TECHNOLOGICAL INNOVATION:

WHAT DO THE SCHUMPETERIAN HYPOTHESES IMPLY?

TO

JAPU, CHOTO, GAUTAM

AND MY PARENTS

TECHNOLOGICAL INNOVATION:

WHAT DO THE SCHUMPETERIAN HYPOTHESES IMPLY?

by

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ABSTRACT

A large section of the industrial organization literature is devoted to the interpretation and empirical testing of the hypotheses advanced by Joseph Schumpeter concerning market structure and innovation. One set of hypotheses deals with the monopoly power of firms and its association with innovation, while the other set focusses on the relationship between firm size and innovation. Empirically these two sets of hypotheses may not be independent of each other, although extant empirical studies have concentrated on one in isolation of the other. In this dissertation we build a general framework where these two sets of hypotheses can be considered together in order that we can properly identify either effect -- that is, the effects of monopoly power and of firm size on innovation.

A major objective of our study is to combine two recent developments in the literature. First, it has been empirically demonstrated that proxies for appropriability and technological opportunity, when included in the regression, significantly diminish the explanatory power of concentration (a measure of monopoly power) on innovation and innovation-related activities, such as Research and Development (R&D) expenditures. In this dissertation, we construct several proxies for appropriability and technological opportunity, using new data on innovative activities of firms in Canada collected by the Economic Council of Canada.

Second, it has been recently argued that, except in the short run, both market structure and innovative activities ought to be treated as endogeneous, as opposed to the existing practice of assuming that the market structure is given. Our theoretical framework allows both innovative activity and firm size (a measure of market structure) to be determined by appropriability, technological opportunity and various non-innovative factors such as demand conditions, foreign versus domestic ownership of firms, etc.

It is commonly observed that firms sometimes choose not to hire any R&D personnel, namely, scientists and engineers, and instead entrust the responsibilities of R&D either with a consulting firm or even with its own operating personnel. These decisions result in observations with 'zero' values for R&D personnel in the sample. In this dissertation, we provide an economic underpinning for such decisions by firms and recognize this 'limited-dependent variable' problem in our estimation through use of the Tobit estimation method.

Finally, as a by-product of our theoretical framework we examine some of the common empirical measures which have been used to test the Schumpeterian hypotheses. One of our major findings in this regard is that many of the existing empirical tests of the hypothesis that there is a positive externality from firm size to innovative activities of firms are misspecified in the sense that they are neither necessary nor sufficient for the existence of the above externality.

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This dissertation is my first major research project since I was introduced to economics at South Point High School, Calcutta. One of the profound influences, which has remained with me all these years, came from my former teacher, Professor A. Dasgupta of the department of economics at Calcutta University. Since then the work and influence of the professors in the departments of economics at Calcutta University and McMaster University have had significant effects on the way I have come to approach the subject.

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Needless to say, I alone am responsible for any remaining errors.

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CHAPTER I

INTRODUCTION

I.1 A Statement of the Problem

Economists have always recognized the importance of technological innovation for economic progress. In the early part of this century, Schumpeter (1934) gave innovation a central role in his Theory of Economic Development[1]. He made the important distinction between invention and innovation which has since been incorporated into studies of technological change. In this theory (henceforth referred to as Model 1), Schumpeter stressed the crucial role of the entrepreneur in the complex process of innovation. He claimed that innovations are economically irrelevant unless they are commercialized and hence, that the economic leadership of the entrepreneur is far more important than invention itself. In this model, invention was considered exogenous to the economic system.

Modern industrial Research and Development (R&D) activities, however, suggest a different story. Although no one will disagree with the crucial role of the entrepreneur in the success of a firm

[1] Theory of Economic Development was first published in 1912, and the first English translation appeared in 1934.

and its innovative activities, there is ample evidence of increasing scientific and inventive activity within firms over the last half century (OECD, 1971). Therefore, Schumpeter's Model 1 will be less appropriate for our understanding of modern industrial R&D[2].

Almarin Phillips (1971) has pointed out that in his later work Schumpeter recognized the 'internalization' of much scientific and inventive activity within the firm. In his 1928 article, Schumpeter pointed out that bureaucratic management of innovation was replacing individualistic flair and that the large corporation was becoming the main vehicle for technological innovation in the economy. His later views are best described in his 1942 book, Capitalism, Socialism and Democracy. Two broad views on the subject were expressed: monopoly firms have special advantages in innovative activities (referred to henceforth as Model (2)), and large firms are more innovative than small firms (referred to henceforth as Model (3)). In this dissertation, we reexamine these two views which are commonly referred to in the neo-Schumpeterian literature as the Schumpeterian hypotheses.

Empirical studies of the Schumpeterian hypotheses occupy a large section of the neo-Schumpeterian literature. Researchers

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[2] A parallel interpretation of Model 1 says that autonomous innovative activity by entrepreneurs is the mainspring of economic development. Freeman (1982, pp. 127-128) notes that this is true in the case of radical innovations, such as synthetic materials. An opposite view is held by Schmookler (1966) who claims that innovations respond to market signals and investment behaviour. See chapter II for more on this latter argument.

have examined statistical relationships between various measures of firm size and monopoly power and measures of innovative output and input. The theoretical literature have attempted to broaden the original Schumpeterian hypothesis by introducing specific features of the Schumpeterian 'process of creative destruction', namely, the race to innovate, timing of innovation, imitative versus original innovation, etc. One general characteristic of these theoretical studies is the endogeneity of both market structure and innovative activities (e.g., Dasgupta and Stiglitz, 1980a and 1980b). These studies are mostly based on game theoretic and decision theoretic approaches. For an excellent review of the entire neo-Schumpeterian literature, see Kamien and Schwartz (1982).

In the following section we describe our itinerary for this dissertation.

I.2 Plan of the Dissertation

This dissertation contains seven chapters. In chapter II we provide a description of the historical development of economic thought on technological change. Our discussion traces the major developments in economists' conceptualization of technological change since Adam Smith. This provides us with an opportunity to briefly study some of the non-Schumpeterian views on the subject. Also, in this chapter we describe various terminologies used in studies on technological innovation.

Chapter III describes the Schumpeterian hypotheses and formalizes those hypotheses in a theoretical framework. This framework allows us to examine some common empirical measures of these hypotheses, and later it also guides our own empirical study.

A review of a large portion of the existing empirical attempts to study the Schumpeterian hypotheses is provided in chapter IV. We also devote a section of this chapter to some common measurement problems encountered in empirical studies of the Schumpeterian hypotheses.

In chapter V we describe a statistical framework which we can use to test the Schumpeterian hypotheses.

Our empirical results, which are based on data on innovative activities of firms in Canada, during the period 1960-78, are discussed in chapter VI.

Finally, in chapter VII we provide a summary of the dissertation and suggestions for future research on this topic.

CHAPTER II

ECONOMISTS' CONCEPTUALIZATION OF TECHNOLOGICAL CHANGE

II.1 Introduction

This chapter is an introduction to the subject, technological change; in chapter III we shall discuss the Schumpeterian hypotheses. In this chapter, we sketch the development of economists' conceptualization of technological change since Adam Smith. Most of the authors covered in this discussion were concerned with the problems of development and growth in their respective societies. In this sense, they viewed technological change as a "macro" phenomenon with an all-pervading nature in society, in comparison to most contemporary studies which primarily employ microeconomic tools of analysis in order to analyze the process of technological change in an industry. This dissertation follows contemporary literature in this regard.

The following discussion is organized chronologically, beginning with Adam Smith and ending with Christopher Freeman. We are interested only in the major contributions on the subject and the linkages between those contributions. We, therefore, do not intend to cover all the authors who have contributed to the development of the subject.

II.2 Smith and Marx and Engels

Economists' preoccupation with technological change stems from the fundamental economic truth of any society that, given the limited supply of factors of production, growth in national output in the long run can be achieved mainly through increases in factor productivity. Factor productivity may rise either due to qualitative changes in the factor itself, or through some changes in a complementary factor, or through the introduction of a new factor in the production process.

One of the oldest contributions on the subject is by Adam Smith. He described the pin-making process to explain the role of "division of labour" in the growth of labour productivity:

> "This great increase of the quantity of work which, in consequence of the division of labour, the same number of people are capable of performing, is owing to three different circumstances; first, to the increase of dexterity in every particular workman; secondly to the saving of the time which is commonly lost in passing from one species of work to another; and lastly, to the invention of a greater number of machines which facilitate and abridge labour, and enable one man to do the work of many" (Smith, 1937, p. 7, emphasis mine.)

Therefore, owing to divisions of labour since each workman concentrates on one single object, they "should soon find out easier and readier methods of performing their own particular work, whenever the nature of it admits of such improvements" (ibid, p. 9). This association between invention of machines and division of labour is one of the earliest descriptions of the process of technological change. Note that invention for Smith is endogenous, in the sense that it depends on the scope of further improvements in the work of each workman.

Marx and Engels' treatment[1] differs from that of Smith. They viewed the development of technology in a historical perspective; for instance, Engel (1910, pp. 12-13) put forward the following introduction to Marx's periodization scheme:

> "We divide the history of industrial production since the middle ages into three periods: (1) handicraft, small master craftsmen with a few journeymen and apprentices, where each labourer produces the complete article; (2) manufacture, where greater number of workmen, grouped in one large establishment, produce the complete article on the principle of division of labour, each workman performing only one partial operation, so that the product is complete only after having passed successively through the hands of all; (3) Modern Industry, where the product is produced by machinery driven by power, and where the work of the labourer is limited to superintending and correcting the performances of the mechanical agent."

Although Smith didn't totally lack historical precedent to his arguments, Marx and Engels were definitely ahead of Smith in sketching out a sequence of development of technology. They not only observed that the manufacturing system attained a much

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[1] We shall treat Marx and Engel's contribution on the subject together, and shall refer to it as Marxian.

higher level of productivity over the previous system through extensive exploitation of division of labour, at the same time, they pointed out that the growth in productivity continued to be constrained by the limitations of human strength, speed and accuracy. It was only after the rise of Modern Industry that each production process was transformed into a machine process, to which scientific and engineering knowledge were applied. The establishment of this technological condition made it possible to use machinery in the production of machines. This not only standardized the products both final and intermediate, but also made it possible to produce in bulk in a short period of time.

A common point of interest among students of technical change is whether technological change should be considered as exogenous or endogenous. Marx has been often called a technological determinist,[2] that is to say that technolgoical change is exogenous to social change. In that case, economic expansion is initiated by factors such as navigational improvements which are thought to be lying outside the center of economic activities. This view is surprisingly contradictory to the main theme of Marxian analysis. In the opening pages of the Communist Manifesto we find:

> "Modern Industry has established the world market,
> for which the discovery of America paved the way.

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[2] One of the earliest of such views was expressed by Hansen, 1921.

> This market has given an immense development to commerce, to navigation, to communication by land" (Marx and Engels, 1951, p. 34).

This statement leaves no room for doubt that Marx considered technological changes as responses to expanding profit opportunities. Moreover, without his dialectical analysis of historical change, one cannot fully discuss his views on technological change:

> "It must be kept in mind that the new forces of production and relations of production do not develop out of nothing, nor drop from the sky, nor from the womb of the self-posting Idea; but from the antithesis to the existing development of production and the inherited traditional relations of property" (Marx, 1973, p. 278).

II.3 Schumpeter and Schmookler

One of the most influential contributions on the economics of technological progress is by Joseph Schumpeter. His sharp distinction between invention, innovation and imitation is still maintained by researchers today. On invention his views were quite simple:

> "As long as they are not carried into practice, inventions are economically irrelevant" (Schumpeter, 1934, p. 88).

What is more important, particularly in his early discussions on technological change, is the quality of leadership in carrying out economic innovations:

> ".... to carry any improvement into effect is a task entirely different from the inventing of it, and a task, moreover, requiring entirely different kinds of aptitudes" (ibid., p. 88).

To put it rather succinctly, "Schumpeter placed great stress upon the charismatic figure, the entrepreneur, who possessed the character, courage and, above all, vision, required to depart sharply from accepted routines and practices" (Rosenberg, 1976, p. 67).

The above description of Schumpeter's view of technological change conforms to his Model 1 according to our classification of his contribution to the subject in chapter I. In this model, inventive activity was kept offstage and, therefore, never a topic of discussion. According to Rosenberg (ibid., p. 67):

> "....the characteristics of the inventive process, and stages through which inventions proceed on the way to full commercial application and exploitation, never emerge".

However, in his later discussion, Schumpeter allowed for internalization of much of the inventive activity within the firm. We shall discuss these later views in chapter III, referring to them as the Schumpeterian hypotheses.

In contrast to Schumpeter's Model 1, Schmookler (1966) studied inventive activity as an economic phenomenon. He began his discussion with a set of definitions that cover most of the basic terminologies used in connection with technological change:

> "Technology is the social pool of knowledge of the industrial arts.... That portion of existing knowledge which a people commands, "weighted" by its distribution among the labour force, may be called the nation's technological capacity.
>
> .... The rate of growth of a nation's technological capacity depends jointly on the rate at which it produces new technology and the rate at which it disseminates the old. We shall call the rate at which new technology is produced in any period the rate of technological progress, and the rate at which technology in existence at the beginning of a period is disseminated, the rate of replication.
>
> .... A method of producing a given good or service is a technique. When an enterprise produces a good or service or uses a method or input that is new to it, it makes a technical change. The first enterprise to make a given technical change is an innovator. His action is innovation. Another enterprise making the same technical change later is presumably an imitator and its action, imitation. Since new technological knowledge is usually produced for use, technological progress is associated with innovation as thought to deed. And since replication is likewise usually undertaken with the same objective, replication is similarly linked to imitation" (Schmookler, 1966, pp. 1-2).

It should be pointed out, however, that one making the same technical change <u>later</u> is not necessarily an imitator; he or she can very well be an independent innovator. In fact it might be interesting to look behind the more or less simultaneous innovations in different societies but in the same field: what prompts innovators in different societies to travel the same path unknown to one another?

Where does invention fit into the above set of definitions? According to Schmookler, technology consists of applied science, engineering knowledge, invention and subinvention. He described applied science and engineering knowledge as "tested generalizations" in the form of theories or laws about works of man, the former oriented more toward understanding and the latter toward control. Whereas engineering knowledge deals with a class of economic goods or a class of technical industrial processes, invention and subinvention relate to individual products and processes. "Subinvention results both from relatively straightforward applications of engineering knowledge and from acts of skill by workers, supervisors, users, and so on.... The distinction between invention and subinvention corresponds to that between a new product or process which would receive a patent at the United States Patent Office and one which would not" (ibid., pp. 6).

Corresponding to these various forms of technology, Schmookler defined three types of technology-related activities: research, development, and inventive activity. He defined research as a systematic quest for new knowledge about a class of phenomena, which implies new knowledge in applied science and/or engineering.

The National Science Foundation in the United States defines development as the creation of new products or processes, beginning with the conception of the idea and ending with its readiness for production. However, Schmookler himself used a narrower definition of development which signifies the effort expended in making a patentable invention suitable for production.

His definition of inventive activity "excludes both research, which attempts to discover properties of classes of objects or processes and post invention development which..... refines and perfects individual inventions" (ibid., pp. 8, emphasis original). Inventive activity is performed by special kind of individuals. "The kind of talent required for good scientific research or engineering development is not necessarily that best suited for inventing new products or processes" (ibid., pp. 8).

A few observations are in order. First, invention in Schmookler does not contain knowledge of applied science or engineering. He, however, argued, ".....that inventive activity now must.... be preceeded by scientific research either by the inventor himself or by others in the same organization" (ibid., pp. 8, f.n. 9). In reality, research and inventive activity are intertwined; in fact, modern industrial R&D includes both basic and applied research under the category of research.

Second, his emphasis on invention being something unique and novel, is perhaps felt required to justify use of patent statistics as a measure of invention. However, not all inventions are patented. In fact, inventors do not patent their inventions which they think have very little commercial potential. Large firms in particular, put their products to commercial test even before they apply for patents (Sanders, 1962). Therefore, Schmookler's study can be more appropriately referred to as a study of 'patented inventions'.

Third, it may be recalled that technological change in Smith is based upon the principle of division of labour, which creates inventions and subinventions. Marx and later Rosenberg, on the other hand, put more emphasis on the role of engineering knowledge and applied science as the principal components of modern technology. Rosenberg (1976, pp. 61-62) went even further to criticize contemporary economists for putting overwhelming importance on pure scientific knowledge "which purports to be of the highest and widest degree of generality" whereas engineering knowledge is usually considered in low esteem. In reality, it is usually a continuum of activities even after the major intellectual breakthrough has taken place, in which stage various other forms of technological knowledge are applied.

The question that still remains unanswered is why invention is an economic phenomenon? From the economists' point of view, invention is defined as follows:

> Invention is a new combination of pre-existing knowledge which satisfies some want (Schmookler, 1966).

Newness suggests the novelty of the product which can be partly attributed to the genius of the inventor -- often mentioned in the "transcendentalist approach" (see Usher, 1954) -- and perhaps partly, to chance. The chance factor can be ignored if one is interested in a cluster of inventions. Pre-existing knowledge on the other hand, refers to a society's intellectual heritage -- the so-called "supply side" of invention. Finally, the want-satisfying attribute of an invention implies that wants and changes in them can affect the pace and direction of technological change, via demand. Nevertheless, both the supply side and the demand side are necessary to making an invention.

Schmookler's final analysis can be summarized as follows: he observed in industries such as railroads that there exists a close relation between the purchase of railroad equipment and components and a slightly lagged increase in inventive activity as measured by patents on such items. He explained this precedence of investment over invention by saying that inventors perceive the growth in the purchase of equipment by an industry as signalling the increased profitability of inventions in that industry, and direct their resources and talents accordingly. It is important to note that his results ".... depend critically on the fact that .... capital goods inventions were classified according to the industry that will <u>use</u> them, not according to the industry that will manufacture the product or the intellectual discipline from which the inventions arise" (Schmookler, 1966, pp. 164, emphasis mine). This has invited strong criticism (from Rosenberg (1976) and Stoneman (1979), among others) against Schmookler's analysis which overemphasizes the demand side of invention and neglects the supply side. The supply side, in very general terms, takes into consideration the entire sphere of modern science and the manner in which the growth of specialized knowledge has shaped the timing and direction of inventive activity. Freeman (1982) pointed out that there is evidence for a counter-Schmookler pattern of growth in the case of radically new inventions and innovations, but a large number of secondary and improvement inventions and innovations seem to multiply rapidly as an industry grows and, therefore, seem to respond to market signals. From this he concluded that Schumpeter's Model 1, which emphasizes the autonomous role of entrepreneur, seems to apply more to radical innovations, while a Schmookler-type analysis best explains secondary inventions and innovations.

II.4 Hicks and Freeman

If Schmookler can be restated in very simple terms by saying that an increase in demand provides an incentive to invent, the neoclassical "induced innovation hypothesis" tells us that rising factor costs reduce profit from the current technique of production, hence the entrepreneur will be under pressure to invent a new technique which will economize on the dearer factors of production. This role of relative factor prices in inducing technological change is originally due to Hicks (1932, pp. 124-125):

> "The real reason for the predominance of labour-saving inventions is surely that which was hinted at in our discussion of substitution. A change in the relative prices of factors of production is itself a SPUR to invention of a PARTICULAR KIND -- directed to economizing the use of a factor which has become relatively expensive. The general tendency to a more rapid increase of capital than labour which has marked European history during the last few centuries has naturally provided a stimulus to labour-saving invention" (emphasis mine).

The post-Hicksian literature has primarily concentrated on the direction of inventive activity -- i.e., whether it is labour-saving or otherwise. Azhar (1980) and Binswanger et. al. (1978) are among the few who have pointed out the general failure to recognize the fact that, as Hicks himself mentioned, a change in relative factor prices is itself a spur to invention. In this sense, inventive activity in the induced innovation hypothesis is endogenous to the economic system and not, as commonly supposed, exogenous.

Rene [illegible] n after the publica-
tion of W.E.G. [illegible] y and Technical
Change in 1960 [illegible] comments:

[illegible] to economize more expensive factor

"If. [illegible] abour
stim[illegible] aimed
spec[illegible] s open
to se[illegible] is
inte[illegible] ot
parti[illegible] capital
costs [illegible] ce that
reduc[illegible] her this
is ac[illegible] is
irrel[illegible] e that
atten[illegible] concentrated on labour-saving
techniques" (ibid., pp. 43-44).

