International Trade and Technological Progress:
A Study of Indian Manufacturing Industry

Dissertation submitted to Jawaharlal Nehru University, New Delhi for the award of the Degree of Doctor of Philosophy in Economics

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May, 2005

I hereby affirm that this dissertation entitled "**International Trade and Technological Progress: A Study of Indian Manufacturing Industry**" being submitted to Jawaharlal Nehru University, New Delhi for the award of the Degree of Doctor of Philosophy in Economics is a record of my own research work. It has not previously formed the basis of any degree, diploma, associateship, fellowship or other similar title or recognition.

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Certified that this study is the bonafide work of Mr. M Parameswaran carried out under my supervision at the Centre for Development Studies.

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Dedicated to my beloved parents...

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Abstract of the Dissertation
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Technological progress is considered as the source of long run economic growth. It enhances growth by directly contributing to output and by stimulating accumulation of capital through raising its marginal productivity. In the neoclassical growth models, which focus on factor accumulation, technological progress is exogenous. These models, therefore, are incapable of explaining the long run growth of nations, leading to the emergence of endogenous growth literature. The new growth literature takes the view that technological progress results from the intentional actions of economic agents responding to perceived profit opportunities. Theoretical models in this tradition are trying to explain growth by focusing on various sources of technological progress such as R&D and learning by doing. This literature seeks to explain factors influencing technological progress. In this attempt, it incorporates the role of international trade also, which assumes significance in the present day globalised world. The theoretical literature, however, shows that the effect of trade on technological progress is ambiguous and depends on many economy and industry specific factors. Only empirical analyses can, therefore, shed further light on this issue.

This study examines the effect of trade on technological progress by taking the case of Indian manufacturing industry. In the new growth literature, trade can affect technological progress by: (1) changing the structure or specialisation pattern of the manufacturing industry; (2) facilitating technology spillovers from advanced trade partner countries; and (3) affecting firms' R&D investment. Manufacturing industry, which exhibits many of the features of technological progress depicted in these models, is considered as engine of economic growth. The analysis, therefore, assumes significance from the point of view of over all economic growth. Different from the existing cross-country regression studies on trade and growth, the present one uses micro level data and provides more detailed insights into the effect of trade on technological progress. It also assumes importance in the context of liberalised trade policy regime India has been pursuing.

In the analysis of trade-induced structural change, structure of the manufacturing industry is defined in terms of the shares of various sectors in the total manufacturing output. In this the study examines whether trade expanded or reduced shares of sectors having better opportunities for technological progress and shows that trade negatively affected their shares. The expansion in domestic demand in these sectors, however, was more than offsetting the negative effect of trade, so that they were able to increase their shares. The evidence, thus, suggests that large and growing domestic demand acted as a cushion to absorb the negative impact of trade on specialisation.

In the analysis of trade facilitated R&D spillovers, the study examines the productivity effect of two types of spillovers separately, inter-sectoral variation in their impact and the role of firms' own effort in boosting the productivity effect. Empirical analysis is based on firm level panel data and production function method. Levinsohn and Petrin (2003) method is used to estimate the production function consistently in the presence of simultaneity, where the superiority of these estimates over alternative ones is also demonstrated. The analysis shows that both types of spillovers have significant contribution to output. There also exists inter-sectoral variation in the productivity effect of spillovers. The pattern of sectoral variation, however, depends on the type of spillover. Analysis also suggests that firms' investment in R&D and in plant and machinery are helping them to absorb R&D spillovers.

The analysis of the effect of trade on firms' R&D investment suggests that export encourages innovation effort. Regarding the impact of import competition, the evidence, indicates that market structure has an important role in shaping it. Import competition encourages R&D only when the industry is highly concentrated. In less concentrated industries, on the other hand, import competition discourages investment in R&D.

The study provides more detailed micro level insights into the effect of trade on technological progress in the context of a developing country manufacturing industry. It shows, consistent with the theoretical literature, that impact of trade can be positive or negative depending on many economy and industry specific factors. A trade policy consisting of export promotion and selective import liberalisation emerges as a suitable one for faster learning and technological progress. The study, thus, assumes importance in the context of paucity of detailed empirical evidence on the effect of trade on technological progress and economic growth.

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1

Introduction

Ever since Adam Smith's *Wealth of Nations*, technological progress has assumed a central role in the economists' thinking about the growth of nations. In Smith, sustained economic growth is the result of increasing returns to scale arising from division of labour or specialisation. In this scheme, division of labour accelerates technological progress and technological progress leads to further division of labour. It is the increasing returns to scale, originating from specialisation and technological progress, that forms the heart of Smith's optimistic vision of economic growth as a self-generating process. This is contradicting with the pessimistic predictions of later classical economists like Ricardo and Mill, who believed that economies would end up in a stationary state due to diminishing returns in agriculture, which was later proved wrong because of the opportunities opened up by technological progress (Scherer 1999 and Thirlwall 2002).

The role of technological progress in growth made more explicit in the formal growth models of Solow (1956) and Swan (1956) and in new theories of growth called endogenous growth models[1]. In these models, technological progress is the source of long run economic growth. It enhances growth by directly contributing to output and by stimulating capital accumulation through raising the marginal productivity of capital (Grossman and Helpman 1991a, Romer 1993, Grossman and Helpman 1994 and Barro and Sala-i-Marin 2004). Besides the models advanced by economic theorists, the works of economic historians on the development experience of nations and regions also underscore the role of technological progress in economic growth (Landes 1969 and Rosenberg 1972).

It is, however, recognised that the opportunities for faster technological progress and increasing returns to scale are mainly the characteristics of industry, especially of manufacturing, where the scope for technical change is greater than any other sector

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[1] Though the influence of technological progress is ubiquitous, a precise conceptualisation of it is quite difficult considering the many different forms it can take. Rosenberg (1982, p. 3) writes,

> central problem in examining technical progress, and one that makes it difficult to define or characterise readily is that it takes many different forms. For technical progress is not one thing, it is many things. Perhaps the most useful common denominator underlying its multitude of forms is that it constitutes certain kind of knowledge that makes it possible to produce (i) a greater volume of output or (ii) qualitatively superior output from given amount of resources.

(Kaldor 1996, Rakshit 1997 and Thirlwall 2002). The faster technological progress of the manufacturing sector not only increases its own growth rate but also promotes growth of other sectors and thus the overall growth of the economy. For instance, higher productivity growth, following from technological progress, allows manufacturing sector to generate surplus that creates demand for services and thereby serve to promote the growth of the service sector. Further, at a later stage of development increasing labour productivity in manufacturing sector enables it to release labour for use in service sector, which is highly labour intensive[2]. The importance of manufacturing in the overall growth process is such that it is considered as the engine of economic growth.

Among the policy measures designed for faster technological progress and industrialisation by the developing countries, foreign trade policy has always attracted wider intellectual attention[3]. This wider attention is not only due to the relatively larger influence of trade on technological progress and economic growth but also because of the ambiguity regarding the type of trade policy suitable for rapid technological progress[4]. This study is an attempt to examine the effect of trade on the process of technological progress of Indian manufacturing industry. There are mainly three factors that led us to this study. First, the recent developments in the growth literature, namely endogenous growth theory that identifies a number of channels through which trade can affect domestic technological progress. It, however, shows that the theoretical results are ambiguous and trade can stimulate as well as retard technological progress. Only empirical analyses can shed further light on this issue. Second, lack of convincing empirical evidence on the effect of trade openness on economic growth. A number of studies examined the effect of trade openness on economic growth using various datasets, econometric methods and measures of trade openness. These studies, however, are subjected to many weaknesses and are also unable to yield deeper insights into the link between trade and growth. Third, the liberal trade policy regime that India has been implementing more vigorously since

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[2] In this regard, Thirlwall (2002) observes that there is a close association across countries between the level of percapita income and the degree of industrialisation and there also seems to be a close association across countries between the growth of GDP and the growth of manufacturing industry. It is to be noted that becides the benefits conferred by the rapid productivity growth of the manufacturing sector, agriculture and service sectors also benefit from its extensive backward and forward linkages.

