the circulation of commodities can be observed."[2]

In actuality, however, the production process is characterized by elements which can not be classified as commodities proper. For example, flows across the boundary from the environment to the process include such items as solar energy, land and natural resources, while flows in the reverse direction include tired workers, used tools, and industrial waste. The difficulty associated with the quantification of these non - commodities complicates the analysis and, consequently, we must further assume that "the input and output elements (of a production process) exist in a finite number of discretely distinct and measurable qualities."[3]

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[1] Nicholas Georgescu-Roegen, "Process in Farming versus Process in Manufacturing: A Problem of Balanced Development." reprinted in Energy and Economic Myths - Institutional and Analytical Economic Essays (New York: Pergamon Press, Inc., 1976), p. 79.

[2] Georgescu-Roegen, The Entropy Law, p. 218.

[3] Nicholas Georgescu-Roegen, "Process Analysis and the Neoclassical Theory of Production." reprinted in Energy and Economic Myths - Institutional and Analytical Economic Essays, (New York: Pergamon Press, Inc., 1976), p. 40.

An Analytical Representation of Partial Processes

Now that we have an understanding of the manner in which we must carve up actuality, in order to study Change, we can proceed with our analytical description of these production/partial processes. The reader should keep in mind that the division of actuality into partial processes is a simplification and the effect of this disaggregation of totality must not be ignored.

Firstly, the division of actuality into analytical processes is characterized by two distinct components, the partial process itself, as discussed previously, and the environment specific to that process - the remaining portion of the total universe. Analysis requires that these pieces of actuality be separated by a boundary which contains an "arithmomorphic void". This requirement ensures that a happening or event is part of either the process or the environment.

Secondly, the analytical boundary of the production process must be defined with reference to both time and substance. Firstly, the boundary acts to separate the

process from the environment at all times.[1] Without a clearly defined analytical boundary, we do not have an analytical process. Therefore, identification of the process, is made with reference to the analytical boundary and any happening related to the process must be described in terms of the flows across the boundary from the environment to the process and vice versa.[2]

The second role of the analytical boundary is to dictate the duration of the process. More specifically, the boundary of the process specifies the "time moments at which the analytical process we have in mind begins and ends".[3] Given that we are concerned with the investigation of Change, we must put further restriction on the duration of the process. So as to ensure that we have taken into account all that has occurred within the process, it must begin at time $t(0) > -\infty$, and end at time $t(1) < +\infty$. Furthermore, the process itself is defined for a specific time interval only. That

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[1] Georgescu-Roegen comments on the possibility that the process may impact on its environment or frontier. This factual occurrence is outlined in Chapter 5, in the context of the Entropy Law. That is, in actuality, any productive process does effect the environment through a reduction in the amount of energy and matter available for use.

[2] Georgescu-Roegen, The Entropy Law, pp. 213 - 215.

[3] Georgescu-Roegen, The Entropy Law, p. 214.

is, "a process is inexistent before the origin of its duration (t=t(0)) and after the end of the duration (t=t(1))."1

Extant Descriptions of Production Processes

Traditionally, the analytical description of a process has taken one of the following two forms. Firstly, Leontief's input - output model of the economy impacts on the perception of the analytical process as being characterized and described by flow coordinates. More specifically, it is argued that a process can be described by the flow of commodities across the boundary of that process for a specific duration of time. That is, by recording the flow of commodities into and out of the process between time period t=t(0) and t=t(1). This is formalized by Koopmans as follows:2

> A process, P, is represented by a vector P(a1, a2, ... an), where ai represents the rate of flow per unit of time of each of the n commodities involved in the process. Negative values represent inputs into the production process and positive values represent outputs from the production process.

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1 Georgescu-Roegen, Process Analysis, p. 40.

2 Georgescu-Roegen, Process in Farming, pp. 80 - 81.

The alternate representation of the production process is referred to as the stock model. As the name implies, this model assumes that a complete representation of the partial process can be obtained by comparing the stocks of commodities inside the boundary of the process at two separate points in time. More specifically, the stock model requires that rather than observing what crosses the boundary of the partial process, the process can be observed and described by comparing two snapshots of the commodities contained withn the process - one taken at time t=t(0), the beginning of the process, and another taken at time t=t(1), the end of the process.1

Von Neumann formulated this model explicitly as follows:2

> A process, P, is represented by a two row matrix,
>
> $$P \begin{bmatrix} B1, B2, \ldots\ldots\ldots Bn \\ A1, A2, \ldots\ldots\ldots An \end{bmatrix}$$
>
> Where:
>
> Vector A represents the quantities of commodities existing at the beginning of the period during which the process is completed.

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1 Georgescu-Roegen, The Entropy Law, p. 219.

2 Georgescu-Roegen, Process in Farming, p. 81.

> Vector B represents the quantities of commodities existing at the end of the period during which the process is completed.

The representation of the production process in terms of commodity stocks, has been argued to be more comprehensive than the flow model, as the latter can be derived from the former, but not vice versa. However, the two models are neither distinctly separate nor equivalent. This misinterpretation stems from an inadequate understanding of the terms "stock" and "flow". More specifically, Georgescu-Roegen argues that

> Rather than two stocks and one flow, in the overwhelming number of the relevant cases, the true connection is between one stock and one flow ... (where) a flow is a stock spread out over a time interval.[1]

Consequently, neither model in isolation provides an adequate representation of the "happening" associated with the production process. For example, the stock model is not capable of distinguishing between a process which is merely replacing itself and one in which nothing has happened. That is, when vector A is equal to vector B we are not able to determine what, if anything, has taken place in the

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[1] Georgescu-Roegen, The Entropy Law, p. 223.

production process.[1] Similarly, recording the flow of commodities across the process boundary does not provide an indication of the size of the capital stock within the process. More specifically, "a flow does not necessarily represent either a decrease or an increase in a stock of the same substance."[2]

It is apparent, therefore, that a process can not be completely and accurately defined by either of the two models in isolation.

Sraffa's Model Revisited

Unfortunately, Sraffa's representation of the production process does not give explicit recognition to the difference between commodities which flow through the system as inputs into the production of the final output of each commodity and those which flow into the system as replacement of capital required to be maintained for production. For example, given Sraffa's example of a surplus generating economy with two industries, producing commodities as follows:[3]

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[1] Georgescu-Roegen, Process in Farming, p. 81.

[2] Georgescu-Roegen, The Entropy Law, p. 223.

[3] Sraffa, Production of Commodities, p. 7.

280 q. of wheat + 120 t. of iron ⟶ 575 q.of wheat

120 q. of wheat + 8 t. of iron ⟶ 20 t. of iron

The first industry uses 240 quarters of wheat to produce 450 quarters of wheat as final output. Sraffa viewed all commodities used in the production process as commodity inputs. However, we are now aware that some commodity inputs would be more accurately defined as a maintenance of capital or fund of commodity inputs. More specifically, the use of commodity 'i' in the j'th production process, where i=j, is not similar to the flow of other commodities into the j'th process. Of course, some portion of the iron input in the wheat production process[1] may not be used up completely in production, therefore also representing a fund of capital. This causes a theoretical difficulty for two reasons. Firstly, if the rate of profit is determined outside of the system and is applied as an estimate of the opportunity cost of capital, it should not be applied to commodity flows. Secondly, if the rate of profit is assumed to be determined within the system, by the techniques of production and an exogenously specified real wage rate, it must be evaluated in terms of capital requirements in isolation from the flows of commodities across industries. Therefore, Sraffa's model

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[1] That is, the flow of commodity 'i' into the j'th production process ($i \neq j$).

must be further modified so as to conform to the analytical representation of the economy in terms of flow and fund coordinates.

Flow Versus Fund Coordinates of Production

The specification of Sraffa's model in terms of flow and fund coordinates of production requires the following issues be taken into consideration.

Firstly, the commodities flowing across the process boundary, referred to as factors of production, can be classified under two headings. Fund coordinates, or agents of the process, provide the material base for production, while flow coordinates are used and/or transformed by the agents of production.[1] More specifically, the fund coordinates of the production process are those "elements that appear both as inputs and outputs ... those that enter and come out of the process in an economically if not physically identical form and same amount."[2] On the other hand, the flow coordinates of the production process are those which cross the boundary in one direction only, "an element that

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[1] Georgescu-Roegen, The Entropy Law, p. 230.

[2] Georgescu-Roegen, Process in Farming, p. 84.

is either only consumed[1] or only produced by the process."[2] Flow coordinates can be further reduced to inputs - those commodities which cross the boundary from the environment - and outputs - those commodities which cross the boundary from the process into the environment.[3]

Secondly, unlike the existing stock and flow models, the categorization of commodities as flow or fund coordinates does not restrict a commodity from being classified under both headings. Georgescu-Roegen provides a classic example of this relationship with the case of hammers used (as a fund element) to produce hammers (as a flow element). Similarly, in an agricultural setting, we have the case of clover seed (as a fund coordinate) used to produced clover seed (as a flow coordinate), as compared to clover seed (as a flow coordinate) in the production of clover fodder (as a flow coordinate).[4]

Thirdly, the process itself causes a qualitative degradation of the agents of production, or fund coordinates of that process. For example, the production of commodities

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[1] A commodity is consumed as opposed to used in a specific process if it cannot be directly related to the output of that process. (Georgescu-Roegen, The Entropy Law, p. 225.)

[2] Georgescu-Roegen, Process Analysis, p. 41.

[3] Georgescu-Roegen, Process in Farming, p. 81.

[4] Georgescu-Roegen, The Entropy Law, pp. 225 - 231.

simultaneously produces tired workers and used machinery. However, "an analytical picture in which the same worker (or same tool) is split into two elements would undoubtedly complicate matters beyond description."[1] In order to simplify the analysis of production processes, we must assume that the material fund coordinates of that process are maintained by flows of commodities and services from other processes and that the degradation of the labour portion of the fund coordinates is nonexistent.[2]

Fourthly, Georgescu-Roegen provides a classification of the basic flow and fund coordinates of a factory process as shown in Table 1:[3]

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[1] Georgescu-Roegen, The Entropy Law, p. 216.

[2] Georgescu-Roegen, The Entropy Law, p. 230.

[3] Georgescu-Roegen, Process in Farming, p. 93.

TABLE 1

COORDINATES OF A PRODUCTION PROCESS

FLOW COORDINATES		FUND (SERVICE) COORDINATES	
Inputs			
From Nature	R	Ricardian Land	L
From Other Processes		Capital Equipment	K
Current	i	Labour	H
Maintenance	m	Process Fund	F
		Stores	S
Outputs			
Product	C		
Waste	W		

Where:

Ricardian Land refers to the combination of "solar energy, air chemicals and land - space"[1]

Process Fund refers to "goods in process" at successive stages of the production process.[2]

Stores refers to commodity flow inventories.[3]

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[1] Georgescu-Roegen, Process in Farming, p. 83.

[2] Georgescu-Roegen, Process in Farming, p. 93.

[3] Georgescu-Roegen, Process in Farming, p. 92.

Consequently, we can describe any j'th production process of the economy in terms of the aforementioned elements as follows:1

$$C_j = P(R,i,m,w;\quad L,K,H,F,S)$$

The analytical representation of the economy, therefore, merely requires an aggregation of the individual production processes into two separate tableaus - one which measures flow coordinates and one which measures the fund requirements of the processes. For example, a given economy, surrounded by the natural environment, N, which produces three commodities C1, C2, C3, in three processes or production sectors, P1, P2, P3, and one consumption sector, P4, can be described as shown in Table 2:2

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[1] Georgescu-Roegen, Process in Farming, p. 95.

[2] Georgescu-Roegen, The Entropy Law, p. 254.

TABLE 2

PROCESS REPRESENTATION OF AN ECONOMY

FLOW COORDINATES

	P1	P2	P3	N	P4
C1	x1	-x12	-x13	*	-x14
C2	-x21	x2	-x23	*	-x24
C3	-x31	-x32	x3	*	-x34
R	-r1	-r2	-r3	r	-r4
W	w1	w2	w3	w	w4

FUND COORDINATES

	P1	P2	P3	N	P4
C1	X11	X12	X13	*	X14
C2	X21	X22	X23	*	X24
C3	X31	X32	X33	*	X34
F	F1	F2	F3	*	*
L	L1	L2	L3	*	L4
H	H1	H2	H3	*	H4

NOTE:

Every row in the flow coordinate matrix must sum to zero as any output of a process must be an input of one or all of the remaining processes or the consumption sector.