Salter's position is supported by Fellner (1962) and Rosenberg (1976), among others. Their main argument is that in competitive equilibrium each factor is paid the value of its marginal product, therefore, "all factors are equally 'cheap' and equally 'dear' in the eyes of a competitive firm" (Rosemberg, 1976, p. 109). Hence, the market mechanism does not provide signal for inventions with specific factor saving quality.

Ahmed (1966, 1967) declared Salter's argument as tautological, since the latter has first defined induced innovation out of existence and then has gone on to prove that it cannot exist. More precisely, in Salter's model invention reduces the cost of production by a constant amount and, therefore, it does not matter which type of invention brings about the reduction in the cost of production. Whereas in Kennedy's (1964) exposition of the hypothesis, the objective is to maximize the reduction in cost which reflects, in turn, the possibility of choosing between different types of cost-reducing inventions. Analytically Salter is accused of considering an "along the curve" movement on an isoquant, which by definition rules out invention of any sort, according to the proponents of this hypothesis. As Ahmed (1966, p. 345) explained:

> "We only have to remind ourselves that the act of invention takes us from one production function to another, while factor-substitution is moving from one point to another of the same production function. Thus, whether there has been a change in factor prices or not, as long as we have moved from one production function to another, there has been an invention".

The neoclassical theory is a valuable abstraction in view of the fact that the survival and profitability constraints are important in explaining inventive behaviour of firms. Nevertheless, some contemporary economists argue that rational profit-maximizing behaviour is seldom possible in the face of the uncertainties associated with individual innovation projects. One possible alternative is suggested by Freeman (1982) which looks at the various 'strategies' open to firms when confronted with technical change"[3]. Such an approach does not look to an equilibrium which is never attained, but does take into account the historical context of any industry in a particular country" (Freeman, 1982, p. 169). Although any classification of strategies by type is arbitrary, they are useful for purposes of conceptualization.

Freeman described six alternative strategies, namely, offensive, defensive, imitative, dependent, traditional, and opportunist[4]. Any firm may change from one strategy to another in the course of time or may follow different strategies in different lines of business.

An offensive strategy is designed to achieve technical and market leadership by being "world-first" in the introduction of new products or processes. On the other hand, a defensive innovation does not look forward to being "world-first", neither do they wish to be left behind. Such an innovator usually takes advantage of early

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3 For other alternative approaches, see for instance, Nelson and Winter (1977, 1982).

4 For a detailed discussion of all of these strategies, see Freeman, ibid., pp. 169-183.

mistakes to improve upon design and so on. Defensive R&D is typical of most oligopolistic markets and is closely linked to product differentiation. Both offensive and defensive strategies are marked by strong in-house R&D.

An imitative firm is content to follow way behind the leaders. They usually enjoy either low-cost advantage or significant market protection, and are not required to spend heavily on in-house R&D or patents, training and so on. They often participate in deliberate licensing and know-how acquisition. Dependent firms on the other hand, neither attempt to initiate nor even imitate technical change in its products. They usually operate as satellite firms around large firms as suppliers of components or as a sub-contractor. Typically, they have no R&D facilities.

The traditional firms differ from a dependent firm in the nature of their products. A dependent firm may often change its product in response to an initiative from its customers. The traditional firms are often based on special craft skills and have minimal scientific inputs. They seldom change their products, although they may survive in highly developed capitalist societies. Finally, an opportunist firm relies heavily on imaginative entrepreneurship which allows them to quickly adjust to changing markets or identify some new opportunity without any in-house R&D facilities.

II.5 Concluding Remarks

This brings us to the end of this chapter. We began our discussion with Adam Smith's views on technological change which is based on the principle of division of labour. Then we studied Marx and Engel who viewed technological change in a historical perspective.

We briefly looked at Schumpeter's contribution to the subject with some emphasis on his Model 1, followed by a fairly elaborate discussion on Schmookler. In short, Schmookler's study can be looked upon as a demand side analysis of invention and inventive activity.

Finally, we studied the neoclassical induced innovation hypothesis based on the neoclassical profit-maximizing hypothesis. As an alternative to this maintained hypothesis of profit maximization, we also briefly studied the six 'strategies' of firms suggested by Freeman in his discussion on technological activities of firms.

In the next chapter, we shall discuss the so-called Schumpeterian hypotheses, which are based on Schumpeter's Model 2 and Model 3, as mentioned in chapter I.

CHAPTER III

THE SCHUMPETERIAN HYPOTHESES

III.1 Introduction

In the previous chapter, we discussed a number of alternative conceptualizations of technological change. In this chapter we concentrate on the so-called "Schumpeterian hypotheses". Section III.2 describes the Schumpeterian hypotheses. A framework to formulate tests of these hypotheses is provided in Section III.3. In Section III.4 we examine some existing empirical measures of these hypotheses followed by brief concluding remarks in Section III.5.

III.2 Statement of the Hypotheses

The so-called "Schumpeterian hypotheses" can be broadly partitioned into two sets of hypotheses: one which deals with monopoly power of firms and its association with innovation (Model 2) and the other which focusses on the relationship between firm size and innovation (Model 3)[1].

In Schumpeter, monopoly power and innovation interact primarily in two ways. First, anticipation of monopoly power may

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[1] In chapter I, we classified Schumpeter's views on technological change into three models. In this dissertation, we mostly focus on Model 2 and Model 3.

encourage innovation. Second, possession of monopoly power will generate a larger supply of innovations because:

> ".... there are advantages which, though not strictly unattainable on the competitive level of enterprise, are as a matter of fact secured only on the monopoly level, for instance, because monopolisation may increase the sphere of influence of the better, and decrease the sphere of influence of the inferior, brains, or because the monopoly enjoys a disproportionately higher financial standing" (Schumpeter, 1950, pp. 101).

Furthermore,

> "The product of the new method has to compete with the products of the old ones, and the new commodity has to be introduced, i.e., its demand schedule has to be built up" (ibid., p. 102).

Therefore,

> "Long-range investing.... under the impact of new commodities and technologies, is like shooting at a target that is not only indistinct but moving -- and moving jerkily at that. Hence, it becomes necessary to take resort to such protecting devices as patents or temporary secrecy of processes or, in some cases, long period contracts secured in advance" (ibid., pp. 88).

In other words, Schumpeter envisaged a broad interaction between monopoly power and innovation. Monopoly profits provide firms with financial leverage for long term investment in development projects. More importantly, 'market power' will provide firms with necessary control to take advantage of new opportunities and protect their long term investments in new commodities and technologies.

Arrow (1962) had a slightly different interpretation of Schumpeter's Model 2: the monopoly firm will have a greater demand for innovations because its market power enables it to profit more from the innovation as compared to a competitive firm. He then demonstrated that the existence of market power before the innovation reduces the expected profit from a given cost-reducing innovation. But, as Kamien and Schwartz (1982, pp. 37) rightly put it:

> "Arrow's analysis is not a refutation of Schumpeter's because he refers to the structure of the industry purchasing the innovation rather than to the structure of the industry producing it" (emphasis original).

In this dissertation we are concerned only with firms which produce innovation.

Model 3 is based on two types of economies of scale. First, a large R&D unit is more efficient than a small one. Second, an R&D unit of a given size is more efficient in a large firm.

A large R&D unit is more efficient because it provides room for different categories of specialized personnel, namely, engineers, scientists, and so on, each operating in particular areas of innovative activities of the firm according to their respective skills.

There is more than one reason as to why an R&D unit can operate more efficiently in a large firm.

(a) There is the possibility that a large diversified firm can better cope with the uncertainties surrounding marketability of its new R&D output. Also, a large firm with multiple distribution channels and effective marketing arrangements is in a better position to appropriate returns on its new R&D output.

(b) It has been argued that a large firm enjoys financial economies of scale. This is due to its accessibility to funds at lower rates (including its own reserve of finance from past profits) which help to reduce the costs associated with a given R&D unit. Also, its access to multiple sources of funds allows it to undertake parallel development projects, thereby diversifying the risks associated with research (Fisher and Temin, 1973).

(c) Finally, a large firm may enjoy technical economies of scale in the form of reduced R&D capital for a given R&D unit[2].

The apparent similarity between some of these arguments and the ones discussed previously in relation to Model 2 is noted by Schumpeter who wrote:

> "There cannot be any reasonable doubt that under the conditions of our epoch such superiority (of the monopoly firm) is as a matter of fact the outstanding feature of the typical large-scale unit of control" (Schumpeter, 1950, pp. 101, parenthesis mine).

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[2] The arguments of Model 3 were first formalized by Fisher and Temin (1973).

However, these two sets of hypotheses are independent of each other because possession of monopoly power does not imply large size, except in relative terms and conversely, large firm size does not imply monopoly power. Of course, large firm size and monopoly power do sometimes occur together.

In the following section we describe a framework where both these models can be considered together, in order to properly identify the effect of either in innovative activities of firms. Existing empirical studies of the Schumpeterian hypotheses (see chapter IV), on the other hand, have concentrated on one set of hypotheses or the other. The majority of these studies are on Model 3 primarily because it is difficult to measure monopoly power and secondarily, because there are at least three alternative measures of firm size, namely, assets, sales, and employment. The concentration ratio is the most common measure of monopoly power in studies of Model 2. However, one cannot deny the obvious association between this ratio and firm size. See Section III.4 and chapter IV for more on these empirical measures.

Dasgupta and Stiglitz (1980a) have argued that except in the short run, a true Schumpeterian model should consider both market structure and innovative activity as endogenous; both being determined by demand conditions, firms' ability to borrow funds for R&D, the legal structure (e.g., patent rights), etc. They defined market structure in terms of the 'degree of concentration' in an industry, whose theoretical measure is defined as one over the number of firms in an industry.

Analogous to this neo-Schumpeterian hypothesis, we consider firm size and innovative activity as endogenous. We are unable to consider the 'degree of concentration' (in terms of a 4-firm or an 8-firm concentration ratio) as a variable since the data (see chapter IV) contains information for only five industries. We, however, include the number of firms offering products which directly compete with the innovation, as an explanatory variable in our empirical study. This variable can be looked upon as a measure of the 'degree of competition' pertaining to the innovation, in our cross-section study of innovation by firms in an industry.

III.3 A Framework

We divide profits conceptually into three parts. The first, V(R,N,A) is the value of sales from innovation obtained by a firm which engages in innovative activities to the extent measured by R number of R&D personnel and which has an operating staff, excluding R&D workers, of size N. The shift variable A may be thought of as indexing for special economic or technological opportunities open to particular firms (large or small) in regard to appropriability of returns to innovative activities. For example, following Schumpeter's Model 2, A may include an index of monopoly power of firms, say, patents; but A may also include opportunities not associated with monopoly power.

The second part of profits, $-C(R,N,B)$ is the cost of innovative activities incurred by a firm, where the shift variable B stands for special technical advantages open to particular firms (large or small). For example, B may include the percentage of internal financing as a variable. Both A and B are, therefore, vectors which contain proxies for appropriability and technological opportunity in R&D activities of firm. See chapter VI for more on this point.

Finally, $H(N,G)$ is the value of net revenue from non-innovative activities[3]. Differences in G across firms will lead to among other changes, different firm sizes. For example, G may include a variable to represent differences in the production functions across firms[4]. Thus combining these parts together, we obtain the net profit equation for a firm:

$$\pi(R,N) = V(R,N,A) - C(R,N,B) + H(N,G) \tag{1}$$

Let us now express the Schumpeterian hypotheses in terms of the functions in (1). For purposes of analytical convenience, we

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[3] In this framework, we ignore explicit consideration of personnel costs and non-personnel costs like capital. This is mainly due to the data that we use in our estimation, which does not contain any information on these variables. This point is made clear on pages 31-33 below.

[4] Note that G could well be a vector.

group the various aspects of monopoly power discussed above into two classes: appropriability and technological opportunity associated with return on R&D and technical and other cost-of-funds advantages associated with cost of R&D. The former operates through A in the V-function, and the latter through B in the C-function. Therefore, the Schumpeterian hypothesis of Model 2 that a monopoly firm has special advantages in appropriating returns on its innovative activity, can be expressed as:

(2) $$\frac{\partial}{\partial A} \left(\frac{\partial V}{\partial R}\right) = V_{RA} > 0$$

that is, the marginal return per R&D worker is positively related to monopoly power. The other hypothesis of this model, that a monopoly firm has special technical and/or cost-of-funds advantages, can be expressed as:

(3) $$C_{RB} < 0$$

that is, the marginal cost of innovation per R&D worker is negatively related to monopoly power.

The hypothesis that a large R&D unit is more efficient than a small one, can be described as:

(4) $$C_R > 0 \qquad C_{RR} < 0$$

that is, marginal cost of innovation is positive but declining[5].

The hypothesis of Model 3, that a given R&D unit is more efficient in a large firm, can be described in two parts:

(5) $V_{RN} > 0$

that is, marginal return per R&D worker is positively related to firm size; and

(6) $C_{RN} < 0$

that is, the marginal cost associated with an R&D worker is less in a large firm. Notice that the effects of firm size, N, and the A and B variables are on the marginal return or cost per R&D worker so that they affect the optimal number of R&D workers, which we take here as one measure of innovative input. (See discussion on page 31-33 below.)

The above framework is based on some implicit assumptions which are primarily motivated by the data that we use in our tests of the Schumpeterian hypotheses (see chapter VI). The following example explains these assumptions.

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5 Economies of scale in R&D is a property of the innovation production function and does not strictly fall under the Schumpeterian hypotheses. In fact, such economies may or may not exist, without affecting any of our discussion of Model 2 and Model 3.

Suppose we write the innovation cost function as:

(i) $C(R,N) = Rw + K(R,N)r(N)$ assuming $B = 0$

where w is wage per R&D worker, K is optimal level of R&D capital, and r is opportunity cost of a unit of R&D capital. From (i) we obtain:

(ii) $C_R = w + K_R r(N)$ where $w, r > 0$, $K_R \gtrless 0$

(iii) $C_N = K_N\, r(N) + Kr_N$ where K_N, $r_N \gtrless 0$

(iv) $C_{RN} = K_{RN}\, r(N) + K_R r_N$ where $K_{RN} \gtrless 0$

We will assume that R&D technology is of the fixed coefficient type for all firms, i.e., $K_R > 0$ and $K_{RR} = 0$. Then C_{RN} is negative if there are both financial economies in large firms (i.e., $r_N < 0$) and technical economies in large firms (i.e., $K_{RN} < 0$). If, however, one of these two economies is not present, C_{RN} can still be negative provided one of the economies is sufficiently large to outweigh the diseconomy. If R&D technology is more capital-intensive in larger firms (i.e., $K_N > 0$) and the magnitude of financial economies (i.e., Kr_N) is small, C_N can be positive. In short, therefore, C_{RN} reflects the combined effect of financial and technical economies (or diseconomies) on the marginal cost of R&D, whereas C_N reveals the combined effect of the nature of R&D

technology and the magnitude of financial economies (or diseconomies), on total R&D costs. Note that C_R is positive given that K_R is positive.

There are two alternative units of measurement of innovative effort of firms: R&D cost (C) and R&D workers (R). In the case of R&D cost, one requires measurement of both C_N AND C_{RN} to test the Schumpeterian hypothesis that there is a positive externality from firm size on innovative activities of firms (see Section III.4.2). The data that is available to us contains information only on R&D workers, and neither on the R&D capital nor on wages of R&D workers. Therefore, it is not possible to estimate K_N or K_{RN} in (ii) and (iii). Alternatively, we can estimate an R&D cost function and thereby obtain direct estimates of C_N and C_{RN}, since the data does contain information on total R&D cost of firms (inclusive of capital and labour costs). However, it is not possible to do the same in regard to estimation of V_{RN} and V_N which are described in terms of return on R&D, since there are only a few firms whose return on innovation (V) is reported in the data. (Note that all the arguments made here in regard to R&D costs, are also applicable to return on R&D.)

We, therefore, choose R&D workers as the unit of measurement of innovative effort of firms. Since the ratio of R&D workers to R&D capital is constant for all firms (given our assumption of fixed coefficient R&D technology), R&D workers alone can be used to measure R&D technology of each firm. Consequently, the Schumpeterian hypothesis can be described in terms of the influence of firm size on the marginal cost (and marginal revenue) associated with an R&D worker, i.e., $C_{RN} < 0$ (and $V_{RN} > 0$) under assumption (6); in other words, measurement of C_{RN} and V_{RN} is sufficient to test the hypothesis.

Similar explanations can be provided for the Schumpeterian hypotheses of Model 2.

Maximization of (1) with respect to R and N yields the following first-order conditions:

(7) $V_R - C_R = 0$ where $V_R,\ C_R > 0$

(8) $V_N - C_N + H_N = 0$ where $V_N,\ C_N,\ H_N \gtrless 0$

The condition in (7) tells us that for maximum profit the return associated with a marginal R&D worker should equal to the cost associated with that worker. The condition in (8) indicates that if the total R&D externality from a marginal operating worker is positive, i.e., $(V_N - C_N) > 0$, then marginal revenue product of operating workers (H_N) should be negative in order for profit to be maximized.

Totally differentiating (7) and (8) we obtain:

(9)
$$\begin{vmatrix} V_{RR} - C_{RR} & V_{RN} - C_{RN} \\ V_{RN} - C_{RN} & V_{NN} - C_{NN} + H_{NN} \end{vmatrix} \begin{vmatrix} dR \\ dN \end{vmatrix} = \begin{vmatrix} -V_{RA} \\ -V_{NA} \end{vmatrix} dA$$

$$\ldots . + \begin{vmatrix} C_{RB} \\ C_{NB} \end{vmatrix} dB + \begin{vmatrix} 0 \\ -H_{NG} \end{vmatrix} dG$$

The second-order conditions for maximization of (1) are

(10) $$V_{RR} - C_{RR} < 0$$

(11) $$(V_{RR} - C_{RR})(V_{NN} - C_{NN} + H_{NN}) > (V_{RN} - C_{RN})^2$$

We shall maintain throughout this discussion that even if there are economies of scale in R&D itself i.e., $C_{RR} < 0$, the second-order conditions (10) and (11) hold so that there exist finite profit-maximizing levels of R and N for each firm.

The above framework is a modified version of the framework in Fisher and Temin (1973, henceforth F & T). They defined F(R,N) as the "average" dollar return per R&D worker and RF(R,N) as the total return on R&D. The cost of innovation in their framework is simply $-w^r r$ where w^r is the constant wage per R&D worker. None of these relationships, however, contain exogenous parameters such as A and B. This implies that F & T's model only describes Schumpeter's Model 3. Finally, they described non-innovative profits as we do, i.e., H(N,G). F & T describe the hypotheses of Model 3 in terms of increasing "average" value productivity of R&D workers, namely, $F_R > 0$ and $F_N > 0$. Since the wage per R&D worker is constant whereas the return per R&D worker is increasing, their model does not yield a finite profit-maximizing solution (Rodriguez 1979)[6].

III.4 Some Common Empirical Tests

There is a large empirical literature which attempts to test the Schumpeterian hypotheses in (2) to (6). In chapter IV, we shall review these studies. To name a few, Villard (1958), Schmookler (1959), Worley (1961), Comanor (1965, 1967), Scherer (1965a, 1965b, 1967a), Mansfield (1968a), and more recently, Howe and McFetridge (1976), Levin and Reiss (1984) and Levin, et. al. (1985) have all investigated one or more of the Schumpeterian hypotheses. With the

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[6] Kohn and Scott (1982) attempted a discussion of Model 3 in a framework similar to F & T. In their model, profit was defined as: $\pi = M(Q,N) - C(Q) + H(N,G)$ where M(Q,N) is total value added of R&D and Q is some physical measure of innovative output. Their model does not suffer from internal inconsistency as in F & T.

exception of Comanor (1965), all of these studies attempted to test these hypotheses through indirect measures. First, let us examine a few of the empirical measures commonly employed in studies of Model 3.

Existing studies of Model 3 typically assume a world where there are no special opportunities open to particular firms in regard to R&D productivity, that is, A = B = 0. Firms are allowed to differ in terms of G so that they differ in size. In other words, R&D opportunities vary across firms solely due to differences in size.

The empirical measures in these studies of Model 3 are expressed in terms of relationships between some measure of firm size and some measure of innovative effort. Let us examine four such relationships.