[3] The relationship between trade and growth is one of the highly debated issues. On this Rodriguez and Rodrik (2000,p.261) comments "Do countries with lower barriers to international trade experience faster economic progress? Few questions have been more vigorously debated in the history of economic thought, and none is more central to the vast literature on trade and development".

[4] Rodrik (2003) identifies institutions, international trade and geography as the deep determinants of growth and technology and factor endowments, such as physical and human capital, are taken as the proximate determinants of growth.

1991 to stimulate the growth and competitiveness of Indian industry. An empirical analysis of the effect of trade on the technological progress of the manufacturing industry assumes significance in this context.

This introductory chapter presents the theoretical framework, reviews the empirical literature and states the objectives and methodology of the study. It is organised in four sections. We begin by reviewing the major developments in the growth theory, which led to the emergence of the current literature on endogenous growth in section one. Following this, in section two, we explore the relationship between trade and technological progress as evident in endogenous growth models. Section three reviews the empirical literature on the effect of trade on economic growth. It considers two sets of studies: (1) cross-country studies, and (2) those examined the effect of trade on manufacturing productivity. Against the background of theoretical and empirical literature currently available, the concluding section four delineates the specific objectives of this study and the proposed methodology and chapter scheme.

1.1 Technological Progress and Growth Models[5]

The role of technological progress in sustaining economic growth is formally modelled first in Solow (1956) and Swan (1956). The Solow-Swan model consists of an economy-wide production function of the Cobb-Douglas form with constant returns to scale and diminishing returns to each input[6]. This production function is combined with a constant saving rate rule to generate a simple general equilibrium model of the economy. In this economy, at very low level of capital per worker, capital accumulation and per capita income growth are faster due to the higher marginal productivity of capital. As the capital accumulation continues, diminishing returns to capital sets in, slowing down the rate of accumulation and ultimately placing the economy in the steady state with no growth rate in per capita output[7]. The basic Solow-Swan model, therefore, cannot explain the long run

[5] Admittedly, our review of growth theories is brief and non-technical. For a detailed account of the neoclassical and endogenous growth models see Aghion and Howitt (1999), Solow (2000) and Barro and Sala-I-Martin (2004).

[6] Cass (1965) and Koopmans (1965) made saving decision endogenous and this extension also preserved the predictions of the Solow-Swan model. One implication of Solow-Swan model is that economies having less capital stock per worker (relative to their long-run capital stock) tend to grow faster than economies having more capital per worker, leading to conditional convergence in income levels. Conditional convergence means convergence in income levels conditional on the differences in factors such as technology, saving rates and human capital stock. This is one of the most empirically tested propositions of the neoclassical growth theory (Ray 1998 and Barro and Sala-I-Martin 2004).

[7] In this literature, capital is defined in a narrow sense, referring mainly to machinery and equipment (Grossman and Helpman 1991a)

growth of the now developed economies. It is explained by incorporating technological progress into the model. Technological progress halts the marginal product of capital from falling and thereby sustains the pace of capital accumulation. In these models, however, technological progress is exogenous and hence, they are incapable to explain the long run growth performance of economies (Barro and Sala-i-Martin 2004). Further, the Solow-Swan model, based on exogenous technical change, also failed to account for many of the empirical realities like lack of cross-country convergence, international pattern of migration and capital movement (Romer 1986 and 1994a and Lucas 1988).

The assumption that technological progress is exogenous to the economic system found itself very difficult to reconcile with the reality[8]. Here we quote Schmookler (1966, p.199), who took the view that economic factors have a dominant influence on the pattern of technical change,

> Despite the popularity of the idea that scientific discoveries and major inventions typically provide the stimulus for inventions, the historical record of important inventions in petroleum refining, paper making, railroading and farming revealed not a single, unambiguous instance in which either discoveries or inventions played the roles hypothesised. Instead, in hundreds of cases the stimulus was the recognition of a costly problem to be solved or a potentially profitable opportunity to be seized; in short, a technical problem or opportunity evaluated in economic terms. In a few cases, sheer accident was credited.

Similarly, Dosi (1988) concludes his survey of sources and patterns of industrial innovation that technological progress reflects an interplay of technological opportunities created by scientific discoveries and inducements for applied research that emerge from market opportunities. Not only invention and innovation are determined by the economic factors, diffusion of technology also closely depends on them. For instance, Griliches (1957a) argues that the timing of the diffusion process of hybrid-seed can be explained very well in economic terms and shows that behaviour of both farmers and hybrid-seed producers was firmly founded in expectations of profit. Another study by Mansfield (1961), which examines the speed with which twelve important innovations diffused among firms in four industries, also shows that rate of imitation is a direct function of the

[8] Two prominent scholars, who highlighted the critical role of technological progress in the dynamics of capitalist system, are Marx in the nineteenth century and Schumpeter in the twentieth century. Although technical change is considered as the most important source of dynamism in a capitalist economy, it was relatively neglected in the mainstream economics literature. Various explanations were advanced for this, the most frequent being the 'black box' explanations-that technical change was outside the specialised competence of most economists and had to be tackled by engineers and scientists. This argument went well with the assumption (although erroneous) that technology could be treated as exogenous 'manna from heaven' (Freeman 1994).

profitability of a given innovation and decreasing function of the size of investment required for its installation.

The limitations of the Solow-Swan model as well as the desire to have formal models that can accommodate growth experience of developed as well as under developed countries prompted the theorists to formulate models in which technological progress is endogenous. Earlier attempts to incorporate a theory of technological progress into the neoclassical growth models proved difficult, because most of them assume a competitive market. Technological progress involves creation of new ideas or knowledge, which are non-rival and have features of public good[9]. Inclusion of a non-rival commodity as a factor of production makes the resulting production function exhibit increasing returns to scale, which conflicts with the assumption of perfect competition. A firm, having increasing returns to scale production function, cannot survive as a price taker, since the compensation of non-rival old ideas in accordance with their current marginal cost of production – zero – does not provide the appropriate reward for the research effort that underlies the creation of new ideas (Romer 1990a and Barro and Sala-i-Martin 2004).

The earlier attempts to endogenous technological progress include Arrow (1962), Sheshinski (1967) and Shell (1967). In Arrow (1962a) and Sheshinski (1967) knowledge is generated through learning by doing and, due to its non-rival character, it is assumed to instantaneously diffuse throughout the economy[10]. Shell (1967) incorporates the view that innovation is driven by basic research. This model includes a public research sector and profit-seeking firms that use knowledge produced by the former in production. The public research sector is financed by the government out of its tax revenue and therefore the size of this sector is largely exogenous, reflecting the government's willingness to impose tax. In these models, competitive equilibrium can be maintained, because the knowledge produced either through learning by doing or through public research enters into the public domain and therefore receives no compensation (Romer 1986 and 1990a).

In Romer (1986), the production function that consists of firm's own technological knowledge and a stock of economy-wide knowledge as arguments exhibit increasing returns to scale at the aggregate level. The economy wide stock is formed from the spillovers from individual firms' knowledge stock. Existence of externalities in innovation

[9] These features of knowledge and their implications shall be discussed in detail below.