This matrix is defined for a specified duration of time - time t(0) to time t(1), e. g. the annual flow and fund requirements of the economy.

An Input - Output Model of the Economy

Unfortunately, the description of an economy via flow and fund tableaus, as outlined above, does not conform to the extant data collection techniques. As a result, the analytical representation of the economy developed thus far requires further modification.

Firstly, Georgescu-Roegen suggests that the flow coordinate tableau can be "simply transformed" into the input - output counterpart by "changing the sign of the ... flow coordinates."[1] However, there remains a significant theoretical difference between the flow coordinate matrix and its corresponding input - output table. That is, the diagonal elements of the latter represent internal flows and must be set equal to zero.[2]

The issue regarding the diagonal elements of the input/output table of an economy is the subject of a great deal of controversy. It is suggested that the failure to assign the diagonal elements of the input - output matrix zero values, stems from the belief "that a greater deal of generality is reached if we fill the boxes with some elements."[3]

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[1] Georgescu-Roegen, The Entropy Law, p. 255.

[2] Georgescu-Roegen, The Entropy Law, p. 255.

[3] Georgescu-Roegen, The Entropy Law, p. 256.

Unfortunately, as is the case with any generalization and simplification of actuality, this hinders the accuracy of analysis. Georgescu-Roegen suggests that

> (By seeking) to smuggle funds into a flow structure ... we will find ourselves adding or subtracting flow and fund coordinates ... which are heterogeneous elements ... Unfortunately ... the harm done by smuggling funds into the flow category is not likely to manifest itself on the surface. But below the skin of algebra, things may be distorted substantially.1

Using the first row of our flow matrix, we can readily derive the input - output counterpart. More specifically, process P1 produces commodity C1, which can be defined by the following vector, (x1, -x12, -x13 -x14) indicating that the output x1 of commodity C1, is completely absorbed as an input flow in the remaining procsses P2, P3, and P4. That is, x1 + (-x12) + (-x13) + (-x14) = 0.2 Conversely, the first row of a input - output table of flows defines the use of commodity C1, in the alternate production processes - P1, P2, P3, P4. While the positive values x12, x13, x14 measure the input of commodity C1 into processes P2, P3, and P4 respectively, the input of commodity C1 in the production of commodity C1, does not flow across any

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1 Georgescu-Roegen, The Entropy Law, p. 261.

2 Georgescu-Roegen, The Entropy Law, p. 255.

boundary. As a result, the value of x11, the first diagonal element in the input - output matrix represents an "internal flow"[1] of commodities and must not take on a non - zero value.[2] Generally, the use of commodity Ci in the production process Pi occurs within the boundary of the process and, therefore, will be captured in the fund matrix of the economy.

The resulting input - output tables include production coordinates - both flow and fund - which are predominantly qualitative in nature and, therefore, the model requires one final modification so as to facilitate application. More specifically, the role of flow coordinates such as inputs from the environment and the waste output, as well as, fund coordinates such as Ricardian land, giving implicit recognition to the resource base, are not readily quantifiable. Consequently, these variables must be removed from the tableaus and an alternate route through which the interaction of the production processes with the material environment can be

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[1] Georgescu-Roegen argues that the use of the term "internal flow" is both theoretically and intuitively incorrect as flow has been defined to represent movements of commodities across process boundaries. Georgescu-RoegenG The Entropy Law, p. 260.

[2] Given that x1 = x12 + x13 + x14, x11 must be zero.

incorporated into the model must be developed.1 Finally, so as to conform with Sraffa's representation of the economy - production of commodities by means of commodities and labour - the input output tables must include only commodity processes. Consequently, we remove the labour coordinates, H, for separate inclusion in the model. Similarly , the fourth process, P4, represents a consumption sector and therefore, represents the net production of the economy. As a result this column does not represent commodity production and must be removed from the tableaus. Furthermore, the process fund, F, and the Stores coordinates, S, are removed from the tableaus as the former is a natural, unchanging quality of a "fully - primed" factory setting, while the latter is more accurately incorporated within the commodity fund requirements.

In summary, the economy can be respecified as an aggregation of single commodity producing processes an described in terms of input - output tables as follows:2

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1 The laws of thermodynamics, particularly the Entropy Law, provide the framework within which to investigate the qualitative nature of the material environment. Furthermore, Chapter 5 shows that the unavoidable operation of the Entropy Law is reflected in the economy through both increased labour and material intensity of the production processes. This is incorporated into the model through changes in the input requirements of each production process.

2 Georgescu-Roegen, The Entropy Law, pp. 255 - 257.

TABLE 3

INPUT - OUTPUT TABLE OF AN ECONOMY

FLOW COORDINATES

	P1	P2	P3	Total
C1	0	x12	x13	x1
C2	x21	0	x23	x2
C3	x31	x32	0	x3

FUND COORDINATES

	P1	P2	P3
C1	X11	X12	X13
C2	X21	X22	X23
C3	X31	C32	X33

The Representation of the Economy in Application

The matrices of flow and fund coordinates of production measured in absolute magnitudes requires that the economy be defined for a duration of time and, hence, can only be employed in a retrospective analytical setting. However, if both the flow and fund coordinates are specified as coefficients of production, i. e. the requirements per unit of output, the need for a temporal specification is removed and the usefulness of the model as an analytical and forecasting tool is enhanced. However, this places a restriction on the type of production processes to which the model applies. More specifically, this model is operational only in a "fully primed" factory setting in which each of the processes operate simultaneously and the idleness of the fund coordinates is minimized.[1]

Therefore, the final step in the modification of Sraffa's representation of the economy requires that both the flow and fund coordinates be respecified as coefficients of production - input required per unit of output. More specifically, each j'th process is described by the input of each i'th commodity required per unit of output (commodity) of that process. The respecification of the input - output

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[1] Georgescu-Roegen, The Factory Process, p. 91.

tables in Table 3, is readily obtained by the division of each column by the total production column. For example, the production of quantity x1 of commodity 1 in process P1, requires x21 and x31 units of commodities 2 and 3, respectively, as input flows. These absolute requirements can be respecified in terms of coefficients of production by dividing x21 and x31 by x1. Therefore, we obtain $a_{21} = x_{21}/x_1$ ($a_{31} = x_{31}/x_1$), which represents the flow of commodity 2 (3) required in the production of commodity 1 , per unit output of process 1. Similarly, the absolute fund requirements of the first process are given by X_{11} units of commodity 1, X_{21} units of commodity 2, and X_{31} units of commodity 3. Therefore, we can describe the fund coefficients of production as $b_{11} = X_{11}/x_1$, (or $b_{21} = X_{21}/x_1$) (or $b_{31} = X_{31}/x_1$), where b_{ij} measures the fund of commodity i required per unit production of the j'th process.

The reader should note that the transformation of the flow tableau results in the equivalent - with the exception of the diagonal elements - of the Leontief technological coefficient matrix. Finally, the labour requirements of the production process can be defined by a seperate vector, $[L_1, L_2, L_3]$, where L_j represents the quantity of labour required, directly, in the j'th production process, per unit output of that process.

GENERALIZED ANALYTICAL REPRESENTATION OF A PRODUCTION PROCESS

In summary, the development of the analytical representation of the economy and its component production processes, has required numerous modifications of Sraffa's model of production of commodities by means of commodities. The evolution has consisted of the recognition of qualities which must characterize such a representation, the description of a partial/production process in terms of analytical boundaries, the identification of flow fund coordinates of production, and finally, the respecification of absolute production requirements in terms of input coefficients.

It is now possible to define the model of the economy which will be employed hereafter.

Firstly, assume that the economy is composed of 'n' sectors or industries which produce 'n' commodities. The fund and flow matrices outlined previously are nxn matrices with n columns indexed by the letter i and n rows indicated by the letter j.

Secondly, prior to defining the model explicitly, it is necessary to set out the notation which will be used. Specifying the matrices of flow and fund requirements in terms of production coefficients we have the following:

x_j = the quantity of output of commodity j, in the j'th process, where j=1,....n.

x_{ij} =the quantity of commodity i required in the production of output x_j, units of commodity j where i,j=1, ...,n.

X_{ij} =the quantity of i'th commodity fund required to be maintained in the production of output X_j units of commodity j where i,j = 1, 2, ... n.

a_{ij} =x_{ij}/x_j which represents the quantity of commodity i required in the j'th process per unit output of commodity j. $\forall$ ij, $a_{ij} \geq 0$.

b_{ij} =X_{ij}/X_j which represents the qunatity of the i'th commodity fund required to be maintained intact in the j'th process per unit output scale of the j'th process. $\forall$ ij $b_{ij} \geq 0$.

The reader should keep in mind that we are implicitly assuming constant returns to scale, i. e. a_{ij} is invariant to changes in the quantity of commodity j (X_j) produced as final output.

Consequently, we obtain the analytical representation of the production system of the economy, in terms of a flow matrix $A = [a_{ij}]$, for $i,j = 1,2, ... n$, and if $i = j$ $a_{ij} = 0$, a fund matrix $B = [b_{ij}]$, for $ij = 1,2, ... n$, and a vector of direct labour requirements $L = [L_j]$, for $j = 1,2, ... n$.

Properties of Input Matrices A and B

There are three properties of the commodity flow and fund (capital maintenance) requirements matrices of the production system which require recognition.

Firstly, both matrices A and B are non - negative, i. e. all elements are equal to or greater than zero. More specifically, $a_{ij} \geqslant 0, \quad \forall\, ij = 1,2, \ldots ,n,$ and $b_{ij} \geqslant 0, \quad \forall\, ij = 1,2, \ldots ,n.$ Similarly, the vector of direct labour requirements, expressed in terms of some j'th commodity chosen as numeraire is such that $l_j \geqslant 0, \quad \forall\, j = 1,2, \ldots . n,$ and at least one coordinate is strictly positive.

Secondly, the Sraffian requirement that only basic commodities determine the solution to the system is satisfied by the requirement that matrices A and B are irreducible.[1]

Thirdly, the maximum eigen value of each matrix is positively related to the size of the elements of that matrix - by Perron - Frobenius theorems. More specifically, "the (maximum) eigenvalue, μ_m, of A (or B) is a continuous increasing function of the elements of A (B)."[2] Furthermore, the a_{ij} coefficients of the technology matrix, A, measure

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[1] Ozol, Parable and Realism, p. 356.

[2] Pasinetti, Lectures, p. 272.

the input of each i'th commodity flow required per unit output of a specific j'th commodity. As a result, the maximum eigen value of matrix A provides an indication of the commodity (material) intensity of the technique of production.[1]

CONCLUSION

In conclusion, Sraffa's model of the economy and production processes defined in terms of commodity inputs and outputs is a useful tool for the analysis of the distribution of income in the form of wages and profits. However, it is characterized by numerous theoretical inadequacies and, therefore, can only be considered as the first step toward an accurate theoretical model of the economy. The analytical representation of the economy requires that we divide actuality into partial processes, which are defined by both a physical and temporal boundary - specifying the nature, e.g. commodity production, and the duration of the process, respectively. Furthermore, the description of the partial production process with reference to commodity movements across the boundary of the process requires that the components of each process be classified under one or both of two alternate headings - flow and fund elements. Chapter 4 redefines Sraffa's

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[1] Ozol, Parable and Realism, p. 354.

relative pricing solution and accompanying wage - profit function in terms of the analytical model developed thus far - matrices A and B, and vector L. Finally, the model developed in Chapter 4 is conducive to the incorporation the qualitative nature of the resource base.