III.4.1 Relationship Between R&D Employment and Total Employment

Assuming dA, dB = 0, from (9) we obtain:

$$\frac{dR}{dG} = \frac{H_{NG}(V_{RN} - C_{RN})}{D} \tag{12}$$

and

$$\frac{dN}{dG} = \frac{-H_{NG}(V_{RR} - C_{RR})}{D} \tag{13}$$

where

$$(14) \qquad D = (V_{RR} - C_{RR})(V_{NN} - C_{NN} + H_{NN}) - (V_{RN} - C_{RN})^2$$

Let S = R + N be a measure of firm size in terms of total employment. Then assuming that $H_{NG} \neq 0$, combining (12) and (13) together yields:

$$(15) \qquad \frac{dR}{dS} = \frac{dR/dG}{dR/dG + dN/dG} = \frac{(V_{RN} - C_{RN})}{(V_{RN} - C_{RN}) - (V_{RR} - C_{RR})}$$

Equation (15) contains a "combined" version of the two parts of the Schumpeterian hypothesis of Model 3 described in (5) and (6). Now, even if one of the externalities is not present, that is, $V_{RN} < 0$ or $C_{RN} > 0$, $(V_{RN} - C_{RN})$ can still be positive (given that one of the externalities is sufficiently large), implying that there is a net positive externality from firm size to innovative activity. Henceforth, we shall refer to this "combined" version of the hypothesis as the Schumpeterian hypothesis of Model 3.

From (15) we can establish the relationship between $\frac{dR}{dS}$ and the Schumpeterian hypothesis that there is a positive externality from firm size to innovative activity, that is, $(V_{RN} - C_{RN}) > 0$.[7]

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[7] Note that (15) describes a relationship between two endogenous variables. In other words, in our model we treat both innovative activity and firm size as endogenous.

This relationship is illustrated in Figure III.1, for a given value of $(V_{RR} - C_{RR})$.

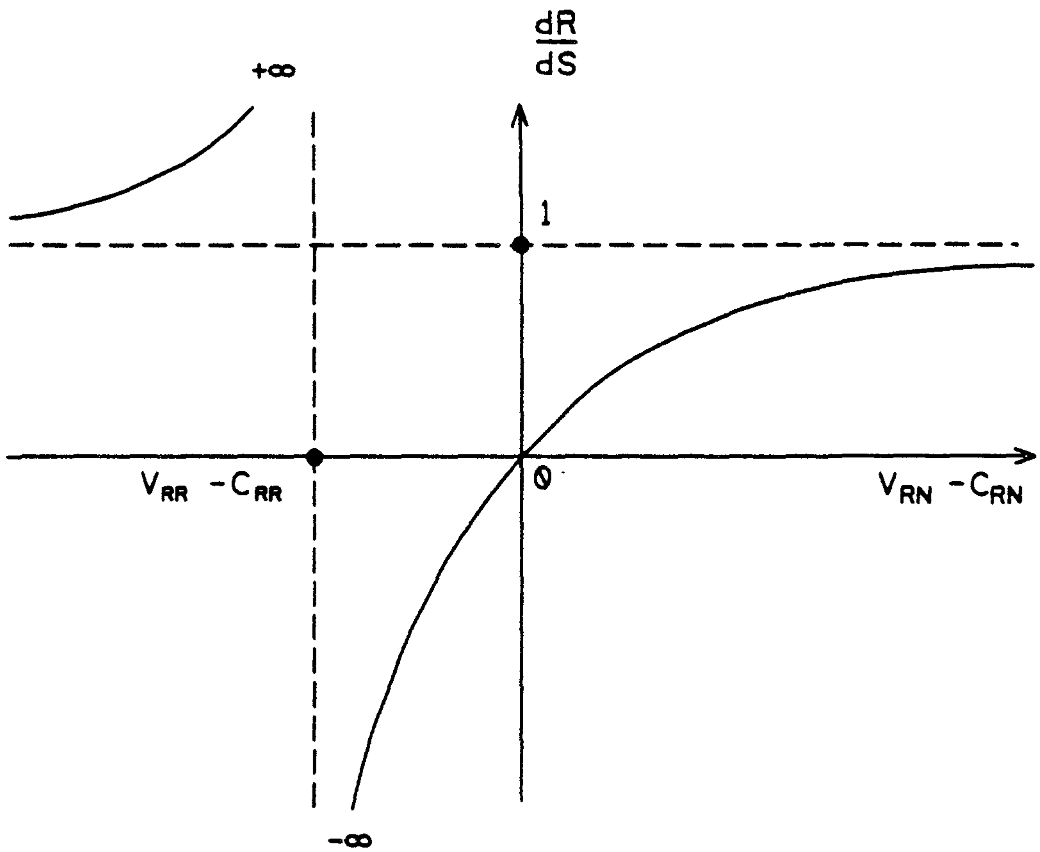

FIGURE III.1: Relationship between $\frac{dR}{dS}$ and $(V_{RN} - C_{RN})$

Figure III.1 is based on (15), given that $(V_{RR} - C_{RR}) < 0$ by (10). From this figure we observe the following:

(16) $0 < V_{RN} - C_{RN} < + \infty$ if, and only if, $0 < \frac{dR}{dS} < 1$

Therefore, we propose the following:

Proposition 1:

$$0 < \frac{dR}{dS} < 1 \text{ implies } (V_{RN} - C_{RN}) > 0, \text{ given that } (V_{RR} - C_{RR}) < 0.$$

Thus, in this context (dA = dB = 0), $0 < \frac{dR}{dS} < 1$ is the appropriate empirical test for a positive externality from firm size to innovative effort, as measured by R&D personnel.

An important corollary of the above proposition is that if $0 < \frac{dR}{dS} < 1$, then $0 < \frac{dN}{dS} < 1$, given that S = R + N. Thus, if the Schumpeterian hypothesis of a positive externality from firm size to R&D activity holds in an industry, larger firms would have both absolutely larger R&D staff and absolutely larger operating staff than smaller firms. Analogously, if $\frac{dR}{dS} > 1$, then $\frac{dN}{dS} < 0$ which implies that larger-sized firms would have absolutely smaller operating staff than smaller-sized firms. This is, however, an extreme case which holds only if there is a sufficiently negative externality from firm size to R&D.

A common empirical test for the Schumpeterian hypothesis of Model 3 is whether the <u>elasticity</u> of R with respect to S is greater than unity (see, for instance, Worley (1961), Hamberg (1966) and Comanor (1967) among others). From (15) we can obtain

$$(17) \qquad E_{RS} \equiv \frac{dR}{dS} \cdot \frac{S}{R} = \left| \frac{(V_{RN} - C_{RN})}{(V_{RN} - C_{RN}) - (V_{RR} - C_{RR})} \right| \left| \frac{S}{R} \right|$$

where E_{RS} is the elasticity of R with respect to S. The relationship between E_{RS} and $(V_{RN} - C_{RN})$, given $(V_{RR} - C_{RR}) < 0$ is illustrated in Figure III.2.

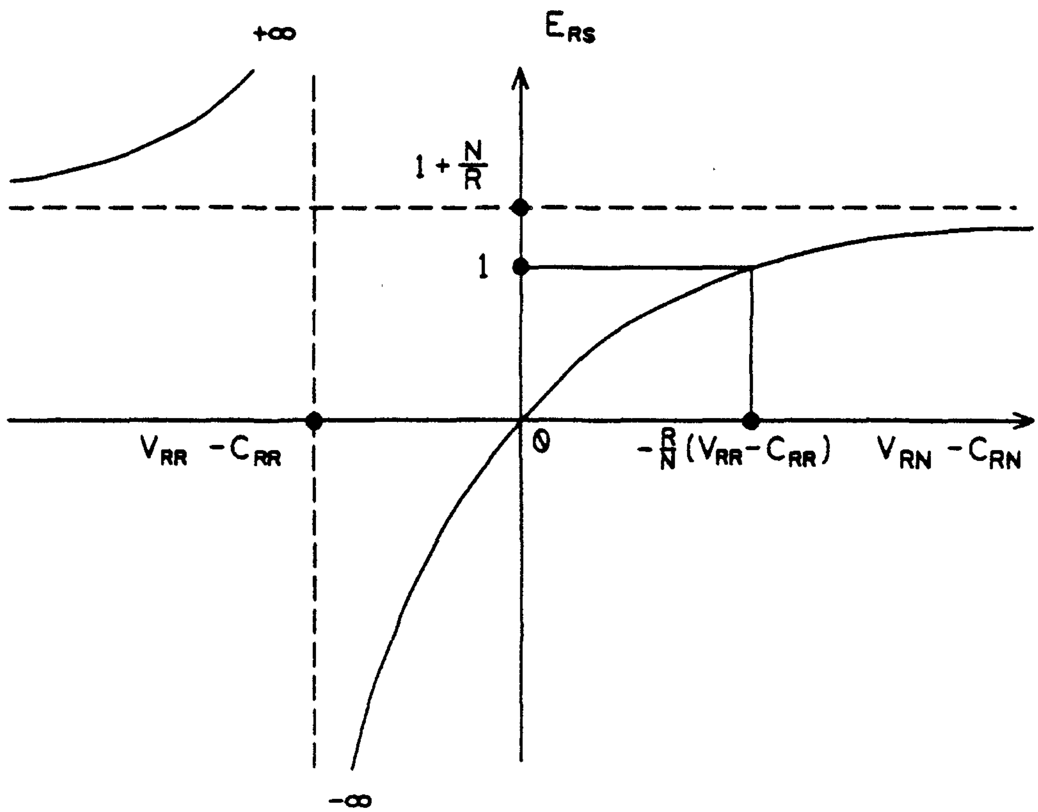

FIGURE III.2: Relationship Between E_{RS} and $(V_{RN} - C_{RN})$

Figure III.2 is based on (17), given that $(V_{RR} - C_{RR}) < 0$. From this figure, we observe the following:

(18) $$0 < V_{RN} - C_{RN} < -\frac{R}{N}(V_{RR} - C_{RR}) \quad \text{if, and only if, } 0 < E_{RS} < 1$$

(19) $$-\frac{R}{N}(V_{RR} - C_{RR}) < V_{RN} - C_{RN} < +\infty \quad \text{if, and only if, } 1 < E_{RS} < 1 + \frac{N}{R}$$

Therefore, we propose the following:

Proposition 2:

$0 < E_{RS} < 1 + \frac{N}{R}$ implies $(V_{RN} - C_{RN}) > 0$ given that $(V_{RR} - C_{RR}) < 0$

A few observations are in order. E_{RS} can be less than unity and the Schumpeterian hypothesis will still hold in an industry. If E_{RS} is greater than unity then its "upper limit" is $1 + \frac{N}{R}$, beyond which a measured positive value of E_{RS} will imply that the hypothesis does not hold. In other words, $E_{RS} > 1$ is <u>neither</u> necessary <u>nor</u> sufficient for $(V_{RN} - C_{RN}) > 0$.

III.4.2 Relationship Between R&D Expenditure and Sales

In this sub-section we explore the relationship between innovative effort as measured by R&D expenditures (C) and firm size measured in terms of sales. These measures have also been frequently used in empirical tests of the Schumpeterian hypothesis. Letting $Y = V + H$ be the total sales revenue of a firm, we get:

$$\text{(20)} \qquad \frac{dC}{dY} = \frac{dC}{dV + dH}$$

After substitution (see Appendix III) we obtain:

$$\text{(21)} \qquad \frac{dC}{dY} = \frac{C_R(V_{RN} - C_{RN}) - C_N(V_{RR} - C_{RR})}{V_R(V_{RN} - C_{RN}) + M}$$

where

$$\text{(22)} \qquad M = \left| -(V_N + H_N)(V_{RR} - C_{RR}) + \frac{H_G D}{H_{NG}} \right| > 0$$

The assumption that M is positive is based on the following arguments. We know that $(V_{RR} - C_{RR}) < 0$ and $D > 0$ by the second-order conditions in (10) and (11). Also, from (8) we know that $(V_N + H_N) > 0$ irrespective of the sign of C_N. Finally, we have implicitly assumed that H_G, $H_{NG} > 0$ since these relationships between H and G tell us as to why some firms are large in an industry. All these indicate that

$M > 0$, as shown in (22). Under these assumptions the relationship between $\frac{dC}{dY}$ and $(V_{RN} - C_{RN})$, for a given value of M and $(V_{RR} - C_{RR})$ is shown in Figure III.3.

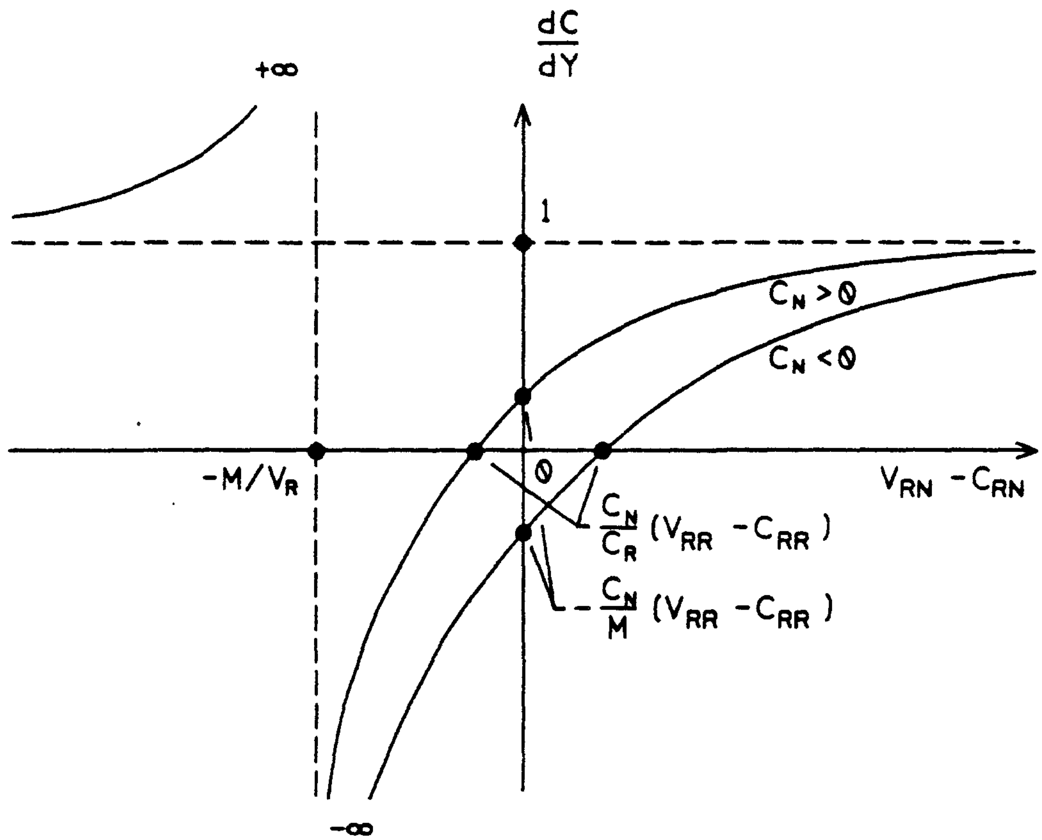

FIGURE III.3: Relationship between $\frac{dC}{dY}$ and $(V_{RN} - C_{RN})$

Figure III.3 is based on (21), given that $M > 0$, $(V_{RR} - C_{RR}) < 0$ and $V_R > 0$, allowing for the possibility that $C_N \lessgtr 0$. If $C_N < 0$, then we observe the following:

(23) $$0 < V_{RN} - C_{RN} < \frac{C_N}{C_R}(V_{RR} - C_{RR}) \text{ if, and only if, }$$

$$-\frac{C_N}{M}(V_{RR} - C_{RR}) < \frac{dC}{dY} < 0$$

(24) $$\frac{C_N}{C_R}(V_{RR} - C_{RR}) < V_{RN} - C_{RN} < +\infty \text{ if, and only if, }$$

$$0 < \frac{dC}{dY} < 1$$

Alternatively, if $C_N > 0$, then we observe the following from Figure III.3:

(25) $$0 < V_{RN} - C_{RN} < +\infty \text{ if, and only if, } -\frac{C_N}{M}(V_{RR} - C_{RR})$$

$$\ldots\ldots < \frac{dC}{dY} < 1$$

Therefore, we propose the following:

Proposition 3:

$-\frac{C_N}{M}(V_{RR} - C_{RR}) < \frac{dC}{dY} < 1$ implies $(V_{RN} - C_{RN}) > 0$, given that $M > 0$, $(V_{RR} - C_{RR}) < 0$, and $V_R > 0$.

A few observations can be made. If $C_N = 0$, then $0 < \frac{dC}{dY} < 1$ implies $(V_{RN} - C_{RN}) > 0$, in which case, measurement of M and $(V_{RR} - C_{RR})$ is not required to make inferences about the Schumpeterian hypothesis from an estimate of $\frac{dC}{dY}$. In this case, the result is similar to $\frac{dR}{dS}$. If $C_N \neq 0$, then measurement of M, $(V_{RR} - C_{RR})$ and C_N as well as $\frac{dC}{dY}$ is required. Also note that if $C_N < 0$, then $\frac{dC}{dY}$ can be negative even though $(V_{RN} - C_{RN}) > 0$. In other words, large-sized firms may be spending less on innovative activities relative to their size, when size is measured in terms of sales.

Analogous to the relationship between R and S, another common empirical test found in the literature is whether the elasticity of C with respect to Y is greater than unity. (See, for instance, Mansfield (1968a)). Therefore, from (21), we can obtain:

$$(26) \qquad E_{CY} \equiv \frac{dC}{dY} \cdot \frac{Y}{C} = \left[\frac{C_R(V_{RN} - C_{RN}) - C_N(V_{RR} - C_{RR})}{V_R(V_{RN} - C_{RN}) + M} \right] \left[\frac{Y}{C} \right]$$

where E_{CY} is the elasticity of C with respect to Y, and M is given by (22).

One can establish the relationship between E_{CY} and $(V_{RN} - C_{RN})$ from (26), given that $M > 0$ by (26) and $(V_{RR} - C_{RR}) < 0$ by (10). This relationship is similar to that shown in Figure III.3, the only difference being a change inthe lower and upper limits on the Y axis by a sclar multiple of $\frac{Y}{C}$. We, therefore, obtain the following proposition, analogous to Proposition 3:

Proposition 4:

$$- \frac{C_N Y}{CM} (V_{RR} - C_{RR}) < E_{CY} < \frac{Y}{C}$$

implies $(V_{RN} - C_{RN}) > 0$, given that $M > 0$ by (26) and $(V_{RR} - C_{RR}) < 0$ by (10).

A few observations can be made from this proposition. If $C_N = 0$, then one does not require measurement of M and $(V_{RR} - C_{RR})$ in order to draw inferences about the Schumbeterian hypothesis from an estimate of E_{CY}, otherwise measurement of these values and C_N is necessary. Since $\frac{Y}{C}$ is normally expected to be greater than unity, E_{CY} can be greater than unity if $(V_{RN} - C_{RN}) > 0$. If, however, $C_N < 0$, then E_{CY} can be even negative and still $(V_{RN} - C_{RN})$

> 0. On the other hand, if $C_N > 0$ but $- C_N Y/CM(V_{RR} - C_{RR}) < 1$, E_{CY} can be positive but less than unity if $(V_{RN} - C_{RN}) > 0$. Therefore, $E_{CY} > 1$ is neither necessary nor sufficient for $(V_{RN} - C_{RN}) > 0$.

There are a number of other empirical relationships that researchers have employed in their studies of Model 3, in particular, the relationship between R and Y and the relationship between C and S. We shall now briefly look at these two relationships in the following two sub-sections.

III.4.3 Relationship Between R&D Employment and Sales

Since $Y = V + H$, we can write the following

$$\frac{dR}{dY} = \frac{dR}{dV + dH} \tag{27}$$

After substitution (see Appendix III), we get:

$$\frac{dR}{dY} = \frac{(V_{RN} - C_{RN})}{V_R(V_{RN} - C_{RN}) + M} \tag{28}$$

where M is given by (22).

From (28) we can establish the relationship between $\frac{dR}{dY}$ and $(V_{RN} - C_{RN})$ which is illustrated in Figure III.4.