[10] In Arrow (1962), knowledge is generated in the private sector through learning by doing in the production process and considered as an increasing function of the accumulated physical capital investment in the economy

makes the aggregate production function exhibit increasing returns to scale, and this is an important novelty of endogenous growth models. The presence of externalities means that if one firm (say) doubles its inputs, inputs of all other firms also increase, resulting in more than proportionate increase in the aggregate output. Romer (1986) shows that if spillovers are strong enough, private marginal product of (physical or human) capital can remain permanently above the consumers' discount rate and thereby sustain the capital accumulation. This model has no explicit micro economic foundation for the production of knowledge (in a separate research sector) itself and hence, does not address the question of market structure and market price for technological change in an explicit way (Verspagen 1992).

Later developments in the endogenous growth literature incorporated a more detailed theory of technological progress into the growth models. In Romer (1990a), Grossman and Helpman (1991a) and Aghion and Howitt (1992), growth is driven by technological progress generated through intentional investment by the profit-seeking firms in R&D and spillovers from it. In these models, research is treated as an ordinary economic activity that requires input of resources and responds to profit opportunities[11].

In these models, spillover of technological knowledge plays an important role in determining the growth rate of economies. Spillovers arise from the two important characteristics of knowledge as a commodity, namely non-rivalry and partial excludability[12]. A non-rival good has the property that its use by one firm or person in no way limits its use by another. Technological knowledge is a non-rival commodity, that is same knowledge can be used in different applications as well as in different locations at the same time. A good is excludable if the owner can prevent others from using it and therefore, excludability is a function of both technology and legal system. In this literature, knowledge is considered as a partially excludable commodity in the sense that inventions usually generate two types of knowledge, namely knowledge that are specific to the product or process invented (*specific information*) and knowledge that are more general (*general information*). The first type of knowledge can be the knowledge specific to the newly invented product and the second type consists of general scientific principles or

[11] Although the beginning of the endogenous growth literature as a topic, irrespective of its conceptual or intellectual legacy, is only dating back, in acknowledged published form, to Romer (1986), the growth of this literature is tremendous after that, making it difficult to cover the entire literature. Fine (2000) observes, "Over the past three years, the number of articles explicitly drawing upon endogenous growth theory almost certainly borders on a thousand. Equally significant, they are spread over 50 or more journals."(p.246).

[12] For a discussion of these characteristics of knowledge and their implications see Romer (1991a) and Marjit and Singh (1995).

theories on which the new product is based. The originators have control over the use of first type of knowledge through instruments like patenting. The second type has wider application and over the use of which the originators have no control. The originators, therefore, have difficulty in extracting payments from others for the use of second type of knowledge (Romer 1990a). Grossman and Helpman (1991a, p.16-17) brings out these distinctions more clearly as follows,

> It may be useful to distinguish between two types of outputs that are (jointly) produced in the industrial research laboratory. Commercial research generates both *specific* technical information, which allows a firm to manufacture a particular product or engage in particular production process, and more *general* information with wider applicability. Firms may be able to keep secret the detailed information concerning product attributes and production techniques. And even if they cannot, the applicable patent laws can be relied upon to prevent others from copying specific product designs or unique processes. So product specific information may be an excludable commodity in many cases. General information is much less likely to be so, both because it is harder to prevent the spread of universal principles and because it is more difficult to invoke existing legal strictures to enforce proprietorship over such information.

Further, Grossman and Helpman (1991a) and Aghion and Howitt (1992) highlight another form of externality when innovators, who bring out successive generations of similar products and each begins where its predecessors left off, make use of the whole knowledge contained in the previous generation of products. For example, a new entrant into the personal computer industry seeking to improve upon the state of the art need not make its own progression from the abacus to the analog computer to the digital computer to the personal computer. Instead, it can inspect the latest generation of products available on the market and extract much of the cumulative investment in knowledge that is embodied in them (Grossman and Helpman 1994). Besides generating spillovers, another implication of non-rival character of knowledge relevant to the growth theory is that non-rival good can be accumulated without bound on a per capita basis, whereas a piece of human capital such as ability to add cannot. Each person has only a finite number of years that can be spent to acquire skills and these skills are lost when the person dies. But any non-rival good that a person produces, for instance a scientific law, lives on after the person goes.

The R&D based growth models make a distinction between research sector and other sectors of the economy. The returns to R&D, in these models, come in the form of monopoly rents in imperfectly competitive product markets. This literature adopts two approaches to product innovation depending upon whether the innovative product bears a *vertical* or a *horizontal* relationship with existing products. The innovative product would bear a horizontal relation if it serves new functions and thereby increases the variety of products available (*increasing product variety*). It would have a vertical relation if it performs similar functions of existing products, but provides greater quality[13] (*rising product quality*). The *rising product quality* approach can also be interpreted as describing a series of process innovations. With this interpretation, each technological breakthrough reduces the costs in some product line. Process innovation and product innovation are similar here because each represents a means by which producers can provide greater "services" at a given cost. The innovation directed towards increasing product quality has a distinct Schumpeterian flavour in as much as successful innovators displace extant industry leaders. The results of Grossman and Helpman (1991a) show that many details of the equilibrium growth path do not depend on the form of innovation that drives growth.

The inputs into the research activity are human capital and the existing stock of scientific knowledge. Larger the already available stock of knowledge, to which researchers have access through spillovers, higher the productivity of human capital in the research sector. The increase in the general stock of scientific knowledge, thus, reduces the cost of innovation and thereby maintains the private incentive to invest in R&D in the face of declining returns to marginal innovation. In other words, the nonappropriable benefits from R&D keep the state of knowledge moving forward and thereby sustain the economic growth (Grossman and Helpman 1991a). Due to the inherent uncertainty of innovation process, growth is uneven and stochastic at micro level. Firms continually race to bring out next generation of products and there may be long periods without success in some industries. Meanwhile other industries may experience research breakthrough and aggregation mask this micro-level turbulence and the macro economy grows at a steady pace (Romer 1990a and Grossman and Helpman 1994).

Grossman and Helpman (1991a) uses a production function specified by Ethier (1982). Here final good is produced from a variety of intermediate inputs and productivity in the final good production sector increases with the number of intermediate commodities[14]. The R&D directed towards increasing the variety of intermediate inputs, therefore, can enhance the productivity of the final goods production. This literature has adopted a general equilibrium perspective and the existence of externalities and cumulative nature of

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[13] See Grossman and Helpman (1991a), ch.3 and 4.
[14] See Grossman and Helpman (1991a), p.47.

innovation make initial conditions important in determining the final outcome. Further, the presence of externalities and consequent market failure also create room for government policy.

The R&D based growth literature argues that there are many reasons to believe that investment in research can drive growth, despite its low share as a per cent of domestic product of industry even in developed countries. First, what is generally recorded as R&D represents only a portion of the resources that firms spend on learning to produce new goods or methods. Learning on the shop floor - consisting of many small improvements in design and technique - is also important in the overall picture of technological advance. Moreover, knowledge is cumulative, with each idea building on the last, whereas machines depreciate and must be replaced. In this sense, every knowledge produced at the margin makes a contribution to the productivity, while a certain portion of investment may be to replace depreciation. Finally, social rates of return on R&D may substantially exceed the private rates of return (Grossman and Helpman 1994) [15].

There are also endogenous growth models that focus on other sources of growth such as human capital formation and learning by doing. In Lucas (1988), human capital formation, which is having positive externalities, is the source of growth. Human capital can be accumulated either through deliberate investment of resources in acquiring skills or through production experience. In Young (1991), the source of technological progress is the knowledge generated through learning by doing and spillovers from it.

It would be relevant to elaborate on the concept of learning by doing, as we use models based on this idea in later chapters. Learning by doing means accumulation of knowledge through production experience. This is identified as an important source of technological progress[16]. It may be conceived of as the exploration and actualisation of the productive potential of new technologies through production experience (Young 1991). It not only leads to a better understanding of the technology and thereby to higher productivity but

[15] Computations in Grossman and Helpman (1994) show that business R&D need not absorb vast resources for innovation to be the engine of a reasonably rapid growth.