CHAPTER FOUR

A MODEL OF THE ECONOMY[1]

Sraffa's production theory - postulating production of commodities by means of commodities and labour - developed in Chapter 3 can be respecified in terms of the analytical representation of the production system - based upon the flow and fund matrices A and B, and the vector of direct labour requirements, L. The implicit pricing solution and accompanying wage - profit function for a particular technique of prouction is analagous to that discussed by Sraffa. The objective of this chapter is to present Sraffa's model and accompanying relative pricing solution in terms of the analytical representation of the production system developed in Chapter 3, as well as, the derivation of a wage - profit function - with particular reference to the determinants of the parameters of this function. Finally, it is shown that there exists a monotonically inverse relationship between the maximum rate of profit and real wage attainable, consistent with a relative pricing solution and specific production technique.

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[1] The model developed in this chapter has been adapted from lectures held by Cengiz Ozol, January - May 1985, at the University of Calgary.

THE MODEL IN APPLICATION

Sraffa's third version of the production model postulates that commodities are produced by means of commodities and direct labour inputs. However, as is shown in Chapter Three, the accurate representation of a production system requires that the former be classified as either commodity flow requirements or commodity fund requirements. Therefore, Sraffa's postulate that the relative price of a commodity not be less that the total cost of production - commodity inputs and primary factors of production - is respecified by the following equation system:

$$Pj = PjA + \pi PjB + w^{j} L \qquad (I)$$

where:

Pj = the vector of relative prices or exchange values of each commodity in terms of some j'th commodity chosen as numeraire.

A = the matrix of technical coefficients representing commodity flows across industries. The non - negative elements of this matrix are indicated by a_{ij} where $i,j = 1, 2, \ldots\ldots n$ such that $a_{ij} \geq 0 \ \forall ij = 1,2, \ldots n$, and the diagonals $= 0$, i. e. $a_{ij} = 0 \ \forall i = j$.

B = the matrix of physical capital required to be maintained intact per final unit output of each commodity. The elements of this matrix are indicated by b_{ij}, where $i,j = 1, 2, \ldots\ldots n$, where $b_{ij} \geq 0$.

π =the rate of profit or interest on capital and is an indication of the opportunity cost of capital stocks.

w_j =the vector of real wages per unit of labour employed in each industry expressed in terms of some j'th commodity chosen as numeraire.

L = the vector of direct labour requirements for each industry.

Although theoretically superior, this model has an empirical difficulty with respect to the measurement of the matrix of capital requirements (matrix B). Therefore, in order to allow for compatibility between theoretical propositions or conclusions and future empirical evaluation, we make a strong assumption and set matrix A equal to matrix B. As a result, a technique of production is represented by the technology matrix A and the vector of labour input requirements, L, "where A denotes the semi - positive Leontief technology matrix and L denotes the non - negative vector of labour input coefficients."[1] Substituting matrix A for Matrix B, equation (I) becomes:

$$P_j = P_jA + \pi P_j A + w_jL \qquad \text{(II)}$$

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[1] Ozol, Parable and Realism, p. 356.

which can be reduced as follows:

$$P_j L = (1+\pi)P_j A + w_j L \qquad \text{(III)}$$

$$P_j - (1+\pi)P_j A = w_j L \qquad \text{(IV)}$$

$$P_j[I - (1+\pi)A] = w_j L \qquad \text{(V)}$$

$$P_j = w_j L[I-(1+\pi)A]^{-1} \qquad \text{(VI)}$$

Equation (VI), above, defines the relative pricing solution of the production system as determined by the technique of production, rate of profit and real wage. However, the system is not determinate as there are k independent equations and k + 1 unknowns - specifically, k - 1 relative prices, the rate of profit π , and the real wage expressed in terms of some j'th commodity chosen as numeraire, w_j, Therefore, like Sraffa's third set of production equations, the system moves with one degree of freedom in the determination of the relative price configurations. Furthermore, it is shown that this relative pricing solution implicitly defines a relationship between the combinations of real wage w_j, and the rate of profit, π , which can be simultaneously obtained under a given pricing regime.

THE SOLUTION TO THE PRICING SYSTEM

As outlined above, there are basically three ways in which we can attempt to solve the system. Firstly we can set the real wage as exogenous to the system thereby determining the relative price configuration and rate of profit which are consistent with the technique of production and real wage. Alternately, we can set the rate of profit as exogenous to the system and, subsequently, determine the relative price configuration and real wage which are consistent with the production technique and rate of profit. Finally, we can select any one of the relative prices as given and solve for the remaining relative prices, the real wage and the rate of profit. The first two options are perhaps the easiest empirically, and the first is consistent with Sraffa's analysis. However, the object of this chapter is to investigate the relationship between the rate of profit and real wage attainable under a specific technique of prodution. As a result, the third option is dismissed as irrelevant.

THE DISTRIBUTION OF INCOME

The classical economists proposition that income generated in production is distributed among the productive sectors of the economy, in the form of rent, wages and

profit, can be extended to the analysis contained in this chapter. The analytical representation of the production process developed in Chapters 3 and 4 is analagous to the classical teachings in that it implicitly defines the determinants of and measures the distribution of income. However, while the classical agricultural based economy presupposed the existence of three productive factors requiring remuneration, the industrial economy analogue does not recognize land as a direct factor of production. As a result, the model outlined above defines and measures two types of income - wages and profits. The classical determinants of income distribution are discussed in Chapter 1. It remains, therefore, to derive a measure of the income forms - real wage and rate of profit - which are consistent with the production technique and relative pricing solution of the production system.

Rate of Profit

The relative pricing solution from equation (V) above

$$P_j[I-(1+\pi)A] = w_j L \qquad (V)$$

can be further reduced by multiplying both sides of the equation by $\eta = 1/(1+\pi)$ (Va)

We, therefore, obtain the following:

$$Pj[\lambda I-A] = \lambda wjL \qquad \text{(VIa)}$$

The above equation allows us to determine the maximum rate of profit obtainable within the system, consistent with a particular relative price configuration, by setting the real wage to zero. That is, by allowing the total surplus product to be distributed in the form of profits. In that case, equation (V) above becomes:

$$Pj\,[\lambda I-A] = \lambda\,(0)L \qquad \text{(VII)}$$

$$Pj\,[\lambda I-A] = 0 \qquad \text{(VIII)}$$

There are two conditions under which a solution to this system is attainable. Firstly, the trivial solution where the relative price vector, Pj, is equal to zero. Secondly, a non - zero solution is attainable if the determinant of the characteristic equation is equal to zero, i. e. $\det[\lambda I-A] = 0$. The roots of this equation are the eigenvalues of the technology matrix A. Perron - Frobenius theorems[1] conclude that the maximum eigen value indicated by μ_m, is real, positive, unique, less than unity, $(0 < \mu_m < 1)$, and yields a strictly positive vector of price solutions.

Substituting into equation (Va) we have:

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[1] Luigi L. Pasinetti, Lectures on the Theory of Production, (New York: Columbia University Press, 1977), pp. 77,269,275.

$$\mu_m = 1/1+\pi \qquad \text{(IX)}$$

Therefore, the maximum eigen value of the technology matrix, A, sets the upper bound on the feasible rates of profit which could prevail in the system as follows:

$$\Pi^* = \pi\,(w=0) = (1/\mu_m)-1$$

Similarly, we can define the following feasible range for the rate of profit consistent with a particular technique of production and real wage.

$$\Pi^* = \{\pi : 0 \leq \pi \leq (1/\mu_m)-1\}$$

Finally, the a_{ij} coefficients of the technology matrix measure the input requirements of each i'th commodity required per unit output of the j'th production process. As a result, the maximum eigen value of the technology matrix (and implicitly, the maximum rate of profit) provide a measure of the "commodity intensity or physical capital efficiency"[1] of the production technique.

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[1] Ozol, Parable and Realism, p. 358.

Real Wage

In order to determine the maximum real wage attainable in the system we must define a pricing solution which is consistent with a zero profit rate as follows:

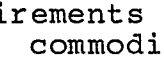
Given the pricing solution defined in equation (VI):

$$P^j = w^j L[I-(1+\pi)A]^{-1} \qquad \text{(VI)}$$

and setting the rate of profit equal to zero ($\pi = 0$) we obtain the following:

$$P^j = w^j L[I-A]^{-1} \qquad \text{(X)}$$

Where:

> $[I-A]^{-1}$ represents a matrix in which any j'th column indicates the amount of output each industry must produce in order to meet both the direct and indirect input requirements of all other industries so as to produce one final unit of commodity j for final use.[1]
>
> $L[I-A]^{-1}$ =  represents the direct and indirect labour requirements per final unit output of each commodity. This vector describes the labour values of commodities analagous to those described by Marx, Dmitriev, and Sraffa.[2]

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[1] Ozol, Parable and Realism, p. 356.

[2] Ozol, Parable and Realism, p. 386.

Rearranging the above pricing solution, the maximum real wage attainable, consistent with a zero rate of profit, $\dot{\pi} = 0$, is given by

$$P_j = w_j \Lambda \qquad \text{(XI)}$$

Multiplying both sides of equation (XI) by e_j - a column vector where the j'th element equals unity and the remaining elements are set equal to zero - we obtain,

$$1 = w_j \lambda_j \qquad \text{(XII)}$$

Finally, rearranging (XII) we obtain

$$w_j = 1/\lambda_j \qquad \text{(XIII)}$$

Equation (XIII) defines the real wage consistent with a particular technique and relative pricing solution - when the rate of profit is equal to zero - as the inverse of the relative labour value of the numeraire commodity.

Given that the relative labour value - $L[I-A]^{-1}e(j)$ - defines the quantity of labour required in production, the maximum real wage provides a measure of the net productivity of labour. More specifically, the greater the quantity of labour required in production - the larger the coefficients

of vector L - the lower the value of labour and consequently, the lower the maximum real wage attainable.[1]

Therefore, we can define the following feasible range for the real wage consistent with a particular technique of production and rate of profit:[2]

$$0 \leqslant w(\pi) \leqslant 1/L[(I-(1+\pi)A]^{-1}e(j)$$

Which can be further reduced to

$$0 \leqslant w(\pi) \leqslant 1/\lambda_j$$

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[1] This conclusion is consistent with Sraffa's analysis in that when the rate of profit within the system is equal to zero, the relative prices generated are proportional to the labour values or direct and indirect labour requirements of the commodities.

[2] Ozol, Parable and Realism, p. 357.

THE WAGE - PROFIT FUNCTION

In summary, the relative price solution, $P_j = w_j L[I-(1+\pi)A]^{-1}$, implicitly defines a wage - profit function[1] the parameters of which are defined as follows:

The Maximum Rate of Profit

Define: The maximum rate of profit which can be obtained under a particular relative pricing structure is given by the inverse of the maximum eigen value of the Leontief technology matrix. This rate of profit is consistent with a zero real wage and is specific to a particular technique of production.

The Maximum Real Wage

Define: The maximum real wage which can be obtained under a particular relative pricing structure equal to the inverse of the relative labour value of the numeraire commodity.[2]

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[1] Ozol, Parable and Realism, p. 357.

[2] The labour value, $\lambda_j = L[I-A]^{-1}e(j)$, is determined by the direct and indirect labour required to produce one final unit output of the j'the commodity.