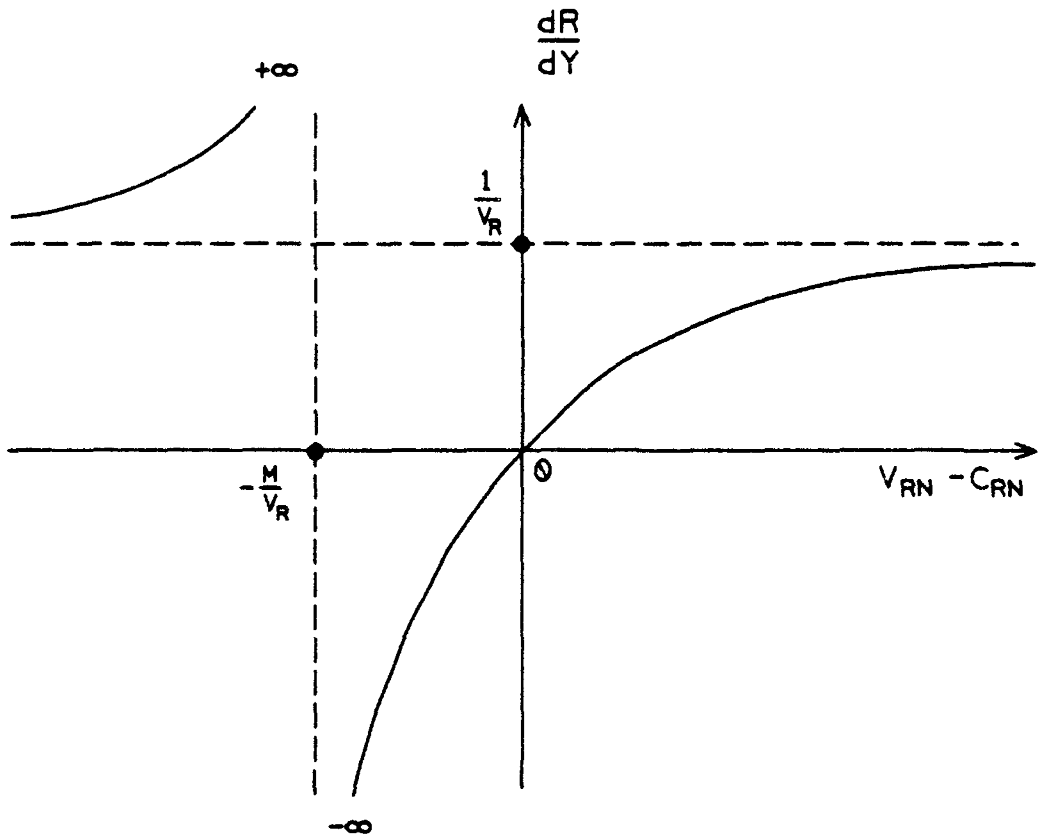

Figure III.4: Relationship Between $\frac{dR}{dY}$ and $(V_{RN} - C_{RN})$

Figure III.4 is based on (28), given that $M > 0$ and $V_R > 0$. From this figure we observe the following:

(29) $0 < V_{RN} - C_{RN} < +\infty$ if, and only if, $0 < \frac{dR}{dY} < \frac{1}{V_R}$

Therefore, we propose the following:

Proposition 5:

$0 < \frac{dR}{dY} < \frac{1}{V_R}$ implies $(V_{RN} - C_{RN}) > 0$, given that $M > 0$ and $V_R > 0$.

In this case, measurement of V_R is required in order to draw inferences about the Schumpeterian hypothesis from an estimate of dR/dY. We can also obtain the relationship between the elasticity of R with respect to Y(E_{RY}) and $(V_{RN} - C_{RN})$ from (28). The upper limit of E_{RY} will now be Y/RV_R. Therefore, we obtain the following proposition:

Proposition 6:

$0 < E_{RY} < \frac{Y}{RV_R}$ implies $(V_{RN} - C_{RN}) > 0$, given that $M > 0$ and $V_R > 0$.

Since we would normally expect $\frac{Y}{RV_R}$ to be greater than unity, E_{RY} can be either greater than or less than unity, if $(V_{RN} - C_{RN}) > 0$. Therefore, $E_{RY} > 1$ is <u>neither</u> necessary <u>nor</u> sufficient for the Schumpeterian hypothesis of Model 3 to hold.

III.4.4 Relationship Between R&D Expenditure and Total Employment

After substitution (see Appendix III) we obtain:

(30) $$\frac{dC}{dS} = \frac{C_R(V_{RN} - C_{RN}) - C_N(V_{RR} - C_{RR})}{(V_{RN} - C_{RN}) - (V_{RR} - C_{RR})}$$

The relationship between $\frac{dC}{dS}$ and $(V_{RN} - C_{RN})$, given a value of $(V_{RR} - C_{RR})$ is shown in Figure III.5.

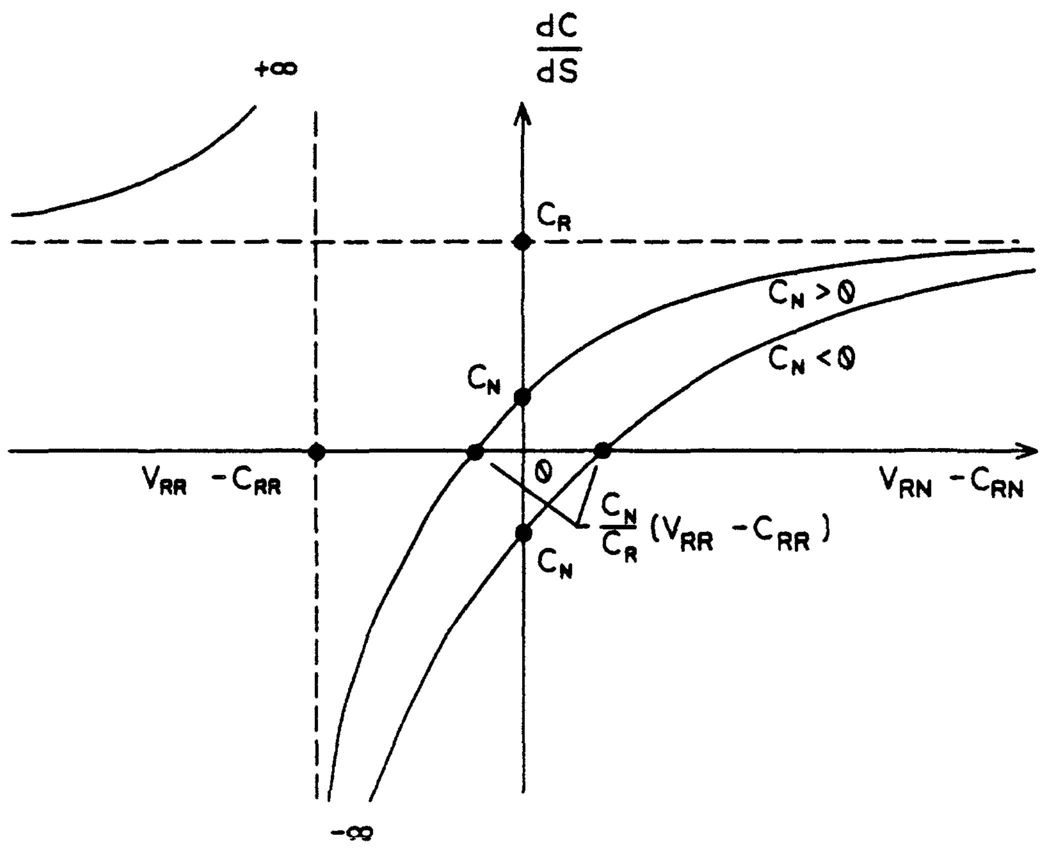

FIGURE III.5: Relationship Between $\frac{dC}{dS}$ and $(V_{RN} - C_{RN})$

Figure III.5 is based on (30) allowing for the possibility that $C_N \lesseqgtr 0$. If $C_N < 0$, we observe the following:

(31) $$0 < V_{RN} - C_{RN} < \frac{C_N}{C_R}(V_{RR} - C_{RR}) \text{ if, and only if, }$$

$$C_N < \frac{dC}{DS} < 0$$

(32) $$\frac{C_N}{C_R}(V_{RR} - C_{RR}) < V_{RN} - C_{RN} < +\infty \text{ if, and only if, }$$

$$0 < \frac{dC}{dS} < C_R$$

Alternatively, if $C_N > 0$, we observe the following from Figure III.5:

(33) $$0 < V_{RN} - C_{RN} < +\infty \text{ if, and only if, } C_N < \frac{dC}{dS} < C_R$$

Therefore, we propose the following

Proposition 7:

$$C_N < \frac{dC}{dS} < C_R \text{ implies } (V_{RN} - C_{RN}) > 0, \text{ given that}$$

$$(V_{RR} - C_{RR}) < 0 \text{ and } C_R > 0$$

One, therefore, requires measurement of C_R in order to draw inferences about the Schumpeterian hypothesis from an estimate of $\frac{dC}{dS}$. Analogous to the relationship between C and Y, if $C_N < 0$, then $\frac{dC}{dS}$ can be even negative when $(V_{RN} - C_{RN}) > 0$. In other words, large firms may be spending less on innovative activities relative to their size, when size is measured in terms of employment.

Finally, we can obtain the relationship between the elasticity of C with respect to S (E_{CS}) and $(V_{RN} - C_{RN})$ from (30). It is similar to the relationship shown in Figure III.5, except that the lower and the upper limits on the Y-axis will shift by a scalar multiple of S/C. We, therefore, obtain the following proposition:

Proposition 8:

$$\frac{C_N S}{C} < E_{CS} < \frac{C_R S}{C} \text{ implies } (V_{RN} - C_{RN}) > 0, \text{ given that}$$

$$(V_{RR} - C_{RR}) < 0 \text{ and } C_R > 0.$$

Similar to Proposition 7, E_{CS} can be negative if $C_N < 0$, even if $(V_{RN} - C_{RN}) > 0$. Also, depending upon the values of C_N, C_R, S, and C, E_{CS} can be either less than or greater than unity, if $(V_{RN} - C_{RN}) > 0$. In other words, $E_{CS} > 1$ is neither necessary nor sufficient for the Schumpeterian hypothesis of Model 3 to hold.

Propositions 1 to 8 describe conditions for the Schumpeterian hypothesis of Model 3, $(V_{RN} - C_{RN}) > 0$, based on relationships between various measures of innovative effort and firm size. There are also a number of attempts to test the superiority of large firms in terms of innovative output. Given that no one has yet been successful in creating a satisfactory measure of innovative output, economists have mostly opted for various measures of inventive activity of firms, for instance, patents, number of major inventions, etc., to test the R&D productivity of firms of various sizes. These efforts are not discussed in this chapter.

III.4.5 Relationship Between R&D Employment and Monopoly Power

A discussion of existing empirical measures of Schumpeter's Model 2 (market power and innovation) cannot be carried out in this framework. These studies have usually employed 'concentration ratios' as a measure of monopoly power in an industry, therefore, researchers were primarily interested in the relationship between innovative effort and monopoly power across industries whereas our framework allows us to study the pattern of innovative activity across firms within an industry.

It is worth pointing out, however, that concentration may have two distinguishable effects on innovative activities of firms, although no one has yet distinguished between them in empirical studies. First, it may have a firm size effect due to its obvious association with firm size, and second, it will have the market power effect which is commonly assumed in its use in empirical studies of Schumpeter's Model 2. This can be shown in the following way.

From (9) we obtain the following relationship between R and A, holding B and G constant:

$$\text{(34)} \qquad \frac{dR}{dA} = \frac{-V_{RA}(V_{NN} - C_{NN} + H_{NN}) + V_{NA}(V_{RN} - C_{RN})}{D}$$

where D is given by (14). From (34) we observe that the relationship between innovative effort (measured in terms of R&D workers) and market power (represented by A) contains two effects: (a) the direct effect of market power on innovative activity -- the first term in the numerator; and (b) the indirect effect through firm size -- the second term in the numerator. If the concentration ratio is used as a measure of market power (A) and if there is a positive association between the concentration ratio and firm size, that is, $V_{NA} > 0$ in the data, any estimated relationship between innovative effort and concentration will, therefore reveal the net effect of both Model 2 and Model 3, and is not, as commonly claimed in existing studies, a test of the Schumpeterian hypotheses of Model 2 only.

III.5 Concluding Remarks

In this chapter, we set out to examine the Schumpeterian hypotheses. We built a framework within which we can not only formalize these hypotheses, but also examine several of the empirical measures of Model 3 and of Model 2 that are found in existing literature. Three related caveats from our discussion of these empirical relationships are worth noting.

First, as shown above, empirical tests such as $E_{RS} > 1$ or $E_{CY} > 1$ are neither necessary nor sufficient for the Schumpeterian hypothesis that there is a positive externality from firm size to innovative activity. Second, if we allow A and B to vary across firms, i.e., firms (large or small) have special opportunities for technical advance or appropriability of returns on their R&D, then it will not be possible to obtain any clear cut relationship between any of these empirical measures and the Schumpeterian hypotheses of Model 3, unless the impact of varying A and B is measureable, and, therefore, can be netted out! Third, the majority of the existing studies of Model 2 are based on simple regression analysis (see next chapter), which is incorrect in view of the fact that the empirical measures E_{RS} and E_{CY} describe relationships between two <u>endogeneous</u> variables and thus, regression estimates are subject to simultaneous equation bias.

In the next chapter we shall review existing empirical studies of these two models.

APPENDIX III

Assuming dA = dB = 0, from (1) we obtain:

(A1) $$dV = V_R d_R + V_N dN$$

and

(A2) $$dC = C_R dR + C_N dN$$

and

(A3) $$dH = H_N dN + H_G dG$$

Combining (A1)-(A3) with (20), we get:

(A4) $$\frac{dC}{dY} = \frac{dC}{dV+dH} = \frac{C_R \; dR/dN + C_N}{V_R dR/dN + V_N + H_N + H_G \; dG/dN}$$

From (12) and (13), assuming $H_{NG} \neq 0$, we obtain:

(A5) $$\frac{dR}{dN} = - \frac{(V_{RN} - C_{RN})}{(V_{RR} - C_{RR})}$$

Substituting (A5) and (13) in (A4), we get (21).

Derivation of (28) is similar to derivation of (21).

Combining (A1) and (A3) with (27) we get:

(A6) $$\frac{dR}{dY} = \frac{dR/dN}{V_R \; dR/dN + V_N + H_N + H_G \; dG/dN}$$

Substituting (A5) and (13) in (A6) we get (28).

Finally, derivation of (30) is also similar to the derivations shown above. From (A2) and given the fact that $S = R + N$, we obtain:

$$\text{(A7)} \qquad \frac{dC}{dS} = \frac{C_R \, dR/dN + C_N}{dR/dN + 1}$$

Substituting (A5) in (A7), we get (30).

CHAPTER IV

EMPIRICAL STUDIES OF THE SCHUMPETERIAN HYPOTHESES

IV.1 Introduction

There are a variety of independent and disimilar studies which attempt to test one or more of the Schumpeterian hypotheses described in the previous chapter. In this chapter, we examine a significant portion of this literature. We begin our discussion in Section IV.2 with a note on some of the common problems encountered in empirical testing of the Schumpeterian hypotheses. In Section IV.3 we briefly examine some empirical evidence on the innovation production function, followed by dicussions of studies of Model 3 in Section IV.4. Existing studies of Model 2 are examined in Section IV.5. Finally, brief concluding remarks are provided in Section IV.6.

IV.2 Some Common Problems

Perhaps the most fundamental problem encountered in any empirical study of technological change is the identification of an innovation. Patent statistics are often used as proxies for innovative output, but they seem to have serious drawbacks.[1]

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[1] Discussion of the use of patent statistics as a measure of innovative output is found in Kuznets (1962), Sanders (1962) and Schmookler (1966), among others.

(a) Patents can only measure invention and not innovation, because many patented products and processes are never commercialized, and also, because many inventions which are commercialized are never patented.

(b) Given the quality of an invention, the propensity to patent varies both from firm to firm and from industry to industry.

(c) The quality of the underlying invention varies from patent to patent.

All these arguments indicate that a head count of patents is not a perfect measure of innovation. Scherer (1965b) used "slope dummies" for each industry to deal with problem (b) above. These industry-dummies explained 12 per cent of the variation in patenting. The other problems are difficult to accommodate in empirical studies based on patent statistics as a measure of innovative output. One way to improve upon the methodology which prevents substantial loss of the qualititative features of innovative output, may be to study separately different types of innovations; for instance, new product versus improved product, process versus product innovations, and so on.

Alternativemeasures of innovative output which have been used in the existing literature are "increased productivity" and the value of "new product sales". The former has its obvious limitations; both economies of scale in production and improvements in factors of production (not owing to innovation) will significantly affect productivity. The value of "new product sales" has its own limitations; it may be highly correlated with the size of the market, therefore, it may overestimate the size of the innovation and R&D productivity of the firm (Scherer, 1973). Comanor and Scherer (1969) examined the effectiveness of "new product sales" compared to patent statistics as alternative measures of innovative activity. They concluded that patents are good predictors of "new product sales" but that patents bear a stronger relation to R&D inputs than does 'new product sales". The reader should, however, be reminded that in Schumpeter's Model 2, patents indicate monopoly power, in which case, it serves the role of an explanatory variable in explaining firms' innovative activities. In most studies, patents have not been allowed to serve this role.

The other major measurement problem is defining the inputs into the innovative process. One standard measure of innovative effort is the number of people assigned to R&D. This includes scientists, engineers, and their support staff. However, a head count of R&D personnel falls short of being an appropriate measure of innovative effort because:

(a) all scientists and engineers cannot be assigned equal weight in the distributions - some are more experienced and qualified than others.

(b) also, account must be taken of the quality and quantity of equipment available to the research personnel.

(c) in addition,

> "In small- and medium-sized firms, part of the job of scientists, engineers, and executives overseeing industrial operations and marketing often consists of improving products and processes. By contrast, greater division of labour in large enterprises commonly assigns this task to separate departments" (Schmookler, 1959, p. 630).

On the other hand, if part-timers are included with equal weight as full-time R&D personnel, it would be an overestimate. Thus, a head count of R&D personnel will give a poor estimate of the share of small - and medium-sized firms in total industry effort towards innovation. For this reason the National Science Foundation in the U.S. ignores the contribution of part-time hired inventors when measuring R&D personnel, particularly in small and medium scale firms.

As an alternative, total spending on R&D is sometimes used as a measure of innovative effort. This measure also does not consider expenses on personnel not directly involved with R&D, who may make significant contributions towards an innovation. Moreover,

(a) the accounting practices of a firm may not reveal the true R&D spending when, in particular, tax treatment is favourable to R&D (see Blair, 1972, pp. 201-4 for empirical evidence on this point).

(b) R&D spending is treated as current spending rather than an investment and, therefore, ignores the accumulation of innovative effort through time.

There are three measures of firm size that are found in the literature, namely, sales, total number of employees, and assets. To my knowledge, there exists no theory about the relationships between these three measures of firm size. Choice of a measure is largely guided by the availability of data. Some empirical studies claim that the employees variable tends to provide the strongest support for the Schumpeterian hypothesis of Model 3. One of the reasons may be the bias built into the data, as mentioned before in this chapter, which tends to make the elasticity of R with respect to S greater than unity (see Proposition 2 in Chapter III). Nevertheless, there are serious drawbacks to each of these measures. None of these measures explicitly takes into consideration the capital structure of a firm while measuring its size. Both the total employees variable and the sales variable can be sensitive to short run fluctuations in demand, the latter not affecting, per se, either innovative effort or innovative output of firms. However, interview studies show that sales is the principal scale variable considered in company research and development budget decisions (Scherer, 1965a).

The last, but not least important, problem is that of measurement of monopoly power. The common practice is to employ a 4-firm or an 8-firm concentration ratio as a proxy for monopoly power. Concentration, however, may embody two effects: a firm size effect -- resulting from its obvious connection with the relative size of the leading firms in an industry, and the market power effect (see chapter III equation (34)). Few studies have attempted to distinguish these effects. Scherer (1967a) included industry-specific dummy variables in addition to a concentration ratio in order to represent technological opportunity in an industry. More recently, Levin, et. al. (1985) used various appropriability and technological opportunity variables as representing different aspects of monopoly power. Inclusion of these variables significantly diminished the explanatory power of the concentration ratio.

Moreover, these ratios are supposed to be surrogates for measures of market performance through the notion that the more firms in an industry and the more alike they are in size, the closer the equilibrium price will be to the perfectly competitive price. However, Kamien and Schwartz (1980) argued that a large number of equal size firms does not necessarily imply a nearly competitive industry performance nor does an industry composition of only a few large firms necessarily preclude it. In our empirical study (see chapter VI), we include both a measure of firm size (Model 3) and various appropriability and technological opportunity variables (Model 2), as explanatory variables in the regression equation.