[16] A number of studies confirmed the importance of learning by doing in increasing the labour productivity in industries such as airframe production, shipbuilding, machine tools and textiles. These studies include Hirsch (1956), Alchian (1963), Rapping (1965) and David (1970). Hollander (1965 cited in Freeman 1994, p.474) in his study of technical change in Du Pont's rayon plants and Townsend (1976 cited in Freeman 1994, p.474) in his study of technical change in British coal industry found that majority of the innovations did not come from formal R&D. Instead, most of the hundreds of the small improvements to the equipment and the organisation of work came from production engineers, systems engineers, technicians, managers, maintenance personal and from production workers.

also helps incremental innovations to take place at the shop floor (David 1975; Rosenberg 1976 and 1982).

Learning by doing and subsequent technological progress emerge mainly due to three features of technology, especially of a new complex technology. First, labour cannot effectively be trained prior to the operation of new technology; workers get more effective training through experience in production. Second, technologies are typically systems of elements that can be integrated in various ways and achieving proper integration requires experimentation that in turn is an art based on experience. Third, technologies are circumstantially sensitive and much of the requisite knowledge about local circumstances and how technology responds to them in its operation can only be acquired through experimentation. All these imply that learning by doing from a given technology would disappear after some time when there is nothing to learn or improve upon and its continuation depends on some breakthrough innovation. Further, the intensity and productivity enhancing effect of learning by doing also depend on other factors, especially on the employment of skilled workers, who can understand and modify the technology (Teitel 1984).

The endogenous growth literature is based on the view that innovation and the consequent technological progress do not fall like manna from heaven, but it is a social process. The intensity and direction of people's innovative activities are conditioned by the laws, institutions, customs, and regulations that affect their incentive and ability to appropriate rents from newly created knowledge, to learn from each others' experience, to organise and finance R&D, to pursue scientific careers, to enter markets currently dominated by powerful incumbents, to accept working with new technologies, and so forth. Clearly, these factors are also influenced by the technological progress. It is, thus, viewed that economic growth involves a two-way interaction between technology and economic life; technological progress transforms the very economic system that creates it. The endogenous growth theory seeks a better understanding of this interplay between technical change and various structural characteristics of the economy and society and how such interplay results in economic growth (Aghion and Howitt 1999).

This literature, thus, incorporates many features of technical progress at the micro level, like intentional investment in R&D by profit seeking firms, existence of externalities in the production and diffusion of innovation, learning by doing and the role of imperfect market structure in inducing innovation. It uses these ideas to explain what was left unexplained in the old growth literature, namely technological progress, to account for the observed pattern of growth of nations[17]. Although, these ideas are not new to the development economists, the specific contributions of this literature could be the followings[18]. The originality lies more in bringing these ideas to the fore and packaging them in the most advanced form of mathematical models (Fine 2000). The formal treatment made these ideas more clear as well as brought out the implicit assumptions in these arguments. To quote Bardhan (1995, p.2985),

> A much more substantive contribution of the new growth theory is to formalise endogenous technical progress in terms of a tractable imperfect competition framework in which temporary monopoly power acts as a motivating force for private innovations.

Another contribution is that this literature provides a useful framework for analysing the effect of various factors like international trade, product market competition and government policy on economic growth. As we shall see below, the extension of these models to include international movement of goods, capital and ideas yielded a theoretical framework that is rich in predictions and consistent with a host of observed phenomena (Grossman and Helpman 1994). To quote Bardhan (1995, p.2986) again "the major impact of this literature on development theory has been in the area of trade and technological diffusion in an international economy".

1.2 Trade and Technological Progress

The important features of endogenous growth theory such as imperfect competition, presence of externalities and increasing returns are also present in the new trade theory, making the integration of trade and growth more easy and natural (Fine 2000). The incorporation of trade into this literature revealed a number of ways through which it can affect technological progress of the domestic industry[19]. This result is different from the

[17] In this context see Prescott (1997). It shows that differences in physical and intangible capital cannot account for the observed differences in percapita income across countries, instead it is the differences in total factor productivity that can account. So the paper concludes that we need a theory of total factor productivity (TFP) to understand the income differences. See also Krishna (2004) for a discussion on the explanation and interpretation of TFP.

[18] Most of the ideas such as increasing returns, learning by doing were also stressed by the development economists of 1940s and 1950s; on this see Krugman (1993) and Thirlwall (2002).

[19] In this context, it should be noted that there exists another set of literature analysing the effect of technological progress on the pattern of trade. For a review of this literature see Grossman and Helpman (1995). Bhattacharjea (2004) provides a critical review of recent developments in trade and development theories that are based on increasing returns of various types.

neoclassical growth models, where trade has no growth effects and has only level effects[20]. Theoretical models examining the effect of trade on technological progress within the endogenous growth framework include Grossman and Helpman (1991a and 1991b), Young (1991), Rivera-Batiz and Romer (1991), Smulders and Klundert (1995), Ben-David and Loewy (1998 and 2000) and Traca (2002). In these models, trade can affect technological progress by: (a) changing the structure or specialisation pattern of the domestic industry, (b) facilitating spillover of technology from the trade partner countries and (c) affecting firms' R&D investment. Since chapters ahead present detailed discussion and empirical analyses of these channels in the context of Indian manufacturing industry, the following paragraphs discuss them only very briefly[21].

(a) Trade-induced structural change and technological progress

By the structure of the manufacturing industry, we mean its composition. Trade usually expands those sectors of the manufacturing industry where the country has comparative advantage by reallocating resources away from other sectors. This trade-induced expansion of some sectors and contraction of others have implications for the technological progress of the manufacturing industry. These implications derive from the fact that various sectors differ in their potential to generate technological progress through investment in R&D, learning by doing and so on (Grossman and Helpman 1991a, Young 1991 and Lucas 1988 and 1993). If the trade-induced resource allocation is from sectors having more potential for learning to those having less potential, the industry as a whole would experience a lower rate of technological progress in the long run. Grossman and Helpman (1991a), Young (1991) and Lucas (1986 and 1993) modelled this aspect of trade, respectively focusing on R&D, learning by doing and human capital accumulation as the source of growth. In these models, if trade expands sectors having higher potential to generate technological progress through any of these sources, the industry would experience a higher growth. Obviously, which sector would expand or contract depends on the comparative advantage of the country in various sectors. Comparative advantage in turn depends on the relative endowment of various factors of production, including technology and human capital.

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[20] In the neoclassical model, trade openness generates gains through better resource allocation, improved X-efficiency, etc. These are short run gains and therefore, exhaust after some time, placing the economy at higher level of income after trade openness (Young, 1991 and Edwards 1993).

[21] Since the empirical analysis is in the context of manufacturing industry, theoretical literature review is presented keeping this in mind, although growth models are formulated for the economy as a whole.

(b) Trade related technology spillovers and technological progress

In the endogenous growth literature, it is postulated that trade is one of the important channels facilitating spillover of technology among the trade partner countries (Grossman and Helpman 1991a and 1991b, Rivera-Batiz and Romer 1991, Ben-David and Loewy 1998 and 2000). Since the lion's share of world R&D is located in developed countries, developing countries are considered as the major beneficiaries of trade-facilitated technology or R&D spillovers[22] (Helpman 2004). Both import and export are assumed to transfer technological knowledge. Import of capital goods can transmit benefits of new technology from exporting to importing countries. Likewise, import of final manufactured goods from technology leader countries to developing countries allows the latter country producers to get familiarity with technologically superior products. This would help them to obtain useful insights to improve their products. Similarly, export gives a chance for the developing country firms to interact with their foreign buyers and learn about new ways to improve the products and production process. Due to the tacitness and circumstantial sensitivity of most of the technology, it is, however, argued that certain level of technological capability is essential for firms to efficiently absorb technology spillovers (Cohen and Levinthal 1989 and Xie 1999). Further, it is also pointed out that technological spillovers might be confined to low and medium technology industries, where tacitness and complexity of technology is lower (Chong and Luisa 2001).