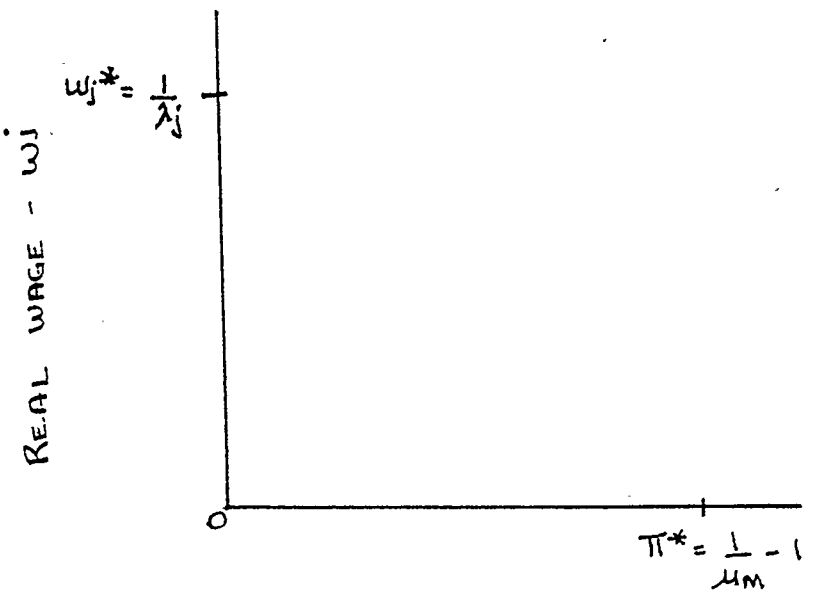
In summary, the parameters of the wage - profit function consistent with a particular technique of production, relative pricing solution and rate of profit is defined as follows.[1]

$$w(\pi)=1/L[I-(1+\pi)A]^{-1}\ e(j),\ 0\leq \pi \leq (1/\mu_m)-1$$

This can be shown graphically as follows:

FIGURE 3

PARAMETERS OF THE WAGE - PROFIT FUNCTION



[1] Ozol, Parable and Realism, p. 357.

The Shape of the Wage - Profit Function

Once the limits of the wage - profit function have been clearly defined, it remains to investigate the general properties of this function. Clearly, the elements of the $L[I-(1+\pi)]^{-1}$ matrix are monotonically increasing functions of the rate of profit, π . Consequently, given that the real wage, expressed in terms of some j'th commodity chosen as numeraire, is an inverse function of this matrix, the real wage, w^j, is a monotonically decreasing function of the rate of profit, π , and vice versa. However, the graphical representation of this function, beyond the horizontal and vertical intercepts - maximum attainable rate of profit and real wage respectively - is not readily ascertainable. More specifically, the shape of the wage - profit function is not necessarily linear and is determined by the structure of the Leontief technology matrix A.[1]

We have determined that the real wage is a monotonically decreasing function of the rate of profit. However, lacking empirical information with respect to the technique of

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[1] The reader should note that exclusion of the fund matrix B from the realtive pricing solution simplifies the investigation of the shape of the wage - profit function.

production, particularly matrix A, we are not able to specify the shape of the function.[1]

For diagrammatic consistency, we assume that the wage - profit function is concave to the origin,[2] keeping in mind that the function may, in fact, be convex to the origin or contain both convex and concave regions.[3] As we are concerned with the parameters of the function, its shape does not alter the analysis or conclusions in any way. Therefore, the graphical representation of the wage - profit function takes the form as shown in Figure 4:

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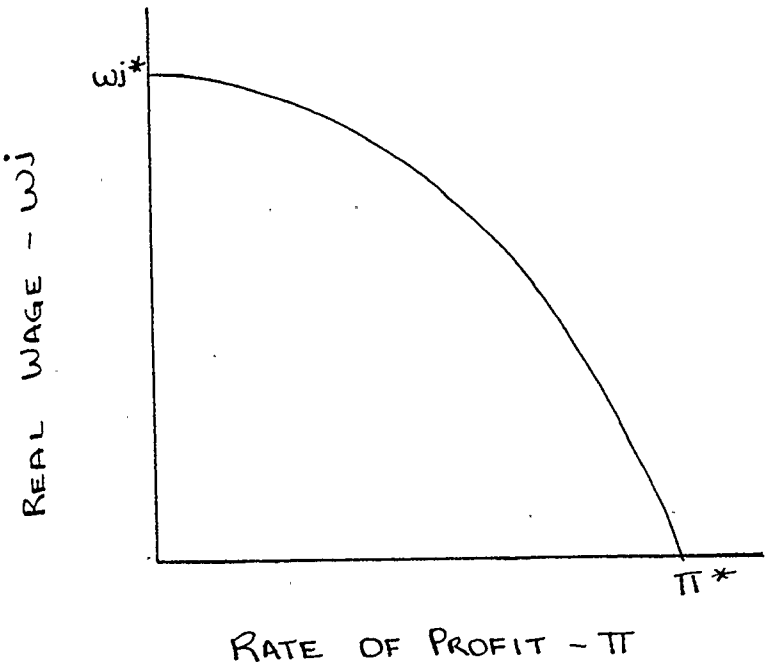
[1] The inverse relationship between the real wage rate and the rate of profit is linear only in the extreme case of uniform composition of capital across all industries. (Pasinetti, Lectures, p. 86.)

[2] This assumption is consistent with empirical findings. Ozol (1984) shows that during the period 1958 - 1969, the graphical representation of the wage - profit function , estimated with U. S. data, is relatively concave to the origin.

[3] Pasinetti, Lectures, p. 88.

FIGURE 4

SHAPE OF THE WAGE - PROFIT FUNCTION



CONCLUSION

In conclusion, the respecification of Sraffa's production model, so as to ensure analytical accuracy, facilitates the investigation of income distribution in an industrial economy. Furthermore, it is shown that, in analogy to classical teachings, income is distributed to the classes of a capitalist society in accordance with ownership of factors of production. The agricultural base of the classical capitalist society

is characterized by three classes - capitalists, landowners, and labourers - which receive income in three forms, respectively - profits, rent and wages. However, the industrial capitalist society does not distinguish between land and capital employed in production. As a result, both the relevant societal classes and income forms reduce to capitalists and labourers receiving profits and wages respectively.

While the classical determinants of wages and profits rested on intuitive discussions of susbsistence levels and residuals after rent payments, the analytical representation of the production system measures the real wage, expressed in terms of some j'th commodity chosen as numeraire, and the profit rate, as inverse functions of the labour value (intensity) and material intensity of the production technique, respectively. We can readily define the parameters of the monotonically inverse wage - profit relation for a given technique of production defined by the matrix of technical coefficients, used as an indicator of both commodity flows and capital maintenance requirements, and the vector of direct labour requirements. Furthermore, the respecification of Sraffa's model into matrix algebra form and making the necessary assumptions with respect to constant returns to scale, facilitates the investigation of the inter - temporal behaviour of the wage - profit functon,

particularly the maximum rate of profit and real wage attainable. Finally, the model of a production system based upon input - output coefficients of production is conducive to the investigation of the interaction of the production process with the material environment.

Georgescu-Roegen suggests that the qualitative degradation of the material environment is explained by the laws of thermodynamics, particularly the Entropy Law. More specifically, the natural and production induced operation of the entropic process results in increasingly labour and material intensive techniques of production. This is reflected in the size of the elements of the Leontief technology matrix, A, and the vector of direct labour requirements, L, which implicitly impacts on the parameters of the derived wage - profit function.

In summary, Chapter 4 defines the industrial analogue to classical static income distribution theories in that the relative pricing solution implicitly measures an accompanying wage - profit function. It remains, however, to investigate the inter - temporal behaviour of this function - specifying the rate of profit and real wage which are attainable simultaneously under a given relative price configuration and production technique. Chapter 5 defines the interaction of the production process with the material environment in terms of the Entropy Law, and investigates

the impact of the entropic process on the parameters of the derived wage - profit function.

CHAPTER FIVE

THE INTERACTION OF THE PRODUCTION PROCESS WITH THE MATERIAL ENVIRONMENT

The analytical representation of the economy developed in Chapters Three and Four indicates that the classical theories of income distribution remain applicable in the context of a predominantly industrial based society. While not identicall , both models do conclude that an inverse relationship exists between the distribution of a given level of output between profits, wages and rent - in the case of the classical school - and profits and wages - in the case of the industrial analogue. More importantly, however, is the similarity between these two models with respect to the intertemporal behaviour of the profit share of income. The classical school's suggestion that the operation of diminishing returns to agriculture causes the shares of rent and wages to increase, thereby indirectly reducing the profit residual, is reaffirmed by the modified Sraffian representation of the economy. That is, it is shown that once we recognize the role of the material environment, in the production system outlined in Chapter Four, we obtain

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[1] The classical school identifies three classes of society, while the production system developed in Chapter Four recognizes only two classes to which income is distributed.

the same conclusions with respect to the long run behaviour of the profit share of income, as discussed in the classical context. However, the industrial analogue requires that the somewhat vague notion of diminishing returns be redefined in terms of the more theoretically valid physical laws of thermodynamics, particularly the Entropy Law.

The objectives of this chapter are fivefold. Firstly, to discuss the limitations of the current theoretical emphasis on mechanical and mathematical representations of the economy. Secondly, to introduce the laws of thermodynamics as the framework within which to describe the qualitative nature of the material environment. Thirdly, to investigate the reciprocal relationship between the operation of the production process and the material environment, via the wage - profit function derived in Chapter Four. Fourthly, to analyze the long run behaviour of the rate of profit earned in the economy, in response to the unavoidable operation of the entropic process. Finally, the implications of the reaffirmed classical prediction that the rate of profit tends toward zero, over time, are discussed.

INADEQUACIES OF THE EXTANT MODELS OF PRODUCTION PROCESSES

As presented in the discussion of Ricardo's theory of income distribution, the

> classical economists thought that, over the long run, population growth and diminishing returns would unavoidably channel the entire economic surplus into rent, thus reducing profit to zero and terminating economic growth.[1]

However, the economic theories and models which developed subsequent to that time disregard the notion of finite resource availability and qualitative change. As a result, economic thought is biased in the direction of continual and rapid expansion or economic growth with little if any consideration of resource scarcity and the long run implications of accompanying policy recommendations. More specifically, Daly suggests that

> continual growth in both capacity (stock) and income (flow) is a central part of the neoclassical growth paradigm. But in a finite world continual growth is impossible.[2]

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[1] Herman E. Daly. "Introduction to the Steady State Economy," in Economics, Ecology, Ethics - Essays Toward a Steady State Economy, edited by Herman E. Daly, (New York: W. H. Freeman and Co., 1980).

[2] Herman E. Daly, Introduction to the Steady State Economy, p. 5.

Neoclassical economists replace emphasis on an accurate and realistic representation of the economic process with a mechanical analogue, emphasizing arithmetization and quantification of the economic process. More specifically, it is suggested that

> Social scientists generally go on a spree of arithmomania and apply arithmetical operations on paper to any numbers they can get hold of or think of without stopping to consider whether these operations have any meaning at all.1

Furthermore,

> This approach has led to a mushrooming of paper - and - pencil exercises and increasingly complicated econometric models which often serve only to conceal from view, the most fundamental issues.2

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1 Nicholas Georgescu - Roegen, The Entropy Law and the Economic Process, (Cambridge, Mass. : Harvard University Press, 1971), p. 99.

2 Nicholas Georgescu - Roegen, "Energy and Economic Myths," reprinted in Energy and Economic Myths - Institutional and Analytical Economic Essays, (New York: Pergamon Press, Inc., 1976), p. 4.

QUALITATIVE CHANGE AND THE ECONOMIC PROCESS

More significantly, however, the fundamental basis or cornerstone of economic thoery is faulty in that the prevailing "narrow" view of economics results in a portrayal of an economic process as "an isolated self - contained and ahistorical process - a circular flow between production and consumption with no outlets and no inlets."[1] However, in reality, the economic process is not an isolated system, but rather, is characterized by continual qualitative change which both impacts on and is influenced by the environment. It is suggested that this misrepresentation of reality is a direct result of the development of neoclassical economics as an analogue to the mechanical doctrines of classical physics.

The appeal of mechanics as a tool in theorizing stems from the use of the concepts of mass, speed and position in the reduction of any process to "locomotion", and to facilitate quantitative prediction.[2] Furthermore, the perceived ability of science to predict the exact time and place of a particular occurrence enhances the appeal of the mechanistic dogma. More specifically, the mechanical doctrine supports the

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[1] Georgescu - Roegen, The Entropy Law, p. 2.

[2] Georgescu - Roegen, Economic Myths, pp. 4 - 6.

perception of an ahistorical economic process characterized by timelessness and reversibility. However, actual phenomena are characterized by qualitative change in a definite direction which is both irrevocable and unquantifiable. As a result, the economic process can not be accurately reduced to an analogue of locomotion and mechanics.[1] Unfortunately, the applicability and reality of economics as a science suffers as a consequence of its reluctance to recognize that "in the economic domain, change is the soul of what happens."[2]

It is argued that the existence of qualitative change in the universe, as well as, the interaction of the economic process with the material environment eludes incorporation into economic theories for the following reasons:

Firstly, it is suggested that economists are of the opinion that "everything nature offers us is gratis"[3] and therefore, there is no need to include the environment in the analysis of the economic process.