This completes our discussion of the data problems generally encountered in any attempt to test the Schumpeterian hypotheses. The choice of measures of innovative activity in existing studies has been largely guided by the availability of data. Despite the potential drawbacks of these measures researchers have been successful in wringing out interesting observations on innovative activities of firms in different industries. The following sections contain a review of these studies. For a clearer understanding of these studies, we wish to follow our discussion in chapter III and the notation used therein.

IV.3 The Innovation Production Function

The first set of empirical evidence that we examine relates to the hypothesis represented by the inequality in (4) in chapter III, namely, whether there exist economies of scale in R&D itself. In empirical studies, the regression equation commonly employed is

$$Q = aZ^{b}u \qquad (35)$$

where Q is some measure of innovative output, Z is some measure of innovative effort available at some constant cost per unit, and u is the error term. An estimated value of b greater than unity in a study across research facilities of various sizes in an industry will suggest that there are economies of scale in larger research units.

In order to allow for the existence of an optimal size research facility, one can employ the following cubic regression equation:

$$(36) \qquad Q = a + bZ + cZ^2 + dZ^3 + u$$

with the sign pattern $b > 0$, $c > 0$, and $d < 0$, implying an interval of increasing returns followed by an interval of decreasing returns. The inflection point is then $Z^* = -\frac{c}{3d}$, where marginal return to the input is greatest.

Mansfield (1968a) found that increases in R&D expenditures (c) result in more than proportional increases in inventive output (measured by number of important inventions) in the chemical industry but that no such evidence was found in the petroleum and steel industries. Scherer's (1965b) regression analysis indicates a very nearly linear relationship between R&D workers (R) and the number of patents issued by a firm. With the exception of these two studies, attempts to discern the properties of the innovation production function have concentrated on the nature of the externality between R&D productivity and firm size (that is, V_{RN} and C_{RN}), hence we now turn to studies of Schumpeter's Model 3.

IV.4 Empirical Studies of Model 3

IV.4.1 Firm Size and Innovative Effort

Among the earliest sets of statistical enquiries, the debate on "Bigness, Fewness and Research" deserves mention. Villard (1958) contended that "competitive oligopoly" -- a term intended to encompass both bigness and fewness -- provides the greatest incentive to research. So long as a greater percentage of larger firms participates in research, an industry composed of a few large firms will generate more research than would one with many small firms, even if the relative amount undertaken by firms of all sizes is the same. In other words, the amount of research in an industry varies directly with the size, and inversely with the number, of firms.

Worley (1961) argued that if among the largest firms in an industry the intensity of research effort $(\frac{R}{S})$ and firm size (S) are inversely related then Villard's suggestion of a policy of increasing industrial concentration seems inappropriate. He then went on to examine whether:

> ".... among only the larger firms in an industry the effort devoted to research and development increases more than in proportion to size" (Worley, 1961, pp. 184).

He employed the following regression equation for each industry:

(37) $$R = AS^{b}$$

which when linearized, becomes

(38) $$\ell n\ R = \ell n\ A + b\ \ell n\ S$$

where R and S have been defined in chapter III. If $b > 1$, (i.e., $E_{RS} > 1$), then Villard's position is supported. Worley, however, could not find any such support except for the petroleum industry, at the five percent level of significance. He noted a tendency for firms near the middle of the distribution in regard to their size, to hire relatively more R&D personnel than the largest and smallest firms in the sample.

Schmookler (1959), in continuation of this debate, suggested that Villard's position is true if the ratio of organized R&D expenditures to sales (C/Y) increases with firm size (S). His findings indicate that in four out of six industries, small firms engaged in R&D activities have higher C/Y ratios than the largest firms engaged in similar activities. Finally, Hamberg (1966) found that R/S is only weakly correlated with S and his log-linear regression (similar to (38) above) reveals that $b > 1$ in only three of the seventeen industries.

Scherer (1965a) criticized the form of the regression employed in these studies. The results, particularly of Hamberg (1966) and Worley (1961) reveal the relationship between research intensity and firm size for firms with sizeable research programmes, and those without large research efforts were dropped from the sample. Also, the log-linear form of the regression equation suppresses both inflection points and nonmonotonicity in the relationship between input intensity and firm size. To correct for the latter drawback in earlier studies, Scherer employed a regression equation similar to (36) to determine the relationship between R and Y. The estimated relationship reveals an inflection point, typically R increasing faster than Y among smaller firms. The few exceptions in his results are the chemical industry and the giant leaders of the automobile and steel industries; their R&D intensity (R/Y) appear to rise with sales.

Comanor (1967) also fitted a log-linear regression form for 387 firms divided into twenty-one industrial groups. For no industry is E_{RS} greater than unity; in fact, for seven industries E_{RS} is significantly less than one. He also found that E_{RY} is significantly less than unity in eighteen of the twenty-three industries and significantly greater than one in no case.

Mansfield (1968a) estimated a log-linear relation between R&D spending (C) and firm size (Y). The estimated coefficient (E_{CY}) was less than unity except for the chemical industry. Also, in a test across time (1954-9) he found that the relationship did not shift systematically in any industry.

Among the non-U.S. studies, Howe and McFetridge (1976) studied the determinants of R&D spending by eighty-one Canadian firms in the chemical, electrical and machinery industries. They treated R&D as an asset acquisition decision, where investment in R&D is assumed to proceed to the point at which marginal rate of return to R&D is equal to marginal cost of funds. (This approach was also employed by Grabowski and Baxter (1973) and Grabowski and Mueller (1972)). In their regression equation, Howe and McFetridge not only included three powers of sales but also profits after taxes, depreciation and government R&D incentive grants among other explanatory variables. One additional feature of their work is the distinction they made between "domestic owned" and "foreign owned" firms through use of dummy variables. They concluded that R&D spending increased more than proportionately with sales in the chemical and electrical industries and then only for intermediate size firms.

More recently Freeman (1982) made a number of interesting observations on the nature of relationship between firm size and R&D expenditures in a number of OECD countries. The vast majority of small firms (probably over 95 per cent) do not carry out any R&D activities. Among those who do R&D, there is a strong correlation between size of total employment of firms (S) and size of R&D programmes (C) in most industries. However, the degree of concentration (in terms of percentage of total industrial R&D) is much less marked by size of firm (measured in terms of total employment) than by size of R&D programme. Finally, in several countries those few small firms who do perform R&D have above average R&D intensity (C/Y).

Soete (1979) refuted Scherer's (1965a and b) claim that research intensity rose with size up to sales of $250 million, but began to fall somewhere between $250 million and $600 million. Soete concluded that the U.S. data supports Schumpeter's Model 3 although patent data still confirms Scherer's finding that there is a 'hump-backed' distribution of patent by size of firm (see our discussion below on innovative output and firm size).

There are a host of other investigations into the relationship between research effort and firm size. (See Kamien and Schwartz, 1982 for a review of these studies.) Most of these studies differ from each other primarily in regard to the data set. The overall conclusion which can be drawn from all these studies is that, except for the chemical industry, research effort, however measured, does not increase more than proportionately with firm size (measured either in terms of employment or sales). Nevertheless, these studies neither refute nor fail to refute Schumpeter's Model 3, in accordance with our discussion of these empirical tests in chapter III. We turn now to studies based on relationships between innovative output and firm size.

IV.4.2 Firm Size and Innovative Output

There are a number of attempts to test the superiority of large firms through measures of innovative output. The output of industrial R&D is a flow of information relating to new and improved products and processes (Freeman, 1982). Although no one has yet found a satisfactory way to reduce this flow to a common denominator which could be used for inter-firm or inter-industry comparison, economists have attempted such comparisons through various measures of inventive activities of firms, for instance, patents, number of inventions, etc.

Scherer (1965b), with the help of the following regression form, attempted to evaluate the relationship between patents and firm size for U.S. industries:

$$(39) \qquad P = a + bY + u$$

where P is patents and Y is total sales of firms. His regression results show that b is less than unity for most industries. This result is somewhat weakened when firm size is measured in terms of employment.

In the same study, Scherer tested for the existence of nonmonotonicity in the relationship using the following cubic regression equation:

$$(40) \qquad P = a + bY + cY^2 + dY^3 + u$$

In particular, his interest was whether:

$$(41) \qquad \frac{d^2P}{dY^2} = 2c + 6dY > 0$$

His results reveal a relationship of patents increasing at a decreasing rate up to a point of inflection of $5.5 billion sales. Only three firms in the sample are larger than this. Due to extreme multicollinearity among the exogenous variables, as he explained, none of the coefficients are statistically significant. For most industries, both b and d are positive whereas C is negative.

A similar study is conducted by Smyth, Samuels, and Tzoannos (1972) for 86 firms in the U.K. Patents awarded are regressed on the first two powers of firm size (measured by net assets), profits and cash flow. The number of patents awarded increases more than proportionately with firm size within the chemical industry and, for all but the largest firms within the electrical, engineering, and electronics industry. In contrast, patenting decreased with firm size in the machine tool industry.

However, these studies cannot be claimed as evidence of superior productivity of small-firm R&D. Schmookler (1966) empirically demonstrated that large firms in the U.S. have a lower propensity to patent than the small ones. He argued that anti-trust actions on the patent policies of large firms and the greater security of large firms in relation to patent-sharing and know-how exchange arrangements have lowered their propensity to patent. On the other hand, small firms neither could afford not to patent nor could afford to wait. Hence, patent statistics may well exaggerate the contribution of small firms to inventive output.

Some studies included both a measure of R&D input and firm size as explanatory variables in their regression equations. Scherer (1965b), for instance, used the following regression equation in his study:

$$(42) \qquad \frac{P}{Y} = \text{Constants} + bY + c\,\frac{R}{Y} + d\left(\frac{R}{Y}\right)^2 + u$$

The ratios are "patent intensity" (P/Y) and "R&D intensity" (R/Y). His results indicate that patent intensity varies inversely with firm size (i.e., $b < 0$) and increases with R&D intensity. The fitted quadratic attained a maximum at an input intensity exceeded by only one firm.

Comanor (1965) estimated a functional relationship similar to the V-function in (1) (see chapter III). His regression equation is of the following form:

$$(43) \qquad \frac{V}{Y} = a + b\,R/Y + c\,R^2/Y + dY + fF + gI/Y + u$$

where V is total sales revenue attributed to new products of a firm in the pharmaceutical industry in the U.S., and Y is total sales of a firm. The variable F interacts between firm size and scale of research establishment (i.e., $F = R \times Y$) and I is an index of output diversification.

R is measured in two ways:

a) average number of professional R&D personnel employed in 1955 and 1960.

b) average number of total R&D personnel (professional plus supporting) employed in the same years.

The variables R, I and V are deflated by sales to correct for heteroscedasticity. His regression results reveal that marginal productivity of professional research personnel is inversely related to firm size. The estimated elasticities of V with respect to R exceed unity for small firms and are below unity for large firms. The above results are obtained following the methodology described below:

Multiply (43) throughout by Y:

(44) $$V = a_0Y + b_0R + C_0R^2 + d_0Y^2 + f_0RY^2 + g_0I + e$$

or

(45) $$V = m + nR + \ell R^2 + kY^2 + e$$

where

$m = a_0Y + g_0I$

$n = b_0 + f_0Y^2$

$\ell = c_0$

$k = d_0$

Therefore, from (45) we get:

$$(46) \qquad \frac{\partial V}{\partial R} = n + 2\ell R$$

He found that n is negatively related to Y, therefore, from (46) he concluded that for any given R, $\frac{\partial V}{\partial R}$ is large for small values of Y, and vice versa.

There are some other studies on the efficiency of inventive activity among firms of different sizes. Schmookler (1972) found that the efficiency of inventive activity varies inversely with firm size. The former is defined in terms of R&D expenditures (C) per patent pending and the latter, in terms of employment (S). In an analogous study, Mansfield (1968a) attempted to relate the number of significant inventions per dollar of R&D expenditure with firm size and research budget. For a constant R&D outlay, the effect of firm size on the average productivity of such spending is found to be negative, that is, inventive output per dollar of R&D spending is lower in the largest firms than in the small and medium size firms.

These studies, however, do not take into account the relative importance of say 'radical primary' inventions as compared to 'secondary improvement' inventions. Jewkes et. al. (1969) noted that only twelve out of sixty-one major inventions of this century (prior to 1960) can be attributed to large corporations. Similar ideas were expressed by Hamberg (1966).

Even if we accept the fact that smaller firms are scoring better on number of patents or number of 'major' inventions, it does not follow that they are consistently more efficient in R&D performance than large firms. The final aim of industrial R&D is a flow of innovations, so that efficiency in development is just as important as the earlier stages of inventive work (Freeman, 1982). Even Jewkes et. al. (1969) noted that a number of private inventions were brought to the market by large firms. W.F. Mueller's (1962) study of major innovations by Du Pont indicates that Du Pont is more successful in improving discoveries of others than in originating major inventions.

Freeman (1982) reported from the study by Townsend et. al. (1982) on important innovations in Britain since 1945 that,

a) small firms (less than 200 employees) account for 12 per cent of all industrial innovations made since the war.

b) the share of small firms in innovation has been fairly steady, but their share of output and employment has been falling.

c) the share of the largest firms (10,000 employees and over) in the total number of innovations has increased substantially over the period, at the expense of medium-sized firms (1,000-9,000 employees).

Freeman (1971) observed that small firms contributed more in terms of innovations in industries characterized by low entry costs and low capital intensity in final goods and low development costs for innovations. Small firms contribute little in industries of high capital intensity. Pavitt and Wald (1971) in their study concluded that both large and small firms play essential, complementary, and independent roles in the process of innovation. Large firms contribute most in areas requiring large-scale R&D, production or marketing, whereas small firms tend to concentrate on specialized but sophisticated components and equipment. Next, we review some of the attmepts to test the hypotheses of Schumpeter's Model 2 (monopoly power and innovation).

IV.5 Empirical Studies of Model 2

Analogous to the empirical studies of Model 3, researchers have attempted to test for the superiority of monopoly firms through measures of innovative input and innovative output. In most of these studies, concentration ratios are used to measure monopoly power, hence these cross-industry studies cannot be evaluated within the framework described in chapter III.

Horowitz (1962) examined the hypothesis that research input intensity is positively correlated with the concentration of industry sales in the leading four firms. On the basis of the Kendall rank correlation coefficient he concluded that research expenditure as a per cent of industry sales is positively but weakly related to the four-firm concentration ratio. Among other measures of research inclination, he found that in more concentrated industries (a) research laboratories are not as likely to be held by the top 20 per cent of firms, and (b) firms are more likely to maintain research organizations. Hamberg (1966) also found similar results.

Scherer (1967a) examined the hypothesis that R&D activity increases with the concentration of market power holding other relevant variables such as total industry employment, technological opportunity, and product characteristics constant. He employed three measures of R&D input: technical engineers (E_i) plus natural scientists (T_i); T_i only and $RD_i = f_i \times p_i \times (E_i + T_i)$ where f_i is the proportion of the i^{th} industry's scientific and engineering work force engaged in formal R&D, and p_i is the proportion of the i^{th} industry's R&D financed privately. Independent variables include a four-firm concentration index, industry employment, dummy variables for such qualitative factors as the technological class (general and mechanical, electrical, chemical and traditional) and finally, type of good (producer or consumer, durable or nondurable). Since the general belief is that the errors of untransformed linear regressions are heteroscedastic and that observations from extremely large industries may dominate the coefficient estimates, he defined his first model in multiplicative form:

$$(47) \qquad R_i = a \times ST_i \times CR_i \times (\pi_j \; 10^{\Psi_j D_{ij}}) \times u_i$$

where R_i is a measure of technical employment, ST_i is total employment in industry i, CR_i is the concentration index of industry i and $D_{ij} = 1$ if the i^{th} industry is in the j^{th} technology or product class. Note that in this model, as $CR_i \to 0$, $R_i \to 0$ no matter how large Ψ_j or ST_i are -- that is, no matter how large the industry is and how favourable the technological opportunities confronting the industry are.

Parameter estimates were obtained from a logarithmic transformation of (47). The coefficient of the concentration index is positive and significant across industries when the technological opportunity dummies are dropped. When these dummies are included, the influence of concentration is small.

In a second model, Scherer regressed the various technical measures of R&D input as ratios to total employment on concentration and the dummy variables:

$$(48) \qquad \frac{R_i}{ST_i} = C_i + \sum_j d_j D_{ij} + g\, CR_i + v_i$$

In this model, inter-industry differences in qualitative factors work independently of the concentration. The coefficient of the concentration index is found to be barely significant at the 10 per cent level when E_i and RD_i are used as measures of R&D employment, and not significantly different from zero when T_i is used. He concluded from these two models that technology-class dummies compete with concentration, and, therefore, the latter variable has less influence when these dummies are included in the regression.

In a third regression, the square of the concentration index is added to (48). The relation between research intensity (R_i/ST_i) and this index is concave but the coefficient of the squared term is significant at the 5 percent level in only one case. The threshold level reached a maximum at concentration levels between 50 and 55 percent.

Comanor (1967) regressed estimated research input elasticities against average firm size and an eight-firm concentration ratio. The coefficient for average firm size is significant and positive, but there is no apparent effect of concentration. Then he went on to find out whether market power derived from concentration influenced the level of research differently when products are differentiable as opposed to when they are not. (He grouped industries into high, exceeding 70 per cent, and low concentration industries.) Comanor concluded that high concentration tends to be associated with high research when product differentiability is not a major element of market behaviour.

Globerman (1973) conducted a study of Canadian manufacturing industries. The industries are divided into greater and lesser technological opportunity classes following Scherer. The explanatory variables include percent of industry assets held by foreign companies, a measure of government finance, technology class dummies, and a four-firm concentration index. The dependent variable is R&D personnel per 1000 employees. His regression results indicate that in industries with greater technological opportunity, the research intensity varies inversely with concentration and directly with foreign ownership and government financing. All coefficients are highly significant. In contrast, for industries with lesser technological opportunity, all signs are reversed and none of the coefficients are statistically significant.

It seems, therefore, that technological opportunity in an industry competes with concentration in explaining research efforts of firms. Levin et. al. (1985, pp. 20), argued:

> "Technology classes differ in more than opportunities for technical advance, however; they also differ in the inherent ease of imitation and in the strength of patent protection. The technology class variables used in the literature (as in Scherer, 1967a) are thus interpreted as proxies for opportunity and appropriability" (parentheses mine).

In their own study, Levin et. al. regressed research intensity (C/Y) and the rate of innovation on various measures of technological opportunity (e.g., closeness to science, external sources of technical knowledge, etc.) and of appropriability (e.g., average time required to duplicate a patented, major innovation, etc.). Their results indicate that opportunity variables are jointly significant and that the concentration variable is not.

There are a few studies involving concentration which use patents as a measure of inventive output. Scherer (1965b) couldn't detect any significant positive relationship between the two. Mansfield (1968a), in a study of major innovations, found that the largest four bituminous coal and petroleum refining firms have executed a larger share of innovations than their share of the market. The opposite relationship was found in the case of the largest four steel producers. Williamson (1965), using Mansfield's data, regressed the largest four firms' share of innovation, relative to their market share, on a concentration index. Both linear and log-linear regression forms reveal a negative influence of concentration.

Finally, a few attempts are made to examine the hypothesis that monopoly firms enjoy financial economies. In these studies, researchers included various measures of liquidity and profitability to determine such effects on innovative activities of firms. Hamberg (1966) could not find any significant influence of depreciation of non-R&D capital (a source of liquidity) and profitability on research intensity (R/S). Grabowski (1968) used the sum of after-tax profits, depreciation and depletion (lagged one period) as a measure of internally generated funds. His regression results indicated that in competitive industries, the effect of this variable is stronger on research intensity (C/Y). Grabowski inferred from this result that the more important research is as a competitive strategy in an industry, the greater is the effect of all explanatory variables, including internally generated funds, on research intensity. Further support for this result is provided by Brabowski and Baxter

(1973). Scherer (1965b), however, could not find any significant relationship between profits and liquid assets on the one hand, and patenting or R&D effort on the other.