(c) Trade and R&D Investment

Trade can affect firms' R&D investment through several ways and these include import competition, export, technology import and trade related technology spillovers. Formal theoretical analysis of the direction of the effect of import competition, however, is not clear and is sensitive to modelling assumptions on domestic market structure, cost structure of firms, ease of entry and exit in the domestic industry and so on. Export can encourage innovation efforts by allowing firms to produce on a large scale and thereby to exploit increasing returns to scale made possible by fixed investment like R&D. Hughes (1986) argues that export will have a positive effect on R&D because elasticity of export demand with respect to R&D is likely to be greater than that of the domestic demand. Technology import - both embodied and disembodied - can affect innovation effort of the firm. This is one of highly debated issues in the literature on the technological progress of the

[22] In this study, we use the terms *R&D spillovers* and *technology spillovers* synonymously. In chapter three, which empirically examines the trade related R&D spillovers, the term *R&D spillovers* is used throughout, because technological knowledge stock is proxied by R&D capital stock.

developing countries (Evenson and Westphal 1995). Whether technology import encourages or discourages innovative effort is not clear and depends on many factors.

The review of theoretical literature shows that, though the new growth theory identifies a number of channels through which trade can affect technological progress, the direction of the effect is ambiguous and contingent on many factors that are specific to the country and industry. Whether trade can really stimulate technological progress of the manufacturing industry of an economy depends on many factors, including its already achieved level of technological development, its resource endowment and market structure. These are features that distinguish one country from another. It is, therefore, quite plausible to expect that the effect of trade on technological progress can differ from one country to another.

1.3 Review of Empirical Literature

In this brief review of empirical literature on the effect of trade on technological progress and economic growth, we consider two types of studies. (1) Studies examining the issue across countries, mainly using cross-country regression techniques, and (2) those examined the effect of trade on manufacturing productivity[23].

The empirical literature on the effect of trade on growth has registered a tremendous increase during the past four decades. The early studies are multi-country comparative studies, in which a team of researchers undertook detailed study of a number of countries. They include studies coordinated by Little, Scitovasky and Scot (1970), Balassa (1971), Kruger (1978), Bhagwati (1978) and Michaely et al. (1991). Since several alternative instruments like tariff and non-tariff measures, exchange rate controls, direct and indirect subsidies can be used to intervene in the foreign trade regime, the major difficulty faced by these studies was the identification of the trade orientation of countries. This made the tracking of the evolution of the trade orientation over time more problematic. The general conclusion of these studies is that inward oriented trade policy regime has an adverse effect on economic growth.

Later studies examined this issue using cross-country regression techniques. The early cross-country econometric studies assumed that trade was affecting growth through export

[23] There exist excellent reviews of both types of studies. Edwards (1993), Rodriguez and Rodrik (2000) and Lewer and Van den Berg (2004) review the cross-country studies. Tybout (1992) reviews the studies on the effect of trade on manufacturing productivity and Tybout (2000) also contains a brief review of these studies.

and on this basis (implicitly or explicitly) followed a two-stage methodology. In the first stage, it was assumed (rather than tested) that exports grew faster in economies having more open trade policy regime. In the second stage, they examined the effect of export growth on economic growth. Studies in this group include Feder (1983), Balassa (1985), Ram (1985) and Kohli and Singh (1989) among others. Although these studies, in general, found a positive effect of export on economic growth, they were plagued by several problems like simultaneity between export and GDP growth[24] (Edwards 1993).

With the availability of comparable data sets on various aspects of national economies as well as with the improvements in the econometric and computing techniques, regression analysis became the standard tool for the empirical studies of trade and growth across countries[25]. Studies most often specified a linear econometric model of the form:

$$G_{GDP} = a_0 + a_1 G_K + a_2 G_L + a_3 TRADE + a_4 Z + u$$

Where G_{GDP}, G_K, and G_L are the growth rates of real gross domestic product, capital sock, and labour force respectively, *TRADE* is a measure of trade openness, Z is a set of other variables believed to explain economic growth and u is the random error term. The above model specification can be derived from the neoclassical production function. The variables such as *TRADE* and Z explain the intercept of the production function in growth form, which is the growth rate of economy wide total factor productivity (Lewer and Van den Berg 2004).

The major problem faced by these studies also is the construction of a satisfactory and convincing measure of trade openness. Since countries can intervene in trade through several ways, a single measure reflecting only one or two dimensions of the policy regime is found to be totally inadequate as a measure of trade orientation. The recent studies address this problem using either indices of openness that encompass one or more aspects of trade restrictions or by testing the robustness of a number of alternative measures, including subjective indicators[26]. Pritchett (1996), however, finds that common indicators of 'outward orientation' are pairwise uncorrelated, raising the question of whether any of these measures adequately capture economists' intuitive understanding of what means for a country to have an open or liberal trade policy regime. In this context, it should be noted

[24] See Edwards (1993), Table 8, for details.

[25] The data sets include Summers and Heston (1988) and Summers and Heston (1994).

[26] Edwards (1998, p.386) writes "the difficulties in defining satisfactory summary indexes suggest that researchers should move away from this area, and should instead concentrate on determining whether econometric results are robust to alternative indexes".

that the empirical literature is concerned with two distinct but closely related questions: (1) *Do countries with lower policy induced barriers to international trade grow faster, once other relevant country characteristics are controlled for?* and (2) *Does international trade raise growth rates of income?* (Rodriguez and Rodrik 2000). Some of the empirical studies employed variables related to trade policy, some others used measures of trade volume and a few used both measures in their econometric model (see Yanikkaya 2003).

These studies also faced the problem of endogeneity of the trade openness variable and this is addressed either using exogenous proxies for trade openness or instrumental variables. The exogenous proxies and instruments used include, among others, subjective indices of trade openness, constructed trade shares that reflect only exogenous component of trade, measures of exchange rate distortions and export and its growth rate. Table 1.1 presents a review of selected previous cross-country studies and their important features.

Since there already exists detailed reviews of the literature, here we consider only the very recent studies, as these are improvements over previous ones in several respects. All the studies except Rodrik et al. (2002) show positive effect of trade openness on economic growth. These results, however, have been criticised on the ground that the proxies used in these studies are highly correlated with other determinants of poor economic growth such as macro economic instability, institutional quality and geographical factors. They, therefore, are reflecting the effect of these omitted variables rather than trade policy *per se*[27]. Rodriguez and Rodrik (2000) re-estimated the regression models of Dollar (1992), Sachs and Warner (1995), Edwards (1998) and Frankel and Romer (1999) by adding variables representing macro economic stability, geography and institutional quality and found openness was insignificant[28]. Again, Rodrik et al. (2002) shows that trade openness has no significant effect once other important determinants of economic growth, like institutional quality, are controlled for. One study showing significant positive productivity effect even after controlling for institutional quality and geography is Alcala and Ciccone (2004). This study, however, suffers from the weakness that the proxy of openness it uses, namely 'real openness', is positively correlated with any increase in productivity

27 Rodrik et al. (2002) argues that trade can have indirect effects on growth by improving the institutional quality. In this context see Batavia and Nandakumar (2002) that formalises the relationship between economic integration and trade union power.

28 Rodriguez and Rodrik (2000) points that these papers belong to the group of most cited ones in the recent trade growth debate.