Secondly, recognition of a continuous mutual influence between the economic process and the material environment complicates the analysis. Furthermore, recognition of this relationship does not fit into the closed circular

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[1] Georgescu - Roegen, The Entropy Law, p. 12.

[2] Georgescu - Roegen, The Entropy Law, p. 62.

[3] Georgescu - Roegen, The Entropy Law, p. 2.

representation conducive to the model of business - where all money remains within the system.1

Thirdly, it is suggested that

> the abscence of any difficulty in securing raw materials by those countries where modern economies (grow) and (flourish is) yet another reason for economists to remain blind to this crucial economic factor.2

Finally, and most importantly, it is suggested that attachment to the mechanistic representation merely stems from an inadequate knowledge and understanding of the precise nature of qualitative change and the implications of its omission. While this may have been true or supportable at the time in which Jevons, Walras and Fisher were laying the foundations of neoclassical economics, subsequent developments in the thermodynamic branch of physics, particularly the Entropy Law, have reduced the magnitude of this problem. More specifically, the laws of thermodynamics provide an irrefutable framework in which we can understand, describe, and analyze the natural and unavoidable degradation of the earth's resource base. Of course, this analysis does not fit into traditional arithmomorphic models, as its inherent qualitative nature prohibits the quantification of

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1 Georgescu - Roegen, The Entropy Law, p. 2.

2 Georgescu - Roegen, The Entropy Law, p. 2.

the change in the resource or energy base.[1] Nonetheless, the exercise is stimulating, challenging and, most importantly, essential, if we are to better understand the impact of man's existence and the economic process on the long run sustainability of the capitalist system.

THERMODYNAMIC TERMINOLOGY

Before we discuss the laws of thermodynamics in detail, it is necessary to define a few recurring terms so as to avoid confusion.

Firstly, energy can be categorized under two qualitative descriptions - free or bound. Free energy is that which man has command over - subject to some accessibility restriction - and is capable of being transformed into mechanical work. Alternately, energy which man can not use in the performance of mechanical work is classified as bound or latent.[2]

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[1] In actuality, although attempts have been made to develop quantitative measures of physical attributes, these models have not been able to overcome the "peculiar nature of quality." As a result, each attempted quantification of physical characteristics, is not completely accurate, as "it leaves a qualitative residual." (Georgescu - Roegen, The Entropy Law, pp. 97 - 101.)

[2] Georgescu - Roegen, Economic Myths, p. 7.

Secondly, the concept of entropy receives numerous interpretations and remains the subject of much controversy. However, in the context of this analysis, it is necessary only to adopt a simple definition as follows: "Entropy is an index of the amount of unavailable energy in a given thermodynamic system at a given moment of its evolution."[1] Alternately, we can describe entropy as "a measure of the amount of energy no longer capable of conversion into work."[2] Accordingly, reference to a structure characterized by high entropy implies that most or all energy is unable to be transformed into mechanical work, i. e. bound energy. Conversely, a structure in which most or all of the energy is free and available for man's use should be referred to as being in a state of low entropy.[3]

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[1] Georgescu - Roegen. Economic Myths, p. 7.

[2] Jeremy Rifkin with Ted Howard. Entropy - A New World View, (New York: Bantam Books, 1980), p. 35.

[3] Georgescu - Roegen, The Entropy Law, p. 5

Thirdly, there are two sources of available or free energy to which man has access - the stock of free energy in the form of the mineral deposits of the earth and the flow of energy provided by the sun. Although both the terrestrial stock and solar flow are forms of free energy, there are a number of significant differences which must be elucidated:1

1) Man is capable of "almost instantaneously" obtaining and using the energy contained in the terrestrial component of low entropy. However, man is not capable of harnessing the future flow of solar energy. More specifically, "the solar source (of energy) is ... strictly limited in its rate and pattern of arrival to the earth."2

2) Both the terrestrial stock and solar flow of energy

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1 Nicholas Georgescu - Roegen. "The Entropy Law and the Economic Problem," reprinted in Economics, Ecology, Ethics - Essays Toward a Steady - State Economy, edited by Herman E. Daly, (New York: W. H. Freeman and Co., 1980), p. 56.

2 Herman E. Daly. Steady - State Economics - The Economics of Biophysical Equilibrium and Moral Growth, (San Fransisco: W. H. Freeman and Co., 1977), p. 22.

are characterized by limited availability. However, although

> the sun's energy is degrading with every passing second ... its entropy will not reach a maximum until long after the earth's available terrestrial stock has been completely used up.[1]

3) While the flow of solar energy is the "primary source of all life on earth",[2] the terrestrial stock of low entropy provides us with the materials required to produce the tools employed in the production process.

Fourthly, one must recognize that availability of energy is a necessary, but not a sufficient condition for the ability to perform mechanical work. Man does not have access to all forms of free energy and different forms of stored, available energy are not subject to the same degree of convertibility into applied work.[3] More specifically,

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[1] Jeremy Rifkin and Ted Howard. Entropy, p. 36.

[2] Georgescu - Roegen, Economic Problem, p. 56.

[3] Paul R. Ehrlich, Anne H. Ehrlich, and John P. Holdren. "Availaility, Entropy, and the Laws of Thermodynamics," in Economics, Ecology, Ethics - Essays Toward a Steady - State Economy. edited by Herman E. Daly, (New York: W. H. Freeman and Co., 1980), p. 45.

Georgescu - Roegen suggests that

> although mankind's spaceship floats with a fantastic store of available energy, only an infinitesimal part of this store is potentially accessible to man ... (Therefore, it must be kept in mind that both the) amount of accessible energetic low entropy ... (and) the amount of accessible material low entropy (are) finite.1

Furthermore, it is argued that the value of free energy to mankind is determined by its accessibility. For example, we must expend work and materials in order to obtain usable energy from the material base of the earth. The energy thus obtained, however, possesses some value and is accessible only if the energy expended in its retrieval does not exceed that which is obtained, i. e. there is a net gain of free energy.2

Finally, one must recognize that inaccessibility of energy does not imply unavailability of energy or the quality of being bound or latent energy. It may be argued that, over time, previously inaccessible free energy may become increasingly accessible. For example, the future flow of solar energy , although unharnessable today, can be accessed in the future through its interaction with the material

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1 Georgescu - Roegen, Economic Myths, p. 11.

2 Georgescu - Roegen. Economic Myths, p. 10.

environment. Therefore, although unavailability (bound energy) implies inaccessibility, inaccessibility does not necessarily imply long run unavailability.

THE LAWS OF THERMODYNAMICS

There are essentially two laws of thermodynamics which are of relevance to the analytical representation of the economic process.

The first law of thermodynamics, The Law of Conservation of Matter and Energy, dictates that the total quantity of matter and energy in the universe is fixed and, therefore, can be neither created or destroyed.[1] Consequently, the transformation of energy is restricted to a qualitative change which is explained by the second law of thermodynamics discussed below. More specifically,

> although transformations can alter the distribution of the amounts of energy among its different forms, the total amount of energy, when all forms are taken into account, remains the same.[2]

It should be noted that this law does not contradict the doctrines of mechanics as it does not impose a restriction

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[1] Rifkin. Entropy, p. 33.

[2] Ehrlich, et al. Laws of Thermodynamics, p. 45.

on the direction of the qualitative transformation. Consequently, "with only (this) law, we are still in mechanics, not in the domain of actual phenomena, including the economic process"[1] as it does not prohibit the use of the same energy time and time again. Furthermore, current economic thought gives implicit recognition to the fixed absolute quantity of energy by concluding that man is incapable of producing matter or energy.[2]

On the other hand, the second law of thermodynamics, The Entropy Law, recognizes the unidirectional qualitative change which is an inherent characteristic of the universe and, therefore, is in opposition to the mechanistic dogma. More specifically, according to the Entropy Law, "the entropy (bound energy) of a closed system continuously and irrevocably[3] increases toward a maximum."[4] Alternately, this law argues that all physical processes, both biological and economic, are characterized by a constant degradation of free energy into latent or unavailable energy.

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[1] Georgescu - Roegen. Economic Myths, p. 7.

[2] Georgescu - Roegen. The Entropy Law, p. 17.

[3] Irrevocability is a stronger condition than irreversibility as it implies that we can not pass through a particular state of existence more than once. (Georgescu - Roegen, The Entropy Law, p. 197).

[4] Georgescu - Roegen. Economic Myths, p. 7.

IMPLICATIONS OF THE LAWS OF THERMODYNAMICS

There are a number of implications of the operation of both laws of thermodynamics which require further discussion.

Firstly, the irrevocable nature of the entropic process implies that once free energy has undergone the degradation process into bound, unavailable energy, it can never be recaptured. As a result, each time that energy is degraded, it results in less available energy to perform work in the future.[1]

Secondly, while life is characterized by an ability to evade the second law of thermodynamics, this is only a temporary and isolated phenomenon. That is, although an individual continually attempts to avoid the gradual degradation of his own system, in doing so, he causes the entropy of his environment, the universe as a whole, to increase. Therefore, "the presence of life causes the entropy of a system to increase faster than it otherwise would."[2] Consequently, both the biological and economic processes are characterized by the degradation of free into bound energy.

While it is apparent that biological life sustains itself "in a quasi - steady state by sucking low entropy from the

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[1] Rifkin. Entropy, p. 35.

[2] Georgescu - Roegen, The Entropy Law, p. 11.

environment and transforming it into higher entropy,"[1] there is an essential difference between the entropic process operating in the biological or material environment and that of the economic process. The transformation of free into bound energy in the material environment is a natural and automatic occurrence. However, qualitative degradation beyond the natural process depends upon the nature of the economic process.[2] That is,

> production represents a deficit in entropy terms ... (as) it increases total entropy by a greater amount than that which would result from the automatic shuffling (of low entropy into high entropy) in the absence of any productive activity.[3]

The reinforcing effect of productive activity on the natural degradation of low entropy is attributable to the following characteristics of the presence of life in the universe. Firstly, man's existence requires that he transform free energy so as to satisfy his basic biological needs, not to mention his desire to obtain luxury goods.[4] Secondly, man's unique ability to develop and employ tools or "external

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[1] Georgescu - Roegen. The Entropy Law, p. 10

[2] Georgescu - Roegen. The Entropy Law, pp. 281 - 282.

[3] Georgescu - Roegen. The Entropy Law, p. 279.

[4] Georgescu - Roegen. The Entropy Law, p. 277.

aids" to facilitate the transformation process futher impacts on the entropic process. More specifically, in the economic process man augments his natural biological tools, endosomatic instruments,[1] with tools which improve his ability to harness, transform and process the stock of availible free energy. Therefore, it can be argued that "man's existence is irrevocably tied to the use of exosomatic instruments and hence to the use of natural resources."[2] Finally, the production of tools to be employed in other production processes impacts directly on the magnitude of the entropic process. That is, the production of tools can be thought of as the transformation of free energy so as to improve the conversion rate[3] in other economic processes. As a result, this causes the entropy of the the environment in which man exists to increase to a greater degree than if man employed only his endosomatic instruments in the production process.

The third consequence of the Entropy Law relates to its usefulness as a forecasting tool. Although the two

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[1] Those instruments which are part of each individual organism at birth.

[2] Georgescu - Roegen. The Entropy Law, p. 21.