IV.6 Concluding Remarks

There are quite a few more studies, in addition to those described above, which are related to the Schumpeterian hypotheses. See Kamien and Schwartz (1982) for an excellent review of these studies. In light of our discussion in chapter III, there is some support for Model 3 (a positive relationship between firm size and innovation), although it appears that growing large research establishments have not impeded small firms from contributing significantly toward industrial research and development. The strongest case for Model 2 (monopoly power and innovation) has been made by Grabowski (1968). However, the general conclusion of the majority of existing empirical studies of the Schumpeterian hypotheses can be best described in the words of Scherer (1965b, p.1112):

> "These findings among other things raise doubts whether the big, monopolistic conglomerate corporation is as efficient an engine of technological change as disciples of Schumpeter (including myself) have supposed it to be. Perhaps a bevy of fact-mechanics can still rescue the Schumpeterian engine from disgrace, but at present the outlook seems pessimistic" (parenthesis original).

In the next chapter we, describe a statistical framework which will enable us to test the Schumpeterian hypotheses using data on innovative activities of firms in Canada.

CHAPTER V

A STATISTICAL FRAMEWORK

V.1 Introduction

One of our primary intentions now is to build a statistical framework in order to test the Schumpeterian hypotheses, which will allow us to overcome some of the weaknesses of previous empirical studies of these hypotheses as pointed out in chapters III and IV. This chapter describes such a framework based on a particular functional form which allows us to consider (a) the structural endogeneity of innovative activity and firm size, and (b) the effects of firm size (Model 3) and monopoly power (Model 2) together, on innovative activities of firms.

The following section elaborates on the framework followed by brief concluding remarks in Section V.3.

V.2 Model Specification

There are three major steps to estimation:

a) choice of a functional form.

b) choice of the regression equations.

c) choice of an estimation method.

We shall discuss each of these in the following subsections.

V.2.1 The Functional Form

We select the following functional form to test the Schumpeterian hypotheses:

$$(48) \qquad Y = a_0 + \sum_i a_i X_i + \sum_i \sum_j a_{ij} X_i X_j$$

where Y is the dependent variable of the function and the X_S represent the set of explanatory variables of the function. This 'quadratic' functional form is originally due to Lau (1974). It is linear-in-parameters and can be interpreted as a second-order Taylor expansion of Y in the powers of the X's.

Our choice of this particular functional form is based on two structural properties of the model described in chapter III (Section III.3). First, the innovative revenue function, V(R,N,A), and the innovative cost function, C(R,N,B), unlike usual revenue and cost functions, are not constrained by any homogeneity restrictions. Among the three arguments in each of these two functions, one describes a factor input into the innovative process, namely, R&D workers, while the rest characterize two types of 'externalities' in the innovative process. Second, in order to obtain estimates of the cross-partials describing the Schumpeterian hypotheses in (2) to (6), at least a quadratic functional form is required.

Let us now express the functions in (1) in terms of (48):

$$V = \alpha_0 + \alpha_1 R + \alpha_2 N + \alpha_3 A + \alpha_{11} R^2 + \alpha_{22} N^2 + \alpha_{33} A^2 \quad (49)$$

$$\ldots. + 2\alpha_{12} RN + 2\alpha_{13} RA + 2\alpha_{23} NA + U_V$$

$$C = \beta_0 + \beta_1 R + \beta_2 N + \beta_3 B + \beta_{11} R^2 + \beta_{22} N^2 + \beta_{33} B^2 \quad (50)$$

$$\ldots. + 2\beta_{12} RN + 2\beta_{13} RB + 2\beta_{23} NB + U_C$$

$$H = \gamma_0 + \gamma_1 N + \gamma_2 G + \gamma_{11} N^2 + \gamma_{22} G^2 + 2\gamma_{12} NG + U_H \quad (51)$$

Note that A, B and G are vectors, U_V, U_C and U_H represent the errors in the equations.

The following parameters of (49) and (50) describe the Schumpeterian hypotheses:

$$\begin{aligned} V_{RA} &\simeq 2\alpha_{13} \\ C_{RB} &\simeq 2\beta_{13} \\ V_{RN} &\simeq 2\alpha_{12} \\ C_{RN} &\simeq 2\beta_{12} \end{aligned} \quad (52)$$

Also, the parameters representing the linkages between the two externalities are:

$$(53)\qquad \begin{aligned} V_{NA} &\simeq 2\alpha_{23} \\ C_{NB} &\simeq 2\beta_{23} \end{aligned}$$

V.2.2 Choice of the Regression Equations

We can choose from three sets of regression equations to test the Schumpeterian hypotheses. One option is to estimate directly the functional relationships in (49) and (50). Since the functional form is quadratic and linear-in-parameters, we would obtain constant estimated values for the coefficients corresponding to the hypotheses as shown in (52). Note that the relationships in (49) and (50) are free of the maintained hypothesis in our theoretical framework that firms maximize profits. Instead, we can assume that the observed values of the variables in (49) and (50) are, respectively, firms' revenue maximizing and cost minimizing decisions.

A second option is to estimate the first-order profit maximizing conditions. Combining (7) and (8) with (49)-(51) and adding an error term in each equation we obtain:

$$(54)\qquad R = \theta_0 + \theta_1 N + \theta_2 A + \theta_3 B + U_R$$

and

$$(55)\qquad N = \delta_0 + \delta_1 R + \delta_2 A + \delta_3 B + \delta_4 G + U_N$$

where

$$\theta_0 = -(\alpha_1 - \beta_1)/a$$

$$\theta_1 = -2(\alpha_{12} - \beta_{12})/a$$

$$\theta_2 = -2\ \alpha_{13}/a$$

$$\theta_3 = 2\ \beta_{13}/a$$

(56) $$\delta_0 = -(\alpha_2 - \beta_2 + \gamma_1)/b$$

$$\delta_1 = -2(\alpha_{12} - \beta_{12})/b$$

$$\delta_2 = -2\alpha_{23}/b$$

$$\delta_2 = -2\beta_{23}/b$$

$$\delta_3 = 2\beta_{23}/b$$

$$\delta_4 = -2\gamma_{12}/b$$

where

(57) $$a = 2(\alpha_{11} - \beta_{11}) \simeq (V_{RR} - C_{RR})$$

(58) $$b = 2(\alpha_{22} - \beta_{22} + \gamma_{11}) \simeq (V_{NN} - C_{NN} + H_{NN})$$

U_R and U_N are the errors in the two equations.

From parameter estimates in (54) and (55) we cannot obtain numerical estimates of the individual cross-partials describing the Schumpeterian hypotheses. However, we can draw inferences about those hypotheses from the signs of these parameter estimates, given that a and b are negative by the second-order conditions of profit maximization in (10) and (11). Note that the hypotheses of Model 3, V_{RN} and C_{RN}, appear together in (54) and (55) in θ_1 and δ_1, corresponding to our discussion of the "combined" hypothesis in chapter III.

Finally, a third set of regression equations can be estimated, namely, the reduced form equations for R and N which we can obtain from (54) and (55):

(59) $$R = \lambda_0 + \lambda_1 A + \lambda_2 B + \lambda_3 G + \varepsilon_R$$

(60) $$N = \rho_0 + \rho_1 A + \rho_2 B + \rho_3 G + \varepsilon_N$$

where λ_i and ρ_i are the reduced form parameters (see Appendix V) and ε_R and ε_N are the errors in the two equations.

There is clearly a problem of identification of the parameters in the system of equations in (54) and (55). All the parameters in (54) are at least exactly identified (in case of more than one G-variable all these parameters are overidentified), whereas, all parameters in (55) are unidentified. Consequently, the parameters in (55) cannot be recovered from the reduced form parameters in (59) and (60). The relationship between the reduced form parameters and the structural parameters in (54) is as follows: (See Appendix V for details.)

$$\frac{\lambda_3}{\rho_3} = \theta_1$$

(61) $$(\lambda_1 - \theta_1\rho_1) = \theta_2$$

$$(\lambda_2 - \theta_1\rho_2) = \theta_3$$

(61) clearly indicates that if there are more than one G-variables, θ_1, θ_2, and θ_3 are overidentified.

V.2.3 Choice of an Estimation Method

Choice of an estimation method in case of each of the three systemsof equations will be largely determined by the structural specification of the model, the stochastic specification of the regression equations, and the properties of the data.

The system of equations in (49) and (50) does not indicate any structural simultaneity, hence these two equations can be estimated by Ordinary Least Squates (OLS) or as Seemingly Unrelated Regressions (SUR). If, however, one believes that these two equations belong to a larger set of equations where in fact, some of the right-hand side variables are endogenously determined, then one can eliminate the simultaneity through use of an Instrumental Variables (IV) method of estimation.

An obvious choice for estimating the structural equations in (54) and (55) would be Two State Least Squares (2SLS). However, in view of the fact that (55) is not identified, simultaneous equation techniques cannot be applied to estimate this equation. Finally, the reduced form equations in (59) and (60) can be estimated by Ordinary Least Squares, with parameter restrictions (61) if there is more than one G-variable.

Turning now to the stochastic specification of the regression equations, there can be multiple sources of errors in the three system of equations discussed above. Two general characteristics of the errors in this particular study deserve mention. First, in a cross-section study like ours, it is natural to expect heteroscedastic disturbances across the sample of firms in an industry. Second, there can be errors originating in the maintained hypotheses of our model. Such specification errors can have their roots in two parts of our model. (a) The innovative revenue and cost functions in (1) may have omitted important variables which firms consider in their decision making processes. (b) Firms may not necessarily follow 'profit maximization' as an optimizing principle in making decisions about innovative activities.

In our empirical study (see chapter VI), we perform various tests for heteroscedasticity before we select a set of results to report. In regard to the specification errors mentioned above, we, however, only admit at this point that in the presence of such errors, the estimation results will be biased.

Coming to the data set on innovative activities of firms, a typical feature is the presence of 'zero' observations on certain variables. For instance, there is always a subset of firms who report zero employment of R&D workers, although their R&D expenditures are positive. This is not entirely implausible if firms choose to use consultants and some of their operating personnel to perform R&D activities.

In our framework, zero values of R can be best interpreted as some firms' failure to meet the first-order profit maximizing condition in (7). More clearly, when the optimality condition dictates a 'negative' value for R, firms choose not to employ any R&D workers.

Technically, the specified functional form in (48) can accommodate zero values of R and still the return and cost of R&D can be positive. The OLS method will still give unbiased estimates of the parameters in (49) and (50).

However, in the case of the first-order equation in (54), where R appears as a 'dependent' variable, usual simultaneous equation estimators will be biased when observations on R include zeroes (Maddala, 1983). The underlying stochastic choice mechanism for this situation can be expressed as follows:

$$(62) \qquad R = \theta_0 + \theta_1 N + \theta_2 A + \theta_3 B + U_R > 0 \quad \text{if } V_R - C_R = 0$$

$$R = 0 \qquad \text{if } V_R - C_R < 0$$

and

$$(55) \qquad N = \delta_0 + \delta_1 R + \delta_2 A + \delta_3 B + \delta_4 G + U_N$$

where θ_i and δ_i are given in (56). Note that since all firms in the sample are expected to be in operation, we assume $N > 0$ throughout the sample.

The above model falls under a particular class of limited dependent variable models known as the Tobit model, originally proposed by Tobin (1958) to conduct regression analysis when many observations on the dependent variable in the sample are zero. Formally, the Tobit model in (62) and (55) can be interpreted as follows: firms' optimal choice of R&D workers, say R^*, is unobservable If $R^* > 0$, then $R = R^*$, where R is observable. On the other hand, if $R^* \leq 0$ then observed R equals zero.

Tobin's original model contained a single regression equation and, therefore, he didn't consider a simultaneous equations structure such as we have. The identification problem in our simultaneous equations Tobit model are the same as in (54) and (55). The only difference lies in the estimation method to be used.

Tobin's estimation method for a single equation structure, however, cannot be applied to our model unless a statistical test of exogeneity of N in (54) indicates acceptance of such exogeneity. One such test of exogeneity is recently proposed by Smith and Blundell (1986). (See chapter VI.)

Nelson and Olsen (1978) suggested a maximum likelihood estimation method for a simultaneous equations Tobit model similar to ours, where one dependent variable is censored and the other is not. There are several other estimation methods that have been suggested by various authors for different kinds of censored models; see Maddala (1983) for a recent review of this literature.

V.3 Concluding Remarks

This ends our discussion of the statistical framework which will be used to test the Schumpeterian hypotheses in the next chapter. The functional form described above will allow us to obtain constant parameter estimates of those hypotheses; alternatively, one can use a cubic functional form to obtain nonlinear estimates of them. The first-order equations and the reduced form equations contain the structural simultaneity between firm size and innovative effort; they also incorporate the effects of both firm size (Model 3) and monopoly power (Model 2) on innovative efforts of firms. Finally, we have demonstrated a possible modification of our regression equations to empirically account for zero observations on R in the sample.

We now turn to our empirical study of the Schumpeterian hypothesis, using data on innovative activities of firms in Canada collected by the Economic Council of Canada.

APPENDIX V

Substituting (55) in (54) we obtain

(A8) $$R = \frac{1}{1 - \delta_1\theta_1} \Big| (\theta_0 + \theta_1\delta_0) + (\theta_2 + \theta_1\delta_2)A$$

$$.... + (\theta_3 + \theta_1\delta_3)B + \theta_1\delta_4 G + (U_R + \theta_1 U_N) \Big|$$

Comparing (A8) with (59) we obtain the following reduced form parameters:

(A9)
$$\lambda_0 = (\theta_0 + \theta_1\delta_0)/x$$
$$\lambda_1 = (\theta_2 + \theta_1\delta_2)/x$$
$$\lambda_2 = (\theta_3 + \theta_1\delta_3)/x$$
$$\lambda_3 = \theta_1\delta_4/x$$
$$\varepsilon_R = (U_R + \theta_1 U_N)/x$$

where

(A10) $$x = 1-\delta_1\theta_1$$

Similarly, substituting (54) in (55), we get:

$$\text{(A11)} \qquad N = \frac{1}{x} \left| (\delta_0 + \delta_1\theta_0) + (\delta_2 + \delta_1\theta_2)A \right.$$

$$\left. \quad \ldots + (\delta_3 + \delta_1\theta_3)B + \delta_4 G + (U_N + \delta_1 U_R) \right|$$

Comparing (A11) with (60) we obtain the following:

$$\rho_0 = (\delta_0 + \delta_1\theta_0)/x$$

$$\rho_1 = (\delta_2 + \delta_1\theta_2)/x$$

$$\rho_2 = (\delta_3 + \delta_1\theta_3)/x$$

$$\rho_3 = \delta_4/x$$

$$\varepsilon_N = (U_N + \delta_1 U_R)/x$$

where x is given in (A10).

CHAPTER VI

EMPIRICAL RESULTS

VI.1 Introduction

This chapter presents an empirical study of the Schumpeterian hypotheses. The regression equations are obtained from the statistical framework described in the previous chapter, and the data have been obtained from a recent survey by the Economic Council of Canada of innovative activities of firms in Canada, during the period 1960-78.

The discussion in this chapter is organized as follows: Section VI.2 contains the empirical specification of the regression equations. A description of the data is presented in Section VI.3. The various hypotheses are tested in Section VI.4 followed by brief concluding remarks in Section VI.5. A summary of this dissertation will be provided in chapter VII.

VI.2 Empirical Specification

We select the structural equations in (54) and (55), and the Tobit model in (62) and (55) to test the Schumpeterian hypotheses. (See chapter V for our discussion of these regression equations.) This choice is primarily made on three grounds:

a) these equations incorporate the structural simultaneity of innovative effort and firm size which we discussed in chapter III.

b) these two systems of equations will allow us to draw conclusions about the impact of observations with 'zero' values for R&D personnel, from comparing the estimates of (54) with (62).

c) due to the nature of the variables, the data contains more information on the set of variables (R, N, A, B) in comparison to the set (V, C, A, B) which make up the system in (49) and (50). Hence, a larger number of firms and their innovations can be covered in the study. It seems that firms in general have had relatively more difficulty in computing the dollar amount of return on their innovations (V), and hence have not reported on this aspect of innovation. (See our discussion of the data in Section VI.3 below.)

However, as has been pointed out in chapter V, the second equation in either system -- Equation (55) -- is unidentified, and hence cannot be estimated using any simultaneous equation technique. This leaves only the first equation in both systems to be estimated. We now turn our attention toward the description and measurement of the variables that are considered in the estimation.

In order to facilitate the following discussion about the expected signs of the coefficients of the variables, let us reconsider (54)(the same set of variables is included in (62)):

(54) $R = \theta_0 + \theta_1 N + \theta_2 A + \theta_3 B + U_R$

where the θ's are described in (56) to (58). If there is a positive externality from firm size on innovative activities of firms (Model 3), we expect $\theta_1 > 0$. Both R and N are firm-specific variables in the year of innovation, referring to the particular Standard Industrial Classification (SIC) category, for instance, telecommunications equipment and components[1]. In other words, in the case of a multiproduct firm, whose products may belong to more than one SIC category, R and N refers to the SIC of interest in which the innovation took place. Following Schumpeter's Model 2, that there is a positive externality from monopoly power on innovative activities of firms, we expect θ_2, $\theta_3 > 0$. However, from a number of A and B variables we can expect a negative externality on firms' innovative activities (explained below) in which case, θ_2 and θ_3 may be either positive or negative depending upon the strength of each of these externalities. All the A and B variables are innovation-specific. The measurement and definition of these variables are shown in Table VI.1. Before we discuss these variables, we shall pause for a brief digression.

The A and B variables in this study are intended to

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[1] N = S-R where S is total employment of a firm. See Table VI.1.

capture two broad aspects of monopoly power: appropriability and technological opportunity. This classification is fairly recent and among the few empirical attempts to measure these aspects of monopoly power, see Levin and Reiss (1984), Levin et. al. (1985), and Pakes and Schankerman (1984). The idea of technological opportunity being a competing explanation for research effort of firms beside the conventional role of concentration, is originally due to Scherer (1967a).

The studies by Levin and his co-authors are of interest for two reasons: first, they attempted to test Model 2 using several proxies for appropriability and technological opportunity; and second, they estimated a generalized version of the model by Dasgupta and Stiglitz (1980a), where market structure (measured by concentration) and innovative activity are both endogenously determined by appropriability, technological opportunity, and other factors like demand conditions, etc. This approach is similar to the framework described in chapter III except that we represent market structure by the distribution of firm size within an industry.

Levin and Reiss (1984) defined technological opportunity as responsiveness of cost of production to firms' own research effort. Such opportunities depend upon the science-base of an industry's technology characterized in terms of electrical, chemical, etc. Also they considered government-funded R&D to be another proxy for technological opportunity on the basis of the argument that such R&D is complementary to private effort.

The authors distinguished between three dimensions of appropriability. First, there is a technological dimension of appropiability which tells us that a firm's cost of production is negatively related to the industry-wide pool of R&D. If this relationship is very elastic, then costless imitation is relatively easy in which case, the returns to R&D are relatively inappropriable. This may also reduce the level of R&D in an industry. One of the empirical measures they employed in their study is the ratio of R&D embodied in inputs to total R&D used. This dimension is also known as the spillover effect in R&D: when investment in new knowledge by one firm spills over to other firms, a positive externality arises within the industry. Such spillovers can have ambiguous effects on firm's own R&D, however; because they can enhance productivity of R&D by strengthening the knowledge base of the industry (Spence, 1984)[2].

Second, Levin and Reiss described a structural dimension of appropriability which tells us that a firm's appropriable benefits from augmenting the common pool of knowledge positively depends on its market share. In their model, which describes a symmetric Cournot equilibrium, market share is defined as one over the number of firms in the industry. The empirical measure is the concentration ratio.

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[2] Jaffe (1984) attempted to measure such spillovers in R&D.

Finally, there is a behavioural dimension of appropriability which tells us that if a firm can borrow costlessly from another firm's R&D effort, the former may choose to be a 'free rider' and cut back on its own R&D effort. In Levin and Reiss' model this is represented in terms of the parameter reflecting conjectural variations of firms. They allowed both restricted and unrestricted values for this parameter in their estimation.

This empirical study also considers several proxies for appropriability and technological opportunity. Many of these proxies can be described in terms of both A and B variables; however, what interests us is the nature of the externality from these variables on innovative effort of firms, that is, the sign of θ_2 or θ_3 (see equation (54)).

Spillover in R&D can affect both opportunity for technical advance by individual firms and appropriability of returns on their R&D efforts. This makes it difficult to classify these various proxy variables into two mutually exclusive groups, namely, appropriability and technological opportunity.