Table 1.1 Selected Review of Studies on Openness and Growth

Study	Data and Time Period	Proxy or instrument for Trade Openness	Result
Edwards (1992)	30 countries data for the period 1970-82	Deviation from the predicted trade constructed by Leamer (1988)	Trade openness has a positive effect on economic growth.
Dollar (1992)	95 developing countries for the period 1976-1985	Two indices of trade restriction (1) Index of real exchange-rate distortion and (2) index of real exchange-rate variation.	The two indices are negatively related to growth.
Sachs and Warner (1995)	79 countries for the period 1970-1989.	A zero-one dummy variable that takes value zero if the economy is closed according to any of the five criteria considered, otherwise it takes value one.	Openness dummy has positive effect on growth.
Harrison (1996)	51 countries for the period 1960-87.	Used seven different proxies for trade openness and adopted panel data technique (fixed effect) for estimation.	Positive effect of openness on growth.
Edwards (1998)	93 countries for 1960-90.	Examining the robustness of trade and growth relationship using 9 alternative proxies.	Positive effect of openness on productivity growth is robust across a number of proxies.
Frankel and Romer (1999)	150 countries for the year 1985	Trade share in GDP has been instrumented by a constructed trade share using a gravity equation on bilateral trade flows.	Trade openness has a positive effect on growth.
Easterly and Levine (2001)	73 countries for the period 1960-95.	Trade share in GDP (ratio of import plus export to GDP) instrumented by lagged values	Positive effect of trade share on economic growth
Wacziarg (2001)	57 countries for the period 1970-1989	Two indices (1) linear combination of import duty share, nontariff barriers and liberalisation status. (2) Liner combination of import duty and nontariff barriers.	Openness has a significant positive effect on growth
Rodrik, Subramanian and Trebbi (2002)	Three data sets: 64, 80, and 140 country samples for the year 1995	Trade share in GDP, instrumented with Frankel and Romer (1999) instrument.	Once institutional quality has been controlled for, openness has no direct effect on per capita income.
Yanikkaya (2003)	Over 100 countries for 1970 to 1997.	Two groups of measures, first group include variables related to trade volumes and second group includes variables related to trade barriers.	Both group of variables have positive effect on growth and trade barrier variables have positive effect particularly in the case of developing countries.
Alcala and Ciccone (2004)	138 countries for the year 1985.	'Real openness' defined as the ratio of import plus export (measured in US $ exchange rate) to GDP in purchasing power parity US $.	Found that trade is a significant and robust determinant of aggregate productivity even after controlling for institutional quality and geography.
Lee et al. (2004)	About 100 countries for 1961-2000.	Five measures: trade share in GDP, import duty as percent of imports, black market premium, average years of openness indicated by Sachs and Warner index and a tariff indicator.	Trade openness is generally found to have positive and significant, but small effect on economic growth, after controlling for endogeneity.

regardless of the source. So under the null hypothesis that trade does not cause productivity, the association between 'real openness' and productivity is spurious. Under the null hypothesis that trade does cause productivity, the observed association would be biased upwards unless the cause of productivity change is only trade[29] (Rodrik et al. 2002).

The major problem in exploring the growth effects of trade openness is, thus, the difficulty in its measurement. Further, these studies, particularly the earlier ones, also lack a convincing theoretical framework that links trade openness and growth[30]. As Edwards (1993, p.1361) notes,

> Although these cross-country investigations have unearthed significant information on trade practices in a score of countries, they have been subjected to two limitations. First, invariably the authors have found it extremely difficult to compute satisfactory indices of protection and trade orientation and second, these studies have not been able to provide a fully convincing theoretical framework that links commercial policy, trade orientation and growth.

In addition to these, the other weaknesses include high collinearity of trade policy regimes with other important determinants of growth, making the identification of its sole effect quite impossible, dubious quality of data on which these studies are based and parameter heterogeneity[31] (Darity and Davis 2005). Further, as we have found, the theoretical literature on the growth effect of trade is not clear and is contingent on many country and industry specific factors. Cross-country econometric studies, therefore, cannot deliver deeper insights into the issue of trade and growth.

Both the shortcomings of the cross-country regression studies and the new theoretical insights provided by the endogenous growth literature raised the need for micro level studies that look into the channels through which trade affects growth. While concluding the detailed review of trade and growth literature, Edwards (1993, p.1390) stresses this point:

> Recent theoretical developments in growth theory have suggested that microeconomic analysis could shed some light on the growth process. Issues related to the use of multiple intermediate inputs, the invention of designs and the absorption of technological progress under alternative trade regimes look particularly relevant. However, it is doubtful that these questions will be adequately addressed through the currently common cross-country regression on aggregate data... More complete evidence on the precise channels through which trade orientation affects growth, will have to wait, then, for new studies that not

[29] Rodrik et al. (2002) is referring to an earlier version of Alcala and Ciccone paper presented at NBER Summer Institute in June 2002 and the criticisms raised by Rodrik et al. are not addressed in the paper published in 2004.

[30] Wacziarg (2001) and Yanikkaya (2003) used insights from new growth theory in their empirical analysis.

[31] For the problems with the data in the cross-country regression studies see Heston (1994) and Iscan (2004).

only look at history but also dig deeply into the microeconomics of innovation, trade, and growth.

Since studies analysing the effect of trade in manufacturing industry are numerous, here we limit the review to Indian case only. A number of studies examined the productivity growth of Indian manufacturing industry, covering different periods of time, based on different data sets[32]. These studies mainly used two methods to measure productivity growth, namely growth accounting and econometric cost/production function and used either industry level or firm level data. In the growth accounting approach, studies employing value added production function adopted single deflation or double deflation procedure to arrive at real value added series[33].

Goldar (1986a) studied the effect of restricted trade policy, proxied by the relative contribution of import substitution to change in output, on industrial productivity using multiple regression technique. The study found that import substitution negatively affected productivity growth. Ahluwalia (1991) also examined the effect of a measure of import substitution on total factor productivity growth[34] (TFPG). Using data on 62 industries for the period 1959-60 to 1979-80 and multiple regression technique, this study found that import protection had a negative impact on TFPG. On this basis, the study concluded that negative effect of protective import substitution dominated its positive effect through expanded domestic market.

Kusum Das (1998) analysed the effect of output growth, import penetration rate and export growth on TFPG using a panel data of 53 three-digit level industries for the period 1980-81 to 1993-94. The period of study was subdivided into two phases according to the trade policy regime and 1985-86 to 1993-94 was classified as post trade reform period. The results show that, out of the 54 models estimated for six industrial groups (including a group consisting of all industries) for the whole period and for the two sub-periods in three different specifications, only in five cases import penetration rate has significant negative effect on TFPG. Variables related to export (export growth rate and ratio of export to output) are significant only in one case out of 36 regressions estimated. This study, thus,

[32] There exist a few detailed reviews of the total factor productivity (TFP) studies of Indian manufacturing industry. For an earlier review see Krishna (1987) and for a recent one see Goldar and Mitra (2002). Krishna (2004) also reviews the economy wide productivity studies.

[33] In single deflation method, the nominal value added series are deflated using the output deflator to obtain the real value added series. In the double deflation method, real value added series are obtained from the real measures of gross output and intermediate inputs. For more details on these as well as of their problems see Balakrishnan and Pushpangadan (1994), Rao (1996) and Goldar (2002).

[34] Ahluwalia (1991), ch. 5.

does not show any robust relationship between productivity growth and the two important dimensions of trade. Study by Goldar and Kumari (2002) examined the effect of effective rate of protection and non-tariff barriers on TFPG using a panel of 17 two-digit industries for the period 1980-81 to 1997-98. The results show that effective rate of protection has a significant and robust negative effect and the study concludes that restrictive trade policy retarded the productivity growth.