[3] Georgescu - Roegen argues that exosomatic arms function to allow man to obtain the a greater quantity of free energy with the same level of exertion of his own low entropy. (Georgescu - Roegen. The Entropy Law, p. 307.

laws of thermodynamics have contributed to the recognition of the inherent evolution which characterizes our existence, they do not in any way facilitate quantitative analysis and prediction. Contrary to the mechanistic appeal of being capable of determining the exact time and location of the occurrence of a particular event, the Entropy Law only enables us to specify the general direction of the entropic process.[1] More specifically, we know with certainty, that over the progression of time[2] the entropy of the universe will increase. However, we can neither measure the quantity of bound energy nor can we predict a specific time at which the entropy of the universe will reach a maximum.[3]

The Entropy Law and Scarcity

The fourth consequence of the operation of the entropy law is that it gives us a framework in which to discuss and analyze the effect of mere existence, not to mention production and growth, on pressing issues such as natural resource availability, pollution and overpopulation. More specifically, the question of scarcity alluded to in Ricardo's

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[1] Georgescu - Roegen. The Entropy Law, p. 12.

[2] Where time refers to the "stream of consciousness" as opposed to mechanical clock time.

[3] Georgescu - Roegen. Economic Myths, p. 9.

theories[1] of income distribution can be more accurately defined in terms of both the first and second laws of thermodynamics.

Scarcity, in the context of thermodynamics, derives from two sources. Firstly, the finite quantity of matter and energy determined by The Law of Conservation of Matter and Energy, implies a long - run scarcity of free energy and matter. However, The Entropy Law, particularly the irrevocability of the entropic process, is the crucial determinant of scarcity in the universe. Once a particular quantity of low entropy has been used, it can never be employed in the performance of mechanical work again.[2] Critics of the role of thermodynamics in the economic process argue that this difficulty can be overcome by recycling waste - high entropy. However, this is not theoretically valid as the process would require that a greater amount of energy be exerted to retrieve less than 100% of the previously used energy.

The use of low entropy, currently, for the satisfaction of any need, particularly one which is non - basic, reduces the quantity of energy available for use in mechanical work sometime in the future and, hence, the attainable standard

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[1] The finite availability of superior quality land - diminishing returns at the extensive margin - as well as, the reduced productivity of a given piece of land over time - diminishing returns at the intensive margin.

[2] Georgescu - Roegen. The Entropy Law, p. 278.

of living. Furthermore, by rapidly exhausting the material base or terrestrial stock of energy, we forfeit the future use of the flow of solar energy. Scarcity and the long - run sustainability of the system are dictated by the earth's stock of resources and the rate at which we deplete them. i.e. the degree to which we magnify the natural entropic process. More specifically, the operation of the Entropy Law implies that "the maximum of life quantity requires the minimum rate of natural resource depletion."[1]

There remains, however, a significant difference between the classical concept of land scarcity and the entropic notion of resource scarcity. The scarcity of Ricardian land is exhibited as production expands at the extensive margin, through the unavailability of an infinite store of high quality land. More specifically, as the scale of production expands, producers must necessarily incorporate lower quality land into the production process. This scarcity is not, however, binding in a temporal sense, as the high quality lands can be employed once again, either at a later point in time or if the scale of production is reduced. The entropic notion of scarcity, however, is final in nature as once the quality of resources employed in production diminish, the high quality resources can not be recovered at any time.

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[1] Georgescu - Roegen. The Entropy Law, p. 21.

Similarly, pollution is the natural consequence of the qualitative degradation of low entropy. More specifically, according to the first and second laws of thermodynamics, the total quantity of energy is fixed, but undergoes a continual transformation. Hence, pollution can be defined as a "measure of the unavailable energy present in the system."[1] Furthermore, given that the economic process accelerates the entropic process, it must also increase the quantity of waste or pollution in the system. Pollution then can be thought of as a natural and unavoidable consequence of production and "bigger and better technology (leads) to bigger and better pollution."[2]

The final and most important consequence of the first and second laws of thermodynamics is that, in opposition to the teachings of mechanical physics, the thermodynamic branch of physics has recognized that qualitative change is an inherent characteristic of existence. More specifically, the Entropy Law, being the "most economic in nature of all natural laws",[3] moves us one step closer to an accurate theoretical representation of both the biological and economic

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[1] Rifkin. Entropy, p. 35.

[2] Georgescu - Roegen. The Entropy Law, p. 19.

[3] Georgescu - Roegen. The Entropy Law, p. 3.

processes. Although we have not yet overcome the quantitative difficulties, we can use the laws of thermodynamics to analyze the long - run impact of the interaction of the production process with the material environment.

INVESTIGATION INTO THE INTERACTION OF THE PRODUCTION PROCESS WITH THE MATERIAL ENVIRONMENT

The question arises as to how the principles of thermodynamics, particularly the Entropy Law, impact on the representation of the production process and the wage profit function developed in Chapter Three and Chapter Four.

Summarizing, a production technique is defined by the semipositive Leontief technology matrix, A, and the nonnegative vector of labour input coefficients, L. The maximum eigen value, μ_m, of matrix A is positive, less than unity and an indicator of the material intensity of the production technique. Denoting the vector of relative prices by Pj, and the real wage by wj - where both are expressed in terms of some j'th commodity chosen as numeraire - and the rate of interest by π, we obtain the following Sraffa solution to the production system:[1]

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[1] Ozol, Parable and Realism, p. 356.

$$Pj = wj[I-(1+\pi)A]-1$$

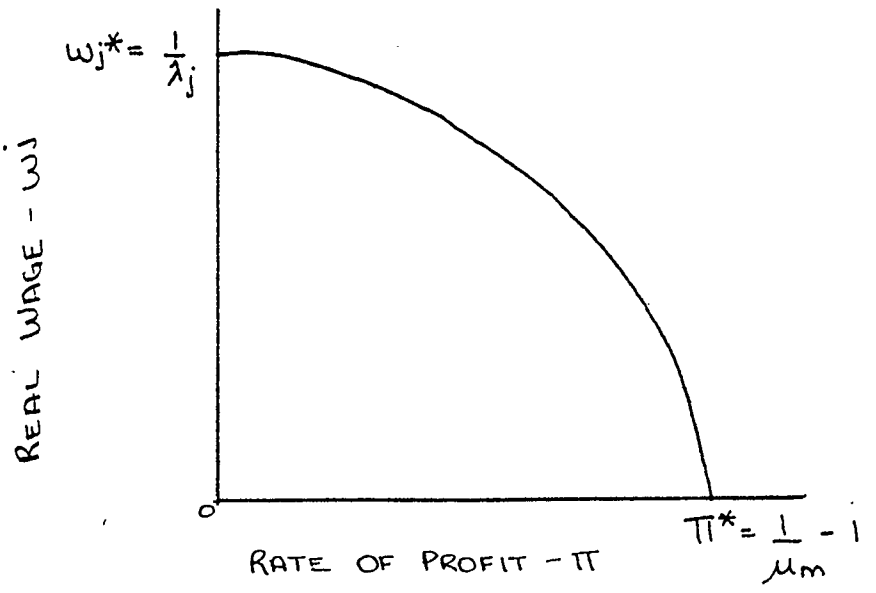
The above solution implicitly defines a relationship between the combinations of real wage, wj, and the rate of profit, π, which can be simultaneously achieved under a given pricing regime as follows:[1]

$$wj(\pi)=1/L[I-(1+\pi)A]^{-1}\, e(j),\quad 0 \leqslant \pi \leqslant (1/\mu_M)-1$$

Consequently, we obtain the following graphical representation of the wage - profit function:

FIGURE 5

THE WAGE - PROFIT FUNCTION



[1] Ozol, Parable and Realism, p. 357.

Ranking of Production Techniques

Before we introduce the Entropy Law into this analysis, it may prove useful, to have the following technique ranking methods at our disposal. Denote the set of production techniques α, β ... γ in the universal technology set, T, as follows: α, β ..... ϵ T.[1]

Labour Intensity

Firstly, a particular technique is said to be labour saving relative to another technique if it requires less of at least one type of labour per final unit output of some j'th commodity chosen as numeraire, λ_j. More specifically:

> Define: For all techniques α and β in the universal technology set T, α is labour saving relative to β iff $\lambda_j(\alpha) < \lambda_j(\beta)$, where λ_j is the relative labour value in terms of some j'th commodity chosen as numeraire, (L[I-A]-1ej) for the specified technique.[2]

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[1] Ozol, Parable and Realism, p. 357.

[2] Ozol, Parable and Realism, p. 358.

Material Intensity

Secondly, a particular technique is said to be material saving relative to another technique if it requires less input of at least one commodity per final unit output of some j'th commodity chosen as numeraire. More specifically:

> Define: For all techniques α and β in the universal technology set T, α is material or physical capital saving relative to β iff $\mu_m(\alpha) < \mu_m(\beta)$, where μ_m is the maximum eigen value of the technology matrix A.1

The Entropy Law and the Wage - Profit Function

As outlined previously, the transformation of free energy into bound energy, i. e. The Entropy Law, is an ongoing and irrevocable natural phenomenon which is both accelerated and intensified by the presence of life and the operation of the economic or production process. Therefore, it is essential that we attempt to incorporate this unavoidable occurrence into our economic representations of the production process.

The operation of the entropic process and the implicit scarcity of resources is somewhat analagous to the concept

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[1] Ozol, Parable and Realism, p. 358.

of diminishing returns in classical distribution theory.[1] However, the representation of the production process, vis - a - vis the Sraffa pricing system and input/output coefficients, requires that we assume a factory, or industrial economy as opposed to an agricultural economy. Therefore, it is necessary to further define the domain of our comparative analysis.

Ricardo's agricultural economy is characterized by diminishing returns at both the intensive and extensive margins. It is suggested that the former, which result from increased intensity of production on a specific piece of land, are incorporated into the neoclassical production function - diminishing marginal productivity of capital and labour. However, the neoclassical assumptions of homogeneous factors of production ignore the operation of diminishing returns at the extensive margin which operate as a result of the "original and indestructible powers of the soil."[2] Consequently, in our discussion of the Entropy Law, as an analogy to classical theories, we are implicitly referring to the operation of the industrial counterpart to diminishing returns at the extensive margin which are experienced in

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[1] Young. Entropy, p. 2.

[2] David Ricardo. "On Rent", in The Works and Correspondence of David Ricardo, vol. I, ed. Piero Sraffa, p. 67.

Ricardo's agricultural setting.[1] Finally, contrary to the agricultural setting which harnesses the relatively more abundant solar low entropy, the mechanized industrial process is dependent upon the finite, terrestrial low entropy.[2] Consequently, the entropic process which we discuss emphasizes the material base or the degradation of free energy contained in the earth.

There are two instances in which the diminishing returns are experienced in the economic process. Firstly, continual operation at a constant scale of production is characterized by a natural reduction of available low entropy which, according to the first and second laws of thermodynamics, can be neither created nor restored.[3] Secondly, the expansion of the scale of production magnifies the natural transformation of free energy, reducing the quantity of energy available for use in mechanical work. More specifically,

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[1] Young. Entropy, pp. 84 - 86.

[2] Georgescu - Roegen. Economic Problem, p. 57.

[3] Georgescu - Roegen. The Entropy Law, pp. 5 - 6.

> the advantages of mechanization (and growth) are not without a price ... we can obtain them by eating more quickly into the "capital" of low entropy with which our planet is endowed.[1]

Furthermore, as the availability of free energy decreases, the production process is forced to attempt to harness previously less accessible forms of low entropy. Consequently, by necessity, the production process must become more labour and material intensive. In the context of entropy, this implies that increasing quantities of free energy must be used merely to obtain the same quantity of final output from poorer qualities and less accessible material low entropy. Georgescu - Roegen defines this phenomenon as development proper[2]

> the innovation of finer sieves for the sifting of low entropy so as to diminish the proportion of it that inevitably slips into waste.[3]

In other words, over time, modifications to the extant techniques of production are required to take the form of an extension of "exosomatic arms", so as to facilitate the

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[1] Georgescu - Roegen. The Entropy Law, p. 303.

[2] As opposed to pure growth represented by an expansion of the scale of output without changing or modifying the tools of production.

[3] Georgescu - Roegen. The Entropy Law, p. 294.

production of the same level of output or so as to maintain the existing level of production. It should be noted that if the economy is growing in scale, it will cause a more rapid degradation of low entropy, thereby requiring the devlopment of even finer sieves or longer exosomatic arms.

As mentioned previously, both the natural and induced entropic process can be analyzed in terms of the model of the production process, particularly the wage - profit function. For simplicity and clarity we restrict this discussion to the case of an economy which is operating at a fixed scale of production.