In Schumpeter's original discussion (see chapter III), monopoly power is meant to serve the dual purpose of providing protection during the development of an innovation and ensuring a guaranteed flow of return after its first commercialization. The neo-Schumpeterian modification of this restrictive version of monopoly power to a consideration of spillover effects in R&D will alter our expectations from a simple 'complementary' role of monopoly power to the possibility of a negative association between these proxies for appropriability and technological opportunity and R&D efforts of firms: θ_2 or $\theta_3 \gtrless 0$.

TABLE VI.1: List of Variables

Variable	Definition and Measurement
R	Number of qualified scientists and engineers engaged in R&D.
S	Number of employees.
N	Number of operating personnel (S-R)
PATENT	Patented innovation (scaled 0-1)
CMKT	Marketing set-up cost of innovation ($)
IMINNOV	Imitative innovation (scaled 0-1)
COMP	Number of firms offering products directly competing with the product innovation or with the products flowing from the process innovation.
TECHOUT	Technology for the innovation is obtained from sources outside the firm (scaled 0-1)
LICENSE	Technology is obtained through licensing or other (written or unwritten) transfer agreement (scaled 0-1).

TABLE VI.1: (continued)

Variable	Definition and Measurement
IDPARNT	Ideas and information useful in the generation and development of the innovation obtained from parent firm or subsidiary or affiliated firms (scaled 0-1)
IDCUST	Ideas and information useful in the generation and development of the innovation obtained from customers (scaled 0-1)
IDMSMP	Ideas and information useful in the generation and development of the innovation obtained from management or sales force or marketing personnel or production personnel of the firm (scaled 0-1)
FUNDOWN	Percentage of funds for the development of the innovation obtained from internal sources or parent or other affiliated firms (%)
FUNDGOVT	Percentage of funds for the development of the innovation obtained from government (%)
CAN	Canadian-owned firm (scaled 0-1)
USA	USA-owned firm (scaled 0-1)
UK	UK-owned firm (scaled 0-1)

This study considers four variables (see Table VI.1) which are thought to have direct consequences for appropriable returns on firms' R&D. The variables PATENT, CMKT, and IMINNOV can be looked upon as variables representing the technological dimension of appropriability. The COMP variable is included to represent the structural dimension of appropriability.

The orthodox Schumpeterian view will dictate positive coefficients for PATENT, CMKT, and IMINNOV and a negative coefficient for the COMP variable: the greater the number of firms offering products which directly compete with the innovation, the smaller is the scope to appropriate returns on R&D. However, as mentioned earlier, the spillover effect may render a negative effect of IMINNOV on firms' R&D, implying firms do less R&D in case of imitative innovation. Also, regarding the marketing set-up costs for an innovation (CMKT) which include expenditures on items like advertising, the firm may consider such expenses as 'substitutes' for its R&D effort. In other words, competing firms may consider 'product differentiation' and 'product innovation' as two alternative strategies, although not exactly perfect substitutes.

Technological opportunity is defined as opportunity for technical advance. Such opportunities are created through firms' licensing or other agreements with other firms regarding the sharing of technological know-how or through informal support for the development of an innovation from a parent firm or other affiliated firms. Seven variables are constructed which are thought to have direct effects on the development of an innovation.

The variable TECHOUT represents externality on R&D efforts of firms when the technology for innovation is obtained from outside the firm instead of being developed through in-house R&D facilities. Due to the clear indication of a spillover effect in this case, we expect either a positive or a negative coefficient for this variable.

When the technology is obtained from outside the firm, it can have a number of alternative sources. To name a few, the technology could have been obtained from the parent firm, another affiliate, or by a licensing agreement from a customer or a supplier to the firm. The LICENSE variable is meant to represent the externality on R&D efforts of firms when the technology for innovation is obtained through licensing or other transfer agreements. These other agreements may involve a cross-licensing agreement, an agreement which specifies the right to manufacture or sell or even the right to use a trademark. Since whenever this variable equals one the variable TECHOUT also equals one, we expect either a negative or a positive coefficient for this variable.

A firm can also obtain ideas and information for its innovation from various sources outside the firm. This study considers three such sources. The variable IDPARNT equals one if such ideas are obtained from the parent firm; IDCUST, when such ideas are obtained from customers; and IDMSMP reflects interaction between the R&D and the non-R&D staff of a firm in generating ideas and information for an innovation. The non-R&D staff consists of personnel from management, sales, marketing and production departments of the firm. In the case of IDPARNT we can expect spillover effects in R&D activities, hence the externality on firms' own R&D can be either negative or positive. In regard to the variables IDCUST and IDMSMP, we do not form any expectation about the nature of their externalities on firms' own R&D.

The remaining two proxies for technological opportunity can be best described as "cost-of-funds" advantages in the process of innovation. The FUNDOWN variable indicates the extent of internal financing and financial support received from parent or other affiliated firms for the development of the innovation. The FUNDGOVT reflects the extent of government support for private R&D. In both cases, we expect a Schumpeterian 'complementary' relationship between firms' R&D effort and the two variables, implying positive coefficients for these variables.

Finally, the three firm ownership dummy variables -- CAN, USA, and UK -- are constructed to represent the G-variables which are required to identify the parameters of (54) in case of a 2SLS estimation of the equation. (See our discussion in chapter V.)

Before we describe the data in the next section it is worth pointing out that our selection of the proxies for appropriability and technological opportunity (Model 2) is largely guided by the data which we use in our estimation of the Schumpeterian hypotheses. A large enough data set covering more industries and more detailed information on firms' innovative activities will allow the investigator to include the traditional measures of concentration in addition to a rigorous set of proxies for Model 2. Exclusion of such important variables like concentration from our study may well lead to biased parameter estimates.

VI.3 The Data

The data is based on a survey by the Economic Council of Canada. In the survey firms from five Canadian industries were asked to report on up to three 'major' innovations which they introduced during the 1960-78 period[3,4]. Out of 410 firms contacted, 173 firms reported on at least one innovation. The data contains information on 279 innovations by 173 firms spread over five industries, namely, Telecommunications Equipment and

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[3] Quite a few firms reported on more than three innovations. Also some firms reported on a total of 23 innovations which were introduced in 1979 and 5 in early 1980.

[4] 'Major' innovation was defined in the survey as those innovations which the firms consider to have contributed most to their profitability in a particular SIC category.

Components, Crude Petroleum Exploration and Production, Plastics Compounds and Synthetic Resins, Non-Ferrous Smelting and Refining, and Electrical Industrial Equipment.

At this point we should note several features of the data which limit its usefulness. The data contains information on only 'major' innovations by some firms during the 1960-78 period. This leaves out information on firms with no innovative activities and some firms with innovations, major or minor, who have not responded to the survey. An estimate of these various categories of firms is shown in Table VI.2. The table indicates that except in the Plastics Compounds and Synthetic Resins and Non-Ferrous Smelting and Refining Industries, a substantial number of firms, possibly with one or more innovations during 1960-78 period, are not covered by the data.

The second and perhaps the most glaring drawback of the data is the extent of 'missing' information due to lack of response by the reporting firms. This aspect of the data is scattered over the entire data set and is particularly noticeable in case of variables like the return on innovation (V). The net result is a further reduction in the number of firms and their innovations that we can consider in our estimation (see Table VI.3).

These weaknesses of the data will obviously make it difficult to formulate policy proposals on the basis of our results.

TABLE VI.2

Total Number of Firms, Number of Firms with No Major Innovation, Number of Firms Possibly with One or More Innovations Not Reporting to the Survey, and Number of Reporting Firms with Major Innovations, by Industry

Industry	Total Number of Firms	Number of Firms With No Major Innovation	Number of Firms Not Reporting	Number of Reporting Firms With Major Innovations
Telecommunications, Equipment and Components	119	7	47	65
Crude Petroleum, Exploration and Production	95	26	53	16
Plastics Compounds and Synthetic Resins	38	5	12	21
Non-Ferrous Smelting and Refining	30	3	6	21
Electrical Industrial Equipment	128	12	66	50
All Industries	410	53	184	173

SOURCE: Demelto et. al., 1980, pp. 276

Nonetheless, given the growing consent on the scarcity of detailed information on firms' innovative activities in almost all countries (see Comanor, 1986), and the significant imbalance created by the recent upsurge of empirically untested theoretical propositions we utilize this limited set of information for our study of the Schumpeterian hypotheses. To accommodate this problem the models will be subjected to various specification tests to examine the coherence of the underlying model with the data.

VI.4 Model Estimates

Estimation of the Schumpeterian hypotheses is based on the regression equations (54) and (62). The number of firms and innovations included in this study, after deleting the records with 'missing' observations, are shown in Table VI.3. Only three industries are considered for individual study: Telecommunications Equipment and Components, Plastics Compounds and Synthetic Resins, and Electrical Industrial Equipment. This selection of industries is not only motivated by the number of observations (innovations) in these three industries, but we also statistically test whether these industries are parametrically different from each other; if not, one study including all three industries together, would suffice for our estimation of the Schumpeterian hypotheses. This test is obtained from Anderson and Mizon (1984) who describe a Chi-Square

TABLE VI.3

Total Number of Reporting Firms and Innovations, and Total Number of Firms and Innovations Included in the Study, by Industry

Industry	Total Number of Reporting Firms	Total Number of Innovations by the Reporting Firms	Total Number of Firms in the Study	Total Number of Innovations In the Study
Telecommunications, Equipment and Components	65	108	48	73
Crude Petroleum, Exploration and Production	16	30	4	8
Plastics Compounds and Synthetic Resins	21	40	17	27
Non-Ferrous Smelting and Refining	21	33	5	11
Electrical Industrial Equipment	50	68	36	48
All Industries	173	279	110	167

test of parameter constancy across industries. It is analogous to the Chow Test except that it also takes into consideration the variation in variance across industries. It can be described as testing that m comes from a central Chi-Squared distribution with 24 degrees of freedom where m is defined as[5]:

$$(63) \qquad m = \sum_{i=1}^{3} \ell_i - \overline{\ell} \sim \chi^2(24)$$

ℓ_i is logarithm of the likelihood function for industry i, obtained from a 2SLS estimation of (54). We consider Crude Petroleum Exploration and Production, Plastics Compounds and Synthetic Resins, and Non-Ferrous Smelting and Refining as one industry for this test. $\overline{\ell}$ is logarithm of the likelihood function for all industries taken together, obtained from a similar estimation of (54).

The value of m is found to be 106.425 which emphatically rejects the null hypothesis that the parameters are similar across industries. The empirical results for each of the three industries will now be discussed in the following sub-sections.

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[5] The degrees of freedom for this test is calculated as follows: for each industry, we consider 12 right-hand side variables in the regression equation, which adds up to 36 for three industries. We then subtract 12 from 36 where 12 is the number of right-hand side variables when all industries are considered together, and hence we get 24 as the number for degrees of freedom for this test.

VI.4.1 Telecommunications Equipment and Components

Tests of the Schumpeterian hypotheses in this industry are based on 73 innovations by 48 firms. The parameter estimates from the regression equations (54) and (62) are shown in Table VI.4. Before we discuss these results, let us examine the results from some diagnostic tests that we have performed on the regression equations. Each of these tests uses a critical value based on its asymptotic null distribution.

The specification test described in Hausman (1978) is applied to check the structural simultaneity between R and N in (54). This test can be described as a test of $\alpha = 0$ in the following regression:

$$R = \theta_0 + \theta_1 N + \alpha\hat{N} + \theta_2 A + \theta_3 B + w_R \tag{64}$$

where $\hat{N}$ is predicted N from an OLS estimation of the reduced form equation for N (see (60)) which includes as regressors all the A, B and G variables listed in Table VI.1. A statistically significant OLS estimate of α from (64) will reject the null hypothesis that N is exogenous in (54).

The estimated t-ratio for α is 1.490 which is not significantly different from zero at the 5 per cent level (two-tail t-test). Therefore, there is no evidence of a simultaneous relationship between R and N. This test result can be interpreted as an acceptance at the 5 per cent level of the hypothesis that OLS is a consistent estimator of the parameters in (54).

The Hausman Test is based on the maintained hypothesis that the errors in (64) are homoscedastic. The test described in Anderson (1981), which is similar to the Chi-Square test in Godfrey (1978), is applied to test for structural heteroscedasticity in (64). This is a test of the hypothesis that $\beta = \gamma = 0$ in the following equation:

$$(65) \qquad \ell n\ \hat{w}_R^2 = \alpha + \beta\ \ell n\ \hat{Y}^2 + \gamma\ \ell n\ \hat{C}^2 + U_{1R} \qquad U_{1R} \sim N(0, \sigma^2)$$

$\ell n\ \hat{w}_R^2$ is the logarithm of the squared residuals of (64). $\ell n\ \hat{Y}^2$ is the logarithm of the squared predicted sales, the predicted values being obtained from the reduced form equation for sales. $\ell n\ \hat{C}^2$ is the logarithm of the squared predicted cost of innovation, where the predicted values have been obtained in similar manner.

The results obtained from OLS estimation of (65) are as follows (t-statistic in parenthesis):

$$(66) \qquad \underset{}{\ell n\ \hat{w}_R^2} = \underset{(-1.037)}{-4.487} + \underset{(1.550)}{.211}\ \ell n\ \hat{Y}^2 + \underset{(.285)}{.040}\ \ell n\ \hat{C}^2$$

$R^2 = .0489$

Wald Chi-Square Test (D.F) = 3.60(2)

The Wald Chi-Square Test indicates that $\ell n\ \hat{Y}^2$ and $\ell n\ \hat{C}^2$ are jointly not significantly different from zero, hence there is no evidence of structural heteroscedasticity in (64) in relation to these two scale variables. Therefore, this test did not uncover any evidence that the Hausman Test of exogeneity is invalid[6].

The OLS parameter estimates from (54) are shown in Table VI.4. There is no evidence of structural heteroscedasticity in (54) in relation to sales and cost of innovation. The following test results are obtained from a regression equation similar to (65) (t-statistic in parenthesis):

$$\ell n\ \hat{U}_R^2 = \underset{(-.184)}{-.729} + \underset{(.359)}{.055}\ \ell n\ \hat{Y}^2 + \underset{(.682)}{.078}\ \ell n\ \hat{C}^2 \quad (67)$$

$R^2 = .0204$

Wald Chi-Square Test (D.F.) = 1.460(2)

where $\hat{U}_R$ are OLS residuals from (54). The Wald Chi-Square Test accepts the null hypothesis, $\beta = \gamma = 0$.

Although there is no evidence of structural heteroscedasticity in relation to sales and cost of innovation, we have obtained the t-ratios of the coefficients using White's (1980) Heteroscedasticity-Consistent Covariance Matrix (WHCCM) estimator. This estimator

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[6] Regression results when these two regressors in (65) are considered separately, do not reveal any strong support for heteroscedasticity either. Note, however, this test, while easy to implement, may well have low power against some alternatives.

corrects for any unknown form of heteroscedasticity in the sample and can be described as follows:

$$(68) \qquad WHCCM = (Z'Z)^{-1}Z'\hat{V}Z(Z'Z)^{-1}$$

where Z is the matrix of N, A and B variables (i.e., the regressors in (54)) and $\hat{V}$ is a diagonal matrix of the squared OLS residuals from (54). The corrected standard errors of the OLS coefficients are the square roots of the diagonal elements of WHCCM. The corresponding t-ratios (see column 3 of Table VI.4) are computed by dividing the estimated OLS coefficients by these corrected standard errors of the respective coefficients[7].

The interested reader is referred to Appendix VI.A for the 2SLS estimates of (54). These estimates are obtained from an over-identified system. We consider 3 G-variables, namely, CAN, USA, and UK, in which case there are two over-identifying restrictions in (54) (see our discussion in chapter V). The Chi-Square specification test described in Pearce et. al. (1976) Appendix, chapter III, is used to test for independence of the instruments in 2SLS estimation of (54) and the error in that equation. This test can be construed as a joint test of the over-identifying restrictions, i.e., of the exclusion of

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[7] In the case of 2SLS, Z is replaced by $\hat{Z}$ in (68) where $\hat{Z}$ is the matrix of $\hat{N}$, A, and B and $\hat{V}$ and is obtained from 2SLS residuals of (54).

instruments (the G-variables) from the specified maintained hypothesis.

The Chi-Square test can be described as a test that m' comes from a Chi-Squared distribution with 2 degrees of freedom under the null hypothesis that the two over-identifying restrictions are true:

(69) $$m' = \frac{\hat{\hat{U}}_R \hat{M}(\hat{M}'\hat{M})^{-1}\hat{M}'\hat{\hat{U}}_R^{1}}{\hat{\hat{U}}_R'\hat{\hat{U}}_R/n} \sim \chi^2(2)$$

where $\hat{\hat{U}}_R$ is the column vector of 2SLS residuals of (54) and $\hat{M}$ is the matrix of the instrumental variables, namely, A, B and G. n is the number of observations. The computed value of m' is 2.009(2) which accepts the null hypothesis at the 5 per cent level that the two over-identifying restrictions in (54) are true.

When A, B = 0 in (54), the following estimates for Model 3 are obtained (t-statistic in parenthesis):

(70) $$R = \underset{(2.857)}{7.513} + \underset{(3.665)}{.019}N$$

$$R^2 = .1591$$

In comparison, when the A and B variables representing Model 2 are included in the regression, the coefficient of N (Model 3) marginally declines to .017 with an estimated t-ratio of 3.402 and the R^2 statistic of the regression equation climbs to .6124. The only

TABLE VI.4

Telecommunications Equipment and Components: OLS and TOBIT Estimates (Asymptotic t-Statistic in Parenthesis)

Variables (1)	OLS (2)	WHCCM-t (3)	TOBIT (4)
Intercept	3.137		3.744
	(.375)	(.666)	(.469)
N	.017[a]		.017[a]
	(3.402)	(2.535)[a]	(3.698)
PATENT	.527		-.635
	(.123)	(.217)	(-.154)
COMP	-.282[b]		-.273[b]
	(-1.711)	(-3.068)[a]	(-1.744)
CMKT	.00001		-.000001
	(.345)	(.621)	(-.061)
IMINNOV	-.222		-2.218
	(-.047)	(-.077)	(-.494)
TECHOUT	-55.193[a]		-56.658[a]
	(-6.139)	(-2.738)[a]	(-5.860)
LICENSE	48.943[a]		49.136[a]
	(4.923)	(2.387)[a]	(4.793)
IDPARNT	5.222		6.247
	(.899)	(.803)	(1.128)
IDMSMP	-.232		-.665
	(-.052)	(-.070)	(-.158)
IDCUST	5.747[c]		6.503[b]
	(1.481)	(2.190)[a]	(1.747)
DUNDOWN	-.024		-.026
	(-.290)	(-.477)	(-.341)
FUNDGOVT	.193[c]		.195[b]
	(1.623)	(2.061)[a]	(1.724)

...continued

TABLE VI.4 (continued)

WALD-CHI SQUARE TEST (D.F.)			
All A and B vars (11)	70.182[d]	25.689[d]	52.721[d]
Appropriability vars (4)	3.532	11.636[d]	3.928
Technological Opportunity Vars (7)	66.688[d]	21.173[d]	51.486[d]
Cost-of-Funds Advan age vars (2)	5.006[e]	5.105[e]	5.775[e]
Spillover vars (4)	40.914[d]	8.163[e]	35.895[d]

[a] Significant at .05 level (two-tailed t-test).
[b] Significant at .05 level (one-tailed t-test).
[c] Significant at .10 level (one-tailed t-test).
[d] Significant at .05 level (Chi-Square Test).
[e] Significant at .10 level (Chi-Square Test).

marked difference can be noticed in case of the intercept (see Table VI.4) and the value of R^2. In other words, Model 2 and Model 3 seem to be fairly independent of each other in their effects on innovative effort of firms.

Table VI.4 shows that there is a significant positive externality from firm size on innovative activities, providing support for Model 3. Among the appropriability variables, the COMP variable shows significant support for the Schumpeterian hypotheses of Model 2. Among the technological opportunity variables, there is a significant negative externality from TECHOUT which indicates the effect of spillover in R&D. However, licensed technologies (LICENSE) show significant positive externality in R&D of firms. The interaction between customers and firms seem to have a positive effect on firms' R&D effort. Also, government support of private R&D (FUNDGOVT) shows a complementary relationship between the two, as we expected.

The Wald Chi-Square Test shows joint significance for the A, B variables and also for the technological opportunity variables and the spillover variables (IMINNOV, TECHOUT, LICENSE, IDPARNT). The cost-of-funds advantage variables are jointly significant only at the 10 per cent level (Chi-Square test).