Another set of studies examined the effect of trade policy changes by comparing TFPG of pre and post liberalised periods and these include Srivastava (1996), Krishna and Mitra (1998) and Balakrishnan et al. (2000), among others[35]. Srivastava (1996) estimated productivity growth of the manufacturing industry using firm level panel data for the period 1981-89 and considered 1981-84 as pre reform and 1985-89 as post reform periods[36]. It shows that TFPG of the whole manufacturing industry improved in the post reform period[37]. Krishna and Mitra (1998) used firm level panel data for the period 1986-93 and considered 1991 as the year of the beginning of liberal trade policy regime. The study reports results for four industries - electrical machinery, non-electrical machinery, electronics and transport equipment - that have undergone substantial reduction in tariff and nontariff protection. Following Hall (1988) methodology, it estimated price-marginal cost ratio and change in productivity growth after 1991. The results show that all industries, except transport equipment, registered higher productivity growth after 1991. Using firm level panel data of five industries, which faced relatively higher reduction in trade protection, for the period 1988-89 to 1997-98, Balakrishnan et al. (2000) estimated change in productivity growth after 1991 using Hall (1988) methodology. The study found a significant decline in the TFPG after 1991 and thus contradicts with Krishna and Mitra[38] (1998). One feature of these studies is that they are not explicitly correlating observed productivity growth with variables related to trade or trade policy. Since observed productivity growth is the outcome of many influences, this kind of studies can only say

[35] Goldar (2000) and Trivedi et al. (2000) estimated TFPG for the 1990s using ASI data. Parameswaran (2004) analysed two components of the TFPG, namely technical change and efficiency change, of four industries belong to the capital goods producing sector during the 1990s.

[36] It should be noted that in Srivastava (1996), the concept of liberalisation include not only trade liberalisation, but liberalisation of industrial policies also.

[37] In this context it is to be noted that studies such as Balakrishnan and Pushpangadan (1994), Rao (1996) and Pradhan and Barik (1998) show that TFPG in the 1980s is lower than that for the previous decade.

[38] Krishna and Mitra (1998) and Balakrishnan et al. (2000) studies differ in the time period of analysis, industries covered and in the measurement of the capital stock of the firm. Balakrishnan et al. uses panel data of five industries, namely electrical machinery, non-electrical machinery, transport equipment, chemicals and textiles and reports results for the pooled sample of these industries. These differences may have produced the contradictory results.

that TFPG is lower or higher during the post liberalisation period and are unable to make any conclusion on the effect of trade on productivity growth.

The productivity studies, above reviewed, address the questions, how variables related to trade or trade policy are affecting industrial productivity and whether there is an improvement in productivity after trade liberalisation. Trade liberalisation can have short run as well as long run effects on industrial productivity. The sources of short run effect include, among others, increased X-efficiency and resource reallocation from less productive industries and firms to more productive industries and firms (Corden 1974). Since these studies are not addressing empirically the underlying mechanism, they cannot say anything on whether the observed change in productivity growth rate is of short run or of long run nature. These studies, though provide richer insights into the productivity performance of the manufacturing industry, are, therefore, unable to conclude anything about how trade affected the process of technological progress and thus the long run growth prospects of the manufacturing industry.

1.4 Problem and Objectives of the Study

The review of the theoretical and empirical literature shows that the question of the effect of trade on technological progress and economic growth is still an open issue. The theoretical literature, instead of giving a clear answer, reveals that the issue is so complex and final outcome is contingent on many factors, most of which are specific to the country and industry. Rodriguez and Rodrik (2000, p.266), while reviewing the evidence on trade openness and growth, also reach the same point:

> Our bottom line is that the nature of the relationship between trade policy and economic growth remains very much an open question. The issue is far from being settled on empirical grounds. We are in fact sceptical that there is a general, unambiguous relationship between trade openness and growth waiting to be discovered. We suspect that the relationship is a contingent one, dependent on a host of country and external characteristics. Research aimed at ascertaining the circumstances under which open trade policies are conducive (as well as those under which they may not be) and scrutinising the channels through which trade policies influence economic performance likely to prove more productive.

Against this background, the present study empirically examines the three channels through which trade can affect technological progress in the context of Indian manufacturing industry. The study also examines the role of some domestic factors in shaping the impact of trade. The ambiguity and country and industry specificity in the influence of trade, it seems, make a study of this kind worth pursuing in the context of a manufacturing industry that has faced dramatic trade liberalisation during the 1990s.

Further, an analysis of channels using micro level information can provide much deeper insights into the relationship between trade and technological progress. The analysis is confined to the manufacturing sector, because most of the channels, through which trade is expected to affect technological progress, are more probable as well as more visible in this sector than any other. Further, as we have found above, manufacturing industry is considered as the engine of growth. A study of this sector, therefore, assumes significance from the point of view of the overall growth of the economy.

The specific objectives of the study are,

(1) To examine the effect of trade on the structure of the manufacturing industry and its implications for technological progress.

(2) To analyse the effect of trade facilitated technology spillovers on manufacturing productivity.

(3) To investigate the inter-sectoral variation in the productivity effect of trade related technology spillovers.

(4) To test the role of firms' investments in R&D, technology import and in plant and machinery in facilitating the absorption of trade facilitated technology spillovers; and

(5) To examine the effect of trade on firms' R&D investment and variation in the impact due to the market structure.

1.4.1 Methodology and Data sources

The empirical analysis of the present study is based on the firm level and industry level data. In this respect, the study improves upon the previous studies that use aggregate country level data. Trade-induced structural change and its technological progress implications are examined by decomposing the change in the shares of sectors having higher potential to generate technological progress in the total manufacturing output into three sources, namely due to domestic demand, import and export. For this, we use Chenery, Robinson and Syrquin (1986) methodology. The industries having higher potential to generate technological progress are identified on the basis of three alternative criteria namely technological intensity, R&D intensity and capital intensity.

Productivity effect of trade related R&D spillovers is examined using production function approach. This analysis uses firm level panel data. To estimate the production function parameters consistently in the presence of simultaneity problem, Levinsohn and

Petrin (2003) methodology is implemented. Here, we also demonstrate the superiority of Levinsohn and Petrin methodology over OLS and Within.

In the analysis of the effect of trade on R&D investment, we examine the impact of import competition, export, technology import and trade related knowledge spillovers on the probability and intensity of R&D investment. Intensity of R&D investment is defined as the ratio of R&D expenditure to sales. For this, probit and tobit regression models and firm level data are employed.

Here we provide only very brief description on the database of the study as the details on various data sources are presented in respective chapters. The study makes use of firm level panel data obtained from Centre for Monitoring Indian Economy's (CMIE) electronic database *PROWESS*. The other important datasets include *Annual Survey of Industries (ASI)* for industry level information, National Sample Survey Organisation's (NSSO) 45^{th} and 51^{st} round sample surveys of the unorganised manufacturing sector, data on bilateral trade in manufactured products collected from World Bank compiled *Trade and Production Database* and industry level R&D expenditure data of fifteen Organisation of Economic Co-operation and Development (OECD) courtiers collected from OECD database, called *Analytical Business Enterprise Research and Development Database (ANBERD).*

1.4.2 Organisation of the Study

The study is organised in five chapters including this introductory chapter. Chapter two analyses the effect of trade on the structure of the manufacturing industry and its implications for technological progress. The chapter begins with a detailed discussion of the theoretical relationship between trade-induced structural change and technological progress. Since the structural change effect of trade depends on the extent of trade openness as well as on the structure of trade, the empirical analysis begins by examining trade openness and structure of trade in manufactures. In the structural change analysis, change in the shares of sectors having higher potential for technological progress has been decomposed into that accounted by domestic demand, export and import. The sum of the last two sources together is attributed to trade.

Chapter three examines the effect of trade facilitated R&D spillovers on productivity. It begins with a detailed discussion of the relevant theoretical literature. Discussion of the production function methodology, econometric issues involved in the production function estimation and the approach of the present study are also provided. The rest of the chapter contains the details of the data and construction of variables, discussion of the results and summary and conclusion of the chapter.

Chapter four analyses the effect of trade on firms' R&D investment. As a background to the empirical analysis, it first examines the trends and composition of industrial R&D investment in India. This is followed by a section discussing the channels through which trade can affect the R&D. The remaining part of the chapter provides details of the data and construction of variables, discussion of the econometric issues, interpretation of results and summary and conclusion.

The final chapter provides summary, conclusions and theoretical and policy implications of the study. It also highlights some of the important issues that call for further research.

2

Trade and Structural Change

This chapter examines the effect of trade on the structure of the manufacturing industry and its implications for technological progress. It is organised in four sections. Section one discusses the theoretical literature linking technological progress with trade-induced structural change. Since the structural change effect of trade closely depends on the extent of trade openness and the structure of trade in manufactures, section two examines the trends in trade openness of the manufacturing industry and structure of trade in manufactures. Section three analyses the effect of trade on the structure of the manufacturing industry and discusses its relevance to technological progress. The last section concludes the chapter.

2.1 Trade and Structural Change: Theory

In this study, by the term structure of the manufacturing industry we mean the relative importance of various industrial groups classified on the basis of technological and factor intensity. The relative importance of sectors can be measured using their shares in the total manufacturing output[1]. The structure of the manufacturing sector of an economy is determined, in general, by the interaction of demand and supply factors. The demand side factors include, among others, level of per capita income, pattern of income distribution, consumers' tastes and preferences and export demand. The supply side determinants include, among others, relative endowment of various factors of production such as natural resources, workforce and its skill level and the level of technological progress attained by the industry. In addition to these, industrial policy also plays an important role in shaping the industrial structure. For example, government may promote certain industries by providing special incentives.

Change in the structure of the manufacturing industry can be the result as well as the cause of economic growth. For instance, rise in income levels generates demand for products beyond basic necessities such as automobiles and electronics products. Growth effects of structural change derive from the fact that sectors vary in their ability to generate technological progress through source like learning by doing and R&D. These

[1] See Syrquin (1988), p.206.

differences arise due to the variation in the opportunities for technological progress across industries. R&D investment and learning by doing usually generate rapid technological progress in industries having greater opportunities for this. If a larger share of the manufacturing output is accounted for by industries having higher potential to generate technological progress, the industry as a whole would experience a higher rate of productivity growth. The dominance of these industries not only generates rapid growth by itself, but also causes faster growth of other manufacturing sectors through positive technological externalities (Pack 2000). Prospects of technological progress, on the other hand, is lower, if a larger share of the manufacturing output is accounted for by industries having lesser opportunities for innovation and learning like traditional industries[2].

Trade can affect the structure of the manufacturing industry by reallocating resources across various industries according to comparative advantage. This improves static efficiency of resource allocation. The recent developments in the growth theory, however, are focusing on the dynamic aspects of this resource allocation, namely technological progress. Endogenous growth models developed by Grossman and Helpman (1991a), Young (1991), Baldwin and Seghezza (1996a and 1996b) and Lucas (1988, 1993 and 2002) examined this aspect of trade openness, each focuses on separate dimensions of technical progress.

Grossman and Helpman (1991a) analysed this aspect of trade openness in a two sector-two factor model focusing on technological progress through R&D. One sector is engaged in the composite activity of inventing and producing innovative high technology goods and the other is engaged in the production of traditional commodities. Obviously, the former enjoys a higher rate of technological progress. The two factors of production are human capital and unskilled labour. The high technology sector uses human capital intensively and the other sector is unskilled labour intensive. The model predicts that country that is human capital rich specialises in the production and export of innovative high technology products. It, therefore, enjoys a higher growth rate in equilibrium with trade. Whereas trade leads the country that is rich in unskilled labour to specialise in the production of traditional commodities and thereby to face a lower rate of technological progress.

[2] In the low technology traditional industries, one source of technological progress is the introduction of new machinery and equipment. In this case, technological progress is not generated endogenously, but coming from out side sources, namely machinery and equipment suppliers.

In Young's (1991) model, the source of technological progress is learning by doing and spillovers from it. Learning by doing is assumed to be bounded in each good; that is in the production of a specific commodity, it disappears after some time. The model consists of two countries, a less developed country (LDC) and a developed country (DC). The latter is technologically advanced and therefore, produces more sophisticated commodities in which learning by doing potential still exists. This model shows that trade openness leads the LDC to specialise in those commodities in which learning by doing potential had been exhausted and the DC to specialise in more sophisticated commodities. The model predicts that in the equilibrium with trade LDC would experience a lower long run growth and DC would have a higher growth compared to the autarky growth rates. This result, however, would be changed, if the LDC has large population and its technology gap with DC is lower. In this model, a large population implies a lower relative wage. A lower relative wage combined with narrow technology gap enables the LDC to specialise in those commodities in which learning by doing still exists and ultimately reduces its technology gap with DC[3].

In Lucas (1988, 1993 and 2002) model, human capital formation is the source of growth. Human capital can be accumulated through production experience or learning by doing, besides formal training. If a larger portion of the workforce of an economy is employed in high technology industries, where workers have to solve many complex production problems and therefore experience more intensive learning, the rate of human capital formation (skill acquisition) is high. This model predicts that if the trade-induced specialisation shifts workers from low technology to high technology industries, the economy would experience a higher growth. Shift of workers to industries, where the potential for learning by doing had already been exhausted, has the opposite effect on growth[4].

Another source of technological progress is the investment in plant and machinery embodying new technology. Trade-induced resource reallocation can also affect the rate of investment. Expansion of capital intensive industries stimulates investment in plant and machinery. A contraction of this sector due to trade-induced shift in specialisation, on the other hand, would lead to a lower rate of investment. Baldwin and Seghezza (1996a and 1996b) modelled this aspect of trade-induced investment led growth.

[3] Stokey (1991) also arrives at similar conclusions in a North-South trade model. For a recent review of the literature on growth, trade and uneven development see Darity and Davis (2005).
[4] Krugman (1987b) also considered this issue.

The review of the theoretical literature shows that trade can affect the prospects of technological progress of the manufacturing industry by changing its structure. However, the direction of trade-induced specialisation can be predictable in the extreme cases of highly developed and very poor countries. Countries in the former group have higher stock of human capital and technological knowledge, allowing trade to further deepen the specialisation in high technology industries. In the latter case, trade usually induces specialisation in traditional low technology and resource intensive industries. India does not belong to either of these extreme cases. It has already accumulated a fairly good technological and human capital base and also enjoys a lower relative wage advantage. Hence, predicting the direction of trade-induced structural change in Indian manufacturing industry on the basis of prior knowledge is difficult. Further, because of its big domestic market one may also doubt the ability of trade to change the structure in such a way that it would have a significant impact on the prospects of technological progress. This ambiguity in the effect of trade on the structure of the manufacturing industry makes examining this issue empirically more important.

The structural change effect of trade is intimately related to the extent of trade openness across industries and the structure or composition of trade in manufactures. So as a background to the structural change analysis, the following section examines the trends in the trade openness and structure of trade in manufactures.

2. 2 Trade Openness and Structure of Trade: Trends and Patterns

The extent to trade openness is measured using shares of import and export in output of the industry, which are respectively known as import and export intensity in the literature. In the analysis of trade structure, trends in