With the passage of time, a given level of production requires increasing quantities of labour and material inputs to maintain itself. The impact of this on the maximum rate of profit and real wage attainable in the system, for a particular technique of production, i. e. the parameters of the wage - profit function can be described as follows:

Firstly, the additional input requirements, and increased material intensity are reflected by an increase in at least one of elements of the Leontief matrix A, the commodity input requirements per unit of final output, aij. Given that the maximum eigen value of a particular technique is an increasing function of the size of the coefficients within that matrix, it will increase as the entropic process takes its toll on the material environment. Similarly, as

$\Pi^* = 1/\mu_m - 1$, the increasing maximum eigen value, μ_m, causes the maximum rate of profit attainable under a particular technique of production is expected to decrease over time.

Secondly, the increased labour intensity is reflected in an increase in one or more of the coefficients in the vector of labour requirements, L. As these coefficients increase, the labour values of commodities, measured by L(I-A)-1, also increase. It should be noted that the increased material intensity magnifies this effect as more labour is required to produce the additional material input requirements. By definition, as λ_j^* increases, the net efficiency of labour employed in production and the maximum wage attainable in the system decline.[1]

Summarizing, our theoretical framework would suggest that the "exosomatic arm" extension which necessarily accompanies the unavoidable operation of the entropic process is reflected in a reduction of the parameters of the wage - profit function. The lower labour efficiency and maximum profit rate allow us to graphically depict the depletion of the resource base by a contraction of the wage - profit function toward the origin as shown below:

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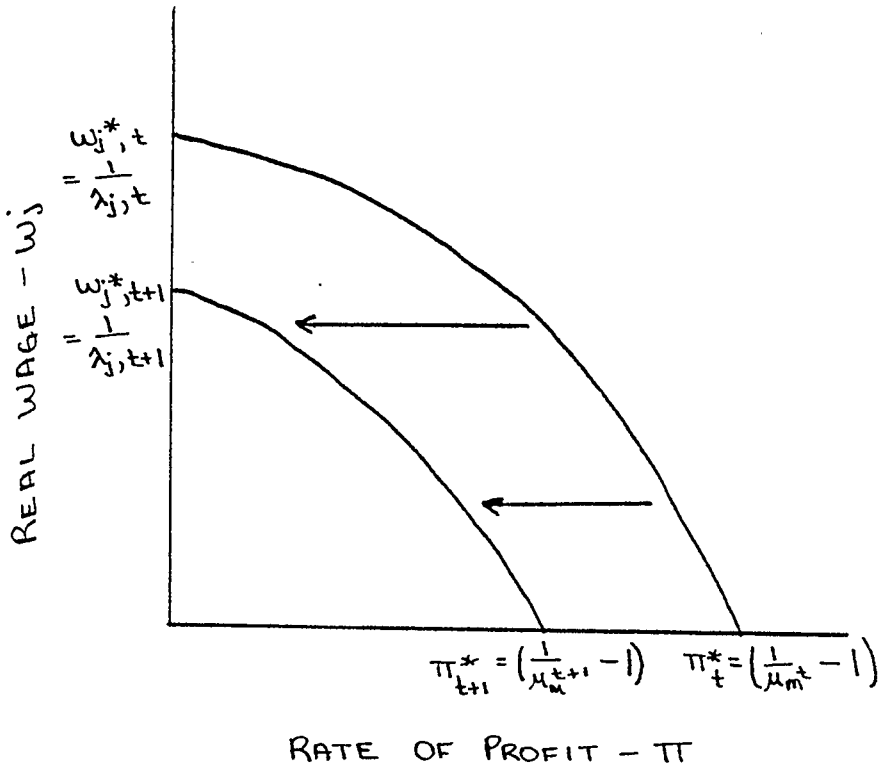
[1] Given that $w_j = 1/\lambda_j$, as λ_j increases, w_j declines.

FIGURE 6

CONTRACTION OF THE WAGE - PROFIT FUNCTION



The reader should note that this contraction is gradual over time and does not occur in discrete quantifiable movements. More specifically,

> the working of the Entropy Law through the economic process is relatively slow, but it never ceases ... It's effect makes itself visible only by accumulation over long periods.1

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1 Georgescu - Roegen. The Entropy Law, p. 19.

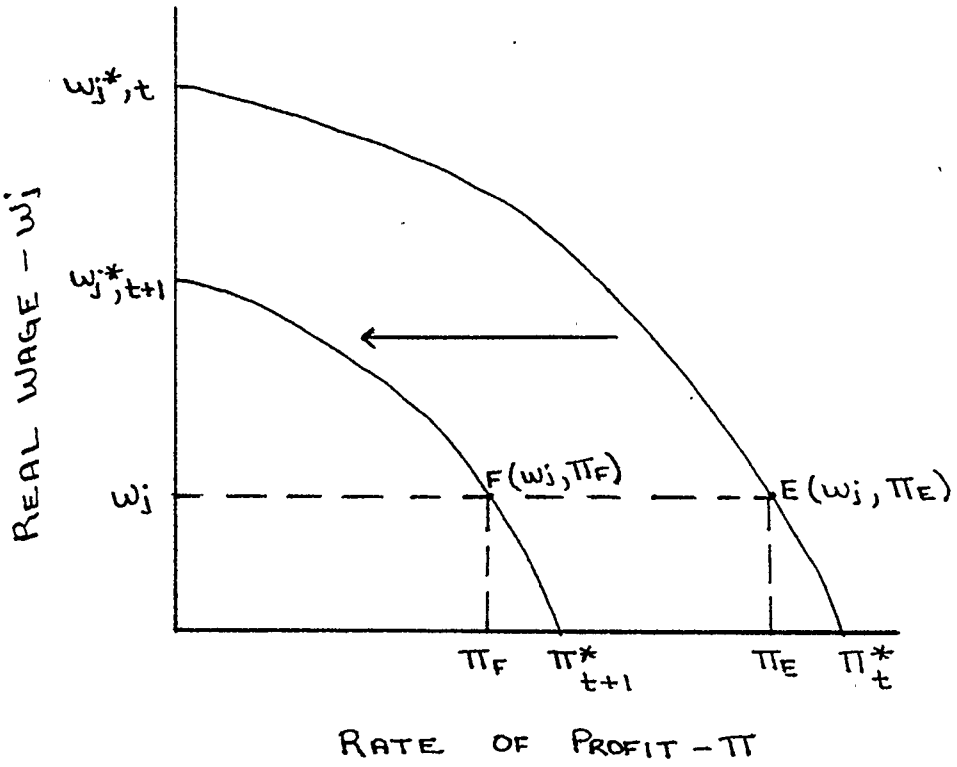
Furthermore, the contraction is not necessarily parallel to the wage profit function of the previous time period. The form of the contracton is determined by the effect of the entropic process on the labour and material input requirements and their relative weights in the technique of production.

The Response of Producers to the Contraction of the Wage - Profit Function

The effects of the interaction of the production process with the material environment, as specified above, do not go unnoticed by producers who find it increasingly difficult to maintain the same level of profit for a particular wage rate at a relative pricing structure. For example, using the Figure 7:

FIGURE 7

ATTAINABLE WAGE - PROFIT COMBINATIONS



During time period t, producers are able to maintain a wage - profit combination such as that indicated by E. However, as the transformation of free into bound energy becomes increasingly difficult, and assuming that wages are downwardly rigid, the rate of profit which the producer can obtain is gradually reduced. At some time period, t+1, we will observe that the attainable wage - profit combination, using the same technique of production, has changed to that

indicated by F. At this point the attainable rate of profit, π_F , is less than in the previous time period, π_E .

Assuming that producers exhibit profit maximizing behaviour, there will be incentive to attempt to halt or reverse the profit reducing impact of entropic degradation. Producers can be expected to adopt cost - minimizing techniques of production so as to maintain the initial profit rate, π_E . There are three ways in which the producers can attempt to compensate for the natural and unavoidable profit reduction. They can adopt techniques of production which are labour - saving, material - saving, or a combination of both.

Let us first address the possibility of impacting on the material intensity of production in the context of the Entropy Law. The first law of thermodynamics prohibits the creation of free energy or unused natural resources, while the second law of thermodynamics precludes the ability to reverse the entropic process. Consequently, impacting on the material intensity of the production technique is not a feasible option. However, this conclusion requires further comment.

At risk of committing the fatal error of employing neoclassical terminology, it has been argued that

technological innovations[1] are subject to diminishing returns. That is, in the early stages of society, there is a vast frontier of "economy innovations" which generate a greater amount of free energy than is exerted in their development.[2] However, as society advances, the entropy of the system reaches a maximum, and the set of available, entropically feasible,[3] technologies diminishes. More specifically,

> sucking more energy out (of the environment) becomes more expensive and complicated. The disorder created by the past flow - through accumulates, exerting increasing pressure and putting further retraints on new technological possibilities.[4]

In summary, during the early stages of productive activity, it may be possible for producers to adopt technologies which reduce material intensity - by substitution of "materials costing less in energy."[5] However, this ability gradually

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[1] Where technology is a transformer of energy.

[2] Georgescu - Roegen. Economic Myths, p. 18.

[3] Those technolgies which allow the productive process to use less low entropy than alternate technologies an which require less low entropy in their own development than the energy which they make available for use in mechanical work.

[4] Rifkin. Entropy, p. 85.

[5] Georgescu - Roegen. Economic Myths, p. 18.

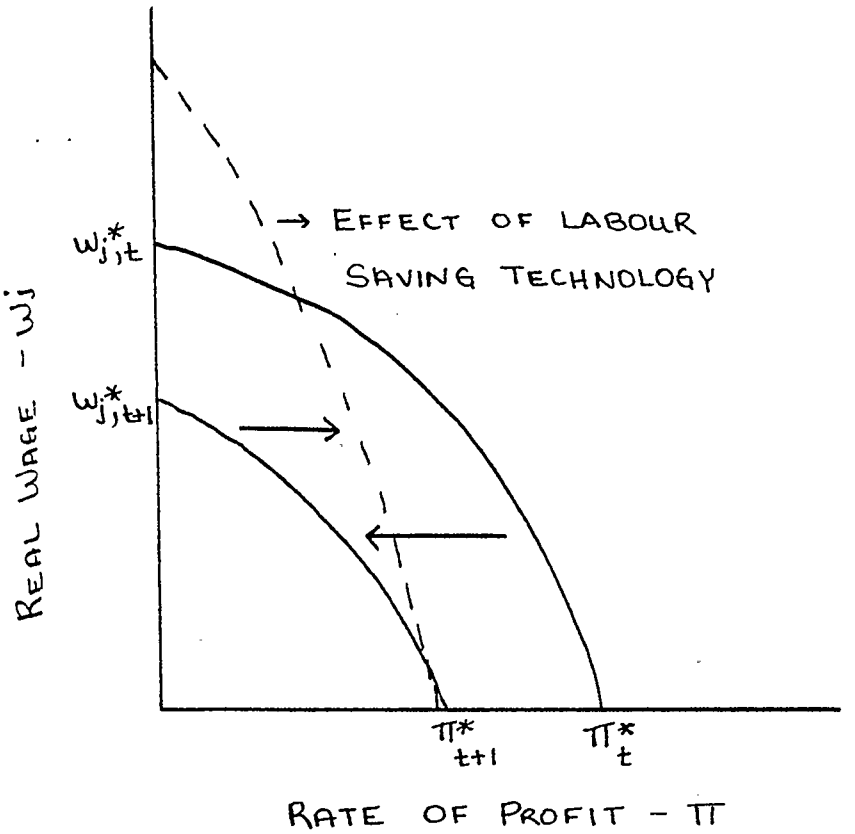
diminishes with the operation of the entropic process over time. Consequently, producers are unable to effectively respond to the contraction of the wage - profit function by adoption of less material intensive techniques.