The WHCCM-corrected t-ratios in column 3 of Table VI.4 show significant reduction in the value of these ratios for TECHOUT and LICENSE variables from the OLS results, although these variables are still statistically significant at the 5 per cent level (two-tail t-test). This is also reflected in the dampening of the joint significance level of the technological opportunity variables and the spillover variables. The COMP variable is now significant at the 5 per cent level (two-tail t-test) which is also reflected in the rise in the joint significance level of the appropriability variables. Also note that the FUNDGOVT variable is now significant at the 5 percent level (two-tail t-test). In other words, there are some heteroscedastic disturbances in the data which are not reflected in our test for heteroscedasticity as shown in (67).

The Tobit estimates of (62) are shown in column 4 of Table VI.4. The test of exogeneity in Tobit models described in Smith and Blundell (1986) is used to test for simultaneity between R and N in (62). This test is analagous to the Hausman Test and can be described as a test of $\delta = 0$ in the following regression:

$$(71) \qquad R = \theta_0 + \theta_1 N + \delta\hat{\varepsilon}_N + \theta_2 A + \theta_3 B + U_R$$

where $\hat{\varepsilon}_N$ is reduced form residuals of N (see equation (60)). (71) is estimated by the Maximum Likelihood (ML) estimation method described in Tobin (1958) to estimate simple Tobit equations. The estimated t-ratio of δ is -1.427 which is not significant at the 5 per cent level (two-tail t-test). This result does not contradict the null hypothesis that N is exogenous. Hence, we estimate (62) as a simple Tobit equation by the ML method mentioned above, which gives consistent parameter estimates when the above null hypothesis is true.

There are only five limit observations, i.e., R = 0, in this industry. Not surprisingly, therefore, the Tobit parameter estimates do not reflect any major change from the OLS results. The only visible difference can be seen in the coefficient estimate of IMINNOV, although the coefficient is still not significant. The Wald Chi-Square Test shows a slight drop in the significance level of technological opportunity variables, which is also reflected in the joint significance level of A and B variables.

VI.4.2 Electrical Industrial Equipment

Tests of the Schumpeterian hypotheses in this industry are based on 48 innovations by 36 firms. As before, all the A, B and G variables listed in Table VI.1 are included in our estimation. We also perform the same set of diagnostic tests on the regression equations.

The Hausman Test of exogeniety of N (see equation (64)) shows an estimated t-ratio of -.472 for α. This result accepts the null hypothesis that N is exogenous in (54). In order to check for heteroscedasticity in (64), the following regression results from (65) are obtained (t-statistic in parenthesis):

(72) $$\ell n\ \hat{w}_R^2 = \underset{(-.668)}{-3.907} + \underset{(.992)}{.166}\ \ell n\ \hat{Y}^2 \underset{(.070)}{-009}\ \ell n\ \hat{C}^2$$

$R^2 = .0224$

Wald Chi-Square Test (D.F.) = 1.032(2)

The Wald Chi-Square Test indicates no structural heteroscedasticity in relation to sales and cost of innovation. Hence, the above test result for exogeneity of N can be considered valid. OLS is, therefore, expected to provide consistent estimates of θ_1, θ_2 and θ_3 in (54).

In order to check for heteroscedastic errors in (54), the following test results are obtained (t-statistic in parenthesis):

(73) $$\ell n\ \hat{U}_R^2 = \underset{(-.811)}{-5.192} + \underset{(1.281)}{.235}\ \ell n\ \hat{Y}^2 - \underset{(-.370)}{.056}\ \ell n\ \hat{C}^2$$

$R^2 = .0352$

Wald Chi-Square Test (D.F.) = 1.640(2)

The Wald Chi-Square Test does not indicate any significant structural heteroscedasticity in relation to sales and cost of innovation.

The OLS parameter estimates are shown in column 2 of Table VI.5. Similar to the previous industry, we found that the regression coefficient and the t-statistic of N (Model 3) do not indicate any major change, with and without the A and B variables in the regression equation. When all the proxies for Model 2 are included in the regression, Table VI.5 shows a significant positive externality from firm size on R&D activities of firms (Model 3). Among the appropriability variables, the COMP variable is significant only at the 10 per cent level (one-tail t-test). Significant spillover

TABLE VI.5

Electrical Industrial Equipment: OLS and Tobit Estimates
(Asymptotic t-Statistic in Parenthesis)

Variables (1)	OLS (2)	WHCCM-t (3)	TOBIT (4)
Intercept	6.818		9.864[b]
	(1.193)	(4.238)[a]	(1.760)
N	.011[a]		.012[a]
	(17.002)	(8.796)[a]	(8.119)
PATENT	.479		-.472
	(.162)	(.180)	(-.162)
COMP	-.264[c]		-.245[c]
	(-1.472)	(-2.098)[a]	(-1.421)
CKMT	-.00002		-.00001
	(-1.226)	(-1.055)	(-1.047)
IMINNOV	-3.428[c]		-3.393[c]
	(-1.444)	(-1.965)[a]	(-1.458)
TECHOUT	-8.725[b]		-10.475[a]
	(-1.783)	(-1.001)	(-2.171)
LICENSE	12.325[a]		12.226[a]
	(2.779)	(1.371)[b]	(2.768)
IDPARNT	-5.520[b]		-5.798[b]
	(-1.876)	(-2.247)[a]	(-1.951)
IDMSMP	.563		-.420
	(.248)	(.398)	(-.187)
IDCUST	-.981		-.863
	(-.456)	(-.644)	(-.410)
FUNDOWN	-.009		-.041
	(-.171)	(-.478)	(-.769)
FUNDGOVT	-.024		-.046
	(-.277)	(-.522)	(-.563)
WALD-CHI SQUARE TEST (D.F.):			
All A and B vars(11)	18.599[e]	31.826[d]	19.418[e]
Appropriability vars(4)	5.833	7.049	4.567
Technological Opportunities vars (7)	16.108[d]	16.271[d]	17.885[d]
Cost-of-Funds Advantage vars(2)	.076	.582	.609
Spillover vars(4)	14.637[d]	8.848[e]	16.236[d]

[a] Significant at .05 level (two-tailed t-test)
[b] Significant at .05 level (one-tailed t-test)
[c] Significant at .10 level (one-tailed t-test)
[d] Significant at .05 level (Chi-Square Test)
[e] Significant at .10 level (Chi-Square Test)

effects are noticeable in case of IMINNOV, TECHOUT, IDPARNT and LICENSE. This is also evident from the Wald Chi-Square Test of these variables. However, note that all A and B variables are jointly significant only at the 10 per cent level (Chi-Square test). This is due to the poor performance of the appropriability variables and the cost-of-funds advantage variables.

As before, we obtain the t-ratios of the coefficients using White's Heteroscedasticity-Consistent Covariance Matrix (see (68)). These corrected t-ratios are shown in column 3 of Table VI.5. There are some noticeable changes in the t-ratios in comparison to the OLS results. The intercept is now significant at the 5 per cent level (two-tail t-test). There is a substantial reduction in the t-ratio for N, although it is still significant at the 5 per cent level (two-tail t-test).

We also notice some changes in case of IMINNOV, TECHOUT, LICENSE, and IDPARNT. The Wald Chi-Square Test indicates that all A and B variables are now jointly significant at the 5 per cent level, although the spillover variables now pass the significance test only at the 10 per cent level (Chi-Square test).

The Tobit estimates from (62) are also reported in Table VI.5. There are only seven limit observations in this industry. The Smith and Blundell Test of exogeneity does not reveal any evidence on simultaneity between R and N in this equation. The estimated t-ratio of δ in (71) is .579. We, therefore, estimate (62) by the ML estimation method for simple Tobit equations described in Tobin (1958). Both the estimated values of the coefficients and the respective t-ratios are similar to the OLS results. The only visible difference between the two sets of estimates can be seen in the case of the N variable whose t-ratio is much smaller under Tobit estimation, although the variable is still significant at the 5 per cent level (two-tail t-test).

The 2SLS estimates of (54) are reported in Appendix VI.B. The Chi-Square test of over-identifying restrictions described in (69) rejects the null hypothesis that these restrictions are valid. The computed value of m' is 6.856 which is significantly different from zero at the 5 per cent level with two degrees of freedom. In other words, two out of three firm-ownership dummy variables will have had significant effect on innovative effort of firms if they were included in (54) as right-hand side variables.

We now examine the results from the last industry which we consider in this empirical study, namely, Plastics Compounds and Synthetic Resins.

VI.4.3 Plastics Compounds and Synthetic Resins

Our tests of the Schumpeterian hypotheses in this industry are based on 27 innovations by 17 firms. Due to its small sample size, we include only six A and B variables in our estimation. Also we consider the just-identified system: the only G-variable considered in our estimation is USA.

The Hausman Test of exogeneity indicates an estimated t-ratio of -.0205 for α (see equation (64)). This provides no evidence of simultaneity between R and N in (54). The test of heteroscedasticity in (64) shows the following results (t-statistic in parenthesis):

$$\ell n\ \hat{w}_R^2 = \underset{(.161)}{11.101} - \underset{(-.124)}{.242}\ \ell n\ \hat{Y}^2 - \underset{(-.262)}{.160}\ \ell n\ \hat{C}^2 \tag{74}$$

$R^2 = .0056$

Wald Chi-Square Test (D.F.) = .136(2)

Thus, there is no evidence of structural heteroscedasticity in (64) to raise doubt about the result from our test of exogeneity. In other words, OLS will give consistent parameter estimates for (54).

There is also no evidence of structural heteroscedasticity in (54). The following results are obtained from a regression similar to (65) (t-statistic in parenthesis):

(75) $\ell n\ \hat{U}_R^2 = 10.883 - .236\ \ell n\ \hat{Y}^2 - .151\ \ell n\ \hat{C}^2$

(.165) (-.127) (-.260)

$R^2 = .0056$

Wald Chi-Square Test (D.F.) = .136(2)

where $\hat{U}_R$ is the OLS residuals from (54).

When A and B variables are excluded from (54), the following regression results are obtained for Model 3 (t-statistic in parenthesis):

(76) $R = 6.039 + .021N$
(2.452) (1.565)

$R^2 = .0893$

When both Model 2 and Model 3 are considered together, the estimated coefficient for N is .03 with a t-ratio of 2.463, the R^2 of this latter regression is .5313, which then indicates that Model 2 and Model 3 are not independent of each other in their role in innovative activities of firms.

The OLS parameter estimates are shown in Table VI.6. (The interested reader is referred to Appendix VI.C for the 2SLS estimates.) There is strong support for Model 3. None of the appropriability variables are significantly different from zero, although PATENT

TABLE VI.6

Plastics Compounds and Synthetic Resins: OLS Estimates
(t Statistic in Parenthesis)

Variables (1)	OLS (2)	WHCCM-t (3)
Intercept	-5.047	
	(-.693)	(-1.020)
N	.030[a]	
	(2.463)	(2.683)[a]
PATENT	1.418	
	(.460)	(.525)
COMP	.078	
	(.166)	(.233)
TECHOUT	-21.411[a]	
	(-2.999)	(-7.913)[a]
LICENSE	16.595[a]	
	(2.208)	(4.915)[a]
FUNDOWN	.098[c]	
	(1.597)	(2.584)[a]
FUNDGOVT	.193[b]	
	(1.901)	(2.682)[2]
WALD-CHI SQUARE TEST (D.F.)		
All and B vars(6)	17.923[d]	235.216[d]
Appropriability vars (2)	.232	.287
Technological Opportunity vars (4)	15.803[d]	103.209[d]
Cost-of-Funds Advantage vars(2)	4.224	10.337[d]
Spillover vars (2)	10.280[d]	63.060[d]

[a] Significant at .05 level (two-tailed t-test).

[b] Significant at .05 level (one-tailed t-test).

[c] Significant at .10 level (one-tailed t-test).

[d] Significant at .05 level (Chi-Square Test).

has the correct sign according to the Schumpeterian hypotheses. All the technological opportunity variables are significant although at different levels of significance. The Wald Chi-Square Test shows joint significance for the A and B variables, the technological opportunity variables and the spillover variables.

The t-ratios using WHCCM are reported in column 3 of Table VI.6. The substantially larger t-ratios of the technological opportunity variables imply some heteroscedastic disturbances in the sample which are not reflected in our test of structural heteroscedasticity. This change in the explanatory power of these variables is clearly evident in the Wald Chi-Square Test. The t-ratios for N and the two appropriability variables do not show any significant change from the OLS results.

The test of over-identifying restrictions is not applicable in this industry since we considered the just-identified system. Also, we do not estimate the Tobit equation in (62) since the sample contains only one limit observation for R. This concludes our discussion of the empirical results.

VI.5 Concluding Remarks

In all three industries, there is significant support for Model 3 that there is a positive externality from firm size on innovative activities of firms. Except Plastics Compounds and Synthetic Resins, there is little evidence that Model 2 and Model 3 are interdependent; Model 3 seems to have its own independent role in innovative activities of firms.

Among the appropriability variables, the only variable which has performed consistently is the COMP variable, providing support for the Schumpeterian view that the greater is the competition, the smaller will be the amount of innovative effort by firms. In all three industries, the OLS results have indicated the correct sign for PATENT although the variable is not significant.

Among the technological opportunity variables, all three industries show significant negative externality from TECHOUT, thus indicating the spillover effect in R&D. The LICENSE variable, however, has consistently shown positive effect on firms' R&D. Also, there is some evidence that government support of private R&D has resulted in increased R&D effort by firms. Finally, there is some noticeable spillover effect in case of IMINNOV and IDPARNT in the Electrical Industrial Equipment industry.

The diagnostic tests reveal no trace of heteroscedasticty in the sample of each of these industries, although the t-ratios based on WHCCM do indicate some unknown heteroscedasticity not revealed by our tests. The tests of exogeneity do not provide any evidence of the structural simultaneity between R&D decisions of firms and firm size. In the Electrical Industrial Equipment industry there is some evidence for firm-ownership as a significant determinant of R&D.

In the next chapter, we provide a summing up of this dissertation along with some suggestions for future research on this topic.

APPENDIX VI.A

Telecommunications Equipment and Components: 2SLS Estimates
(Asymptotic t-Statistic in Parenthesis)

Variables (1)	2SLS (2)	WHCCM-t (3)
Intercept	8.303	
	(.915)	(2.044)
N	.034	
	(2.655)	(2.877)
PATENT	-3.394	
	(-.671)	(-1.108)
COMP	-.343	
	(-2.017)	(-2.733)
CMKT	.00002	
	(.784)	(1.267)
IMINNOV	-1.907	
	(-.397)	(-.555)
TECHOUT	-51.803	
	(-5.583)	(-2.885)
LICENSE	40.760	
	(3.581)	(2.179)
IDPARNT	2.314	
	(.377)	(.329)
IDMSMP	-6.234	
	(-1.032)	(-1.452)
IDCUST	8.942	
	(2.012)	(2.285)
FUNDOWN	-.057	
	(-.674)	(-1.353)
FUNDGOVT	.151	
	(1.246)	(1.674)

APPENDIX VI.B

Electrical Industrial Equipment: 2SLS Estimates
(Asymptotic t-Statistic in Parenthesis)

Variables (1)	2SLS (2)	WHCCM-t (3)
Intercept	6.477	
	(1.293)	(3.993)
N	.011	
	(6.947)	(4.526)
PATENT	.791	
	(.299)	(.252)
COMP	-.257	
	(-1.641)	(-2.085)
CMKT	-.00002	
	(-1.428)	(-.899)
IMINNOV	-3.680	
	(-1.740)	(-1.944)
TECHOUT	-9.082	
	(-2.108)	(-1.018)
LICENSE	12.062	
	(3.102)	(1.374)
IDPARNT	-5.004	
	(-1.834)	(-1.784)
IDMSMP	.869	
	(.423)	(.502)
IDCUST	-.573	
	(-.284)	(-.420)
FUNDOWN	-.004	
	(-.099)	(-.210)
FUNDGOVT	-.012	
	(-.159)	(.218)

APPENDIX VI.C

Plastics Compounds and Synthetic Resins: 2SLS Estimates
(Asymptotic t-Statistic in Parenthesis)

Variables (1)	2SLS (2)	WHCCM-t (3)
Intercept	-4.300	
	(-.142)	(-2.409)
N	.028	
	(.247)	(3.152)
PATENT	1.418	
	(.548)	(.528)
COMP	.057	
	(.060)	(.207)
TECHOUT	-21.536	
	(-2.774)	(-9.006)
LICENSE	16.895	
	(1.251)	(5.944)
FUNDOWN	.095	
	(.707)	(3.916)
FUNDGOVT	.185	
	(.572)	(2.557)

CHAPTER VII

SUMMING UP

VII.1 Summary and Conclusions

Schumpeter's (1950) ideas about innovation in capitalist economies have inspired a substantial literature on the relationship between market structure and innovation. This literature has focussed on two broad hypotheses: first, that monopoly power enhances the appropriability of the returns to R&D and hence there is a positive association between monopoly power and innovation (Model 2), and second, that large firms have special advantages in carrying out R&D and hence, large firms do more R&D than small firms (Model 3). In this dissertation, we have built a framework to reexamine these two sets of hypotheses.

The framework was designed to serve two purposes. First, we examined some of the empirical measures which have been used to test the Schumpeterian hypotheses. Second, the framework provided the foundation for our own empirical study of these hypotheses, using data on innovative activities of firms in Canada.

An important feature of the framework is that both firm size (measured in terms of operating personnel) and innovative activity (measured in terms of R&D personnel) are treated as endogenous variables. This is analogous to the recent suggestion made in the neo-Schumpeterian literature that both market structure and innovative activity ought to be treated as endogenous.

Upon examination of the existing empirical measures which have been used to test Model 3 we found that these measures are neither necessary nor sufficient for the Schumpeterian hypotheses of this model to hold. In regard to the existing measures used to test Model 2, we showed that concentration ratios embody two distinct effects on innovative activities of firms: the effect of monopoly power (which these ratios are meant to reflect), and the effect of firm size. Therefore, studies based on concentration ratios can be looked upon as testing jointly the roles of Model 2 and Model 3 in innovative activities of firms, provided these ratios adequately measure monopoly power.

Despite several shortcomings of the data, our own study found strong evidence of a positive externality from firm size on innovative activities of firms in Canada. Also, a number of appropriability and technological opportunity factors were found to be significant in the R&D decisions of firms.

We do not wish to exaggerate our claims based on this highly stylized framework which obviously abstracts from important considerations, such as the dynamics of Schumpeterian competition. Nonetheless, our study clearly indicates (a) that both firm size and appropriability and technological opportunity are important considerations in determining the R&D efforts of firms in Canada, and hence that both Model 2 and Model 3 should be considered together in studies of innovation, and (b) that there is strong evidence of spillover in R&D activities of firms as indicated by the TECHOUT variable in particular (see chapter VI). An important finding of our empirical study is that the effect of firm size (Model 3) on innovative effort is independent of the appropriability and technological opportunity factors (Model 2) in which case, one can employ any of the various propositions stated in chapter III describing relationships between some measure of firm size and some measure of innovative effort, to test Model 3.

The next section provides some suggestions for future research on the Schumpeterian hypotheses.

VII.2 Suggestions For Future Research

As pointed out in chapter VI, an important binding constraint in empirical studies of the Schumpeterian hypotheses is the availability of data on innovative activities of firms. The framework and the empirical study in this dissertation have been largely guided by the content of the data set that was made available to us by the Economic Council of Canada.

A true model of Schumpeterian competition, where market structure and innovation are both endogenous, can be properly tested using data that covers a sufficiently long period of time. This would also allow one to properly test the Schumpeterian dynamics of the 'process of creative destruction' in capitalist economies. In other words, the relevance of the Schumpeterian hypotheses can be judged more effectively in a dynamic framework where the past is allowed to influence the decisions of the present.

The recent developments in the neo-Schumpeterian literature show significant progress in theoretical attempts to model the innovative behaviour of firms. Kamien and Schwartz (1982) and Reinganum (1983) provide for excellent surveys and reviews of this literature. One obvious route to take in future research is to empirically test the various propositions that this literature has suggested. Among the very few attempts made in this direction, the study by Levin and Reiss (1984) has been discussed and incorporated in our empirical study in chapter VI.

In short, much of the existing data is either too aggregated or insufficient in number of observations over time to test many of the neo-Schumpeterian or even the Schumpeterian hypotheses. In order to progress in the direction of empirical testing, one needs both to extend these models in more realistic directions in order to accommodate existing data, and to gather the specific data that is required to test directly these models of innovative behaviour of firms.

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