In their attempts to maintain the profitability of the production process, most producers will adopt labour saving techniques which normally take the form of mechanization and automation. This will have a counter - acting effect on the growing, entropically induced labour coefficients. The effect of these technological innovations will reduce the quantity of labour required per final unit of output, which further causes the relative labour values, as measured by L(I-A)-1ej, to decline. By definition, therefore, maximum labour efficiency, $1/\lambda_j$, will increase.

The impact of the above profit maximizing behaviour of producers on the contracting wage profit function can be shown diagramatically as follows:

FIGURE 8

PRODUCER'S RESPONSE TO THE CONTRACTION OF THE WAGE - PROFIT FUNCTION



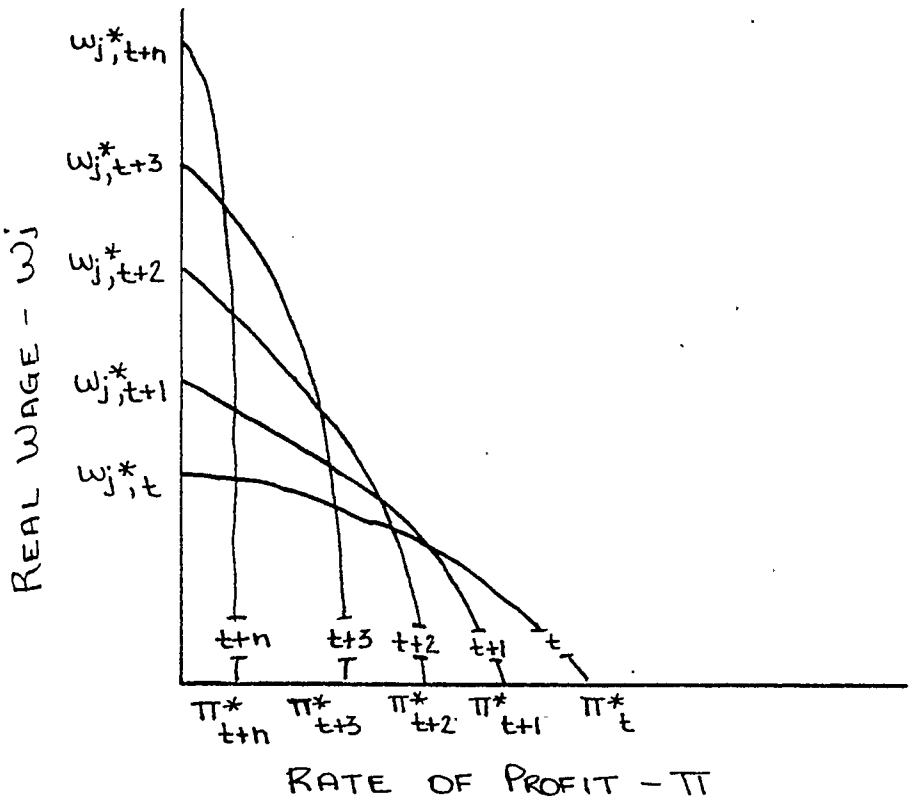
The above figure indicates that at some points in time, producers are able to partially overcome the negative impact of the entropic process on profitability, by adopting labour saving techniques and, therefore, maintain a particular combination of real wage and rate of profit.

The question arises, however, "how long can this game of tag continue?" Given that the harnessing of free energy

and, hence, the production of a specific output level, with a particular combination of physical capital and labour, increases in difficulty, over time, at some point the compensating behaviour of producers is no longer effective. As the size of the coefficients of the labour requirements vector, L, and the technology matrix, A, increase, the implicitly defined wage - profit function contracts toward the origin at an increasing rate. Consequently, the profit maximizing behaviour of producers, as outlined above, would suggest that each successive technique which is adopted must be increasingly effective in terms of its labour saving characteristics. However, the diminishing returns to technology discussed earlier, suggest that the ability to maintain continual advances in the development of labour saving technology of sufficient magnitude is questionable. Over the long run, therefore, we would expect the maximum rate of profit to approach zero as follows:

FIGURE 9

THE LONG RUN BEHAVIOUR OF THE WAGE - PROFIT FUNCTION



IMPLICATIONS OF THE FALLING RATE OF PROFIT

Clearly, the conclusion that the rate of profit attainable within the economy tends toward zero, in response to the unavoidable operation of the Entropy Law, must not be dismissed. The prediction suggests that an economy which operates in accordance with a profit motive is unable to sustain itself in the long run. We can not, however, pass

judgement with respect to the societal structure which can be expected to succeed the capitalist economic system. The development of new technologies which economically harness the solar flow of low entropy, or the return to peasant agricultural based economies, although possible, can not be predicted with certainty.As a result, we can only state, with certainty, that the unavoidable decline in the rate of profit will result in the demise of any economic system which operates in accordance with a profit motive - the capitalist system - whether that system is agricultural or industrial based.

CONCLUSION

In conclusion, recognition of the laws of thermodynamics, particularly The Entropy Law, and their incorporation into economic theories and models enables us to overcome a number of difficulties and inadequacies of mechanistic neoclassical economics. More specifically, we have recognized that qualitative change is an inherent characteristic of our existence. Furthermore, the laws of thermodynamics enable us to explain the natural, unavoidable and irrevocable nature of the issues of resource scarcity., More importantly, however, the operation of the entropic process implies that the maximum rate of profit attainable within the economic system

uncontrollably approaches zero over the long run. This conclusion becomes even more significant with the recognition that a society which operates only to maintain itself, sometimes referred to as a steady state economy, can not escape this fate. That is the diminishing rate of profit can not be counteracted upon by reduction of economic growth to zero. The impact of growth and expansion of production on the economy is merely to magnify and accelerate the natural and unavoidable tendency of the rate of profit to fall to zero. The question arises, however, as to how producers and society in general should respond to this phenomenon. It has been suggested that the only way in which a society can delay the degradation of the energy base and , hence, improve its long run sustainability, is to revert to an agricultural economy which is predominantly dependent upon the abundant flow of solar low entropy rather than the finite stock of material low entropy. However, any comments with respect to the fate and nature of a post - capitalist society, are merely speculative and beyond the scope of this paper.

CHAPTER SIX

CONCLUDING REMARKS

The evolution of the societal infrastructure from a feudal agricultural economy to a capitalist economy - operating in accordance with a profit motive - is necessarily accompanied by theoretical queries into the determination of income distribution among alternate classes of society. The history of economic thought, therefore, is characterized by various theories with respect to both the short run distribution of income generated in production, as well as the long run sustainability of the capitalist economic system. The most significant schools of thought can be classified under two alternate headings - classical and neoclassical.

The classical economists argue that in a predominantly agricultural based economy, income generated in production is distributed among three classes of society - capitalists, landlords and labourers - in the form of profits, rent and wages respectively. The classical teachings, however, are intuitive in nature and argue that the aforementioned income distribution is in accordance with relatively qualitative considerations such as the productive characteristics of land and culturally determined subsistence requirements.

The neoclassical school, on the other hand, argues that income generated in a predominantly industrial economy is distributed to capitalists and labourers - as profit and wages - in accordance with their marginal productivities and the operation of free market forces. Clearly, both schools of thought refer to alternate productive environments and, therefore, differ with respect to both the determination of the distribution of income and the income recipients.

However, the more significant difference between both schools rests in the predictions with respect to the long run behaviour of the distributive shares of income and hence, the sustainability of the capitalist economic system. The classical school, on the one hand, predicts that the intertemporal behaviour of the distributive shares of income is characterized by a gradual decline in the rate of profit attainable, in response to the operation of the principle of diminishing returns. The consequence of this conclusion is perceived to be the ultimate insustainability of the capitalist system. The neoclassical school, on the other hand, ignores the role of the material environment in the production process, assumes that the rate of profit generated in the economy remains relatively stable over time, and consequently, supports continual, unharnessed growth of the scale of production.

The difference between the two theories, with respect to the long run rate of profit generated in the economy stems from the mechanical nature of the neoclassical models which operate in isolation from the material environment. However, once a modified representation of the industrial economy - which recognizes the reciprocal relationship between the production process and the material environment - is developed, it is shown that the "dismal" forecasts of the classical economists can not be avoided. More specifically, Sraffa's representation of the economy, postulating the production of commodities by means of commodities and labour, provides the basis for the analytical representation of the industrial economy developed and analyzed in Chapters Three, Four and Five. While the Sraffian representation of the economy does not lack theoretical inadequacies and inconsistencies, it can be readily modified and expanded so as to facilitate the incorporation of the role of the material environment, quantification of economic process, as well as improving the usefulness of the model as an analytical and forecasting tool.

The analytical modification of Sraffa's representation of the economy requires that we divide actuality into partial processes, which are defined by both a physical and temporal boundary - specifying the nature, e. g. commodity production, and the duration of the process, respectively.

Furthermore, the description of the partial production process with reference to commodity movements across the boundary of the process requires that the components of each process be classified under one or both of two alternate headings - flow and fund elements. The analytical representation of the production system which flows from the above modifications defines a monotonically inverse wage - profit relation for a given technique of production, defined by the matrix of technical coefficients, and a vector of direct labour requirements. More specifically, the analytical representation of the production system measures the real wage, expressed in terms of some j'th commodity chosen as numeraire and the profit rate as inverse functions of the labour value (intensity) and material intensity of the production technique respectively.

Georgescu - Roegen suggests that the qualitative degradation of the material environment is explained by the laws of thermodynamics, particularly the Entropy Law. More specifically, the natural and production induced operation of the entropic process results in increasingly labour and material intensive techniques of production. This is reflected in the size of the elements of the Leontief technology matrix, A, and the vector of direct labour requirements, L, which implicitly impacts on the parameters of the derived wage - profit function. It is shown that the operation of

the entropic process implies that the maximum rate of profit attainable within the industrial capitalist system uncontrollably tends toward zero over time. Even though producers attempt to counteract this phenomenon through the adoption of labour saving techniques of production, the negative impact of the qualitative degradation of the material environment can not be overcome. As a result, the prediction remains consistent with classical teachings - over the long run, the motivating force behind the capitalist economic system - the rate of profit - tends toward zero and the system is unable to sustain itself.

In summary, economic theories can not indefinitely escape the "dismal" forecasts of the classical economists. More specifically, it is shown that the classical prediction that the general rate of profit earned in the economy tends toward zero, over time, applies in both an agricultural and an industrial based economy. The classical catalyst for this conclusion rests in the intuitive discussions of vague issues, specifically, the principle of diminishing returns. However, the analytical representation of the economy developed in Chapters Three and Four, finds the impetus for this conclusion in the operation of the physical laws of thermodynamics, particularly the Entropy Law. Clearly, the Entropy Law is shown to be analagous to the classical theories of diminishing

returns as both recognize the qualitative nature of the material environment.

The development of an analytically superior representation of the economy and its component production processes is not without accompanying inadequacies. The modified Sraffian model of the economy is analytically and theoretically superior to the extant classical and neoclassical models of the economy. However, by solving some problems, we have created numerous others, in that we have obtained validity and accuracy in exchange for quantifiability. Although we now know, with certainty, that the rate of profit generated in the economy diminishes over time, we are unable to specify the rate at which it falls nor the specific point in time at which is reaches zero.

The skeptic must be reminded, however, that analytical accuracy must have priority over quantifiability so as to ensure the validity of economic analysis and policy recommendations. Furthermore, the preoccupation with quantification of economic phenomenon stems directly from the reliance on the inapplicable laws of mechanics. However, given that the underlying basis of all existence is qualitative change, the pursuit of quantification is futile to say the least.

Finally, the effect of the operation of the entropic process on the maximum rate of profit attainable is a gradual

process and its full impact is experienced in the long run. The seriousness with which one considers the implication of the predictions with respect to the falling rate of profit is dependent upon the degree to which one discounts the future. However, unlike the time in which the classical forecasts were made, we are approaching the entropy maximum and the effects of the operation of the Entropy Law are being increasingly apparent through mounting pollution and natural resource scarcity. We are unable, however, to predict the development of alternate technologies which will allow for the reduction of these problems, and provide alternate societal infrastructures which will replace capitalism. We can only state with certainty that the rate of profit generated in the economy approaches zero and the fate of the capitalist society is ultimate unsustainability.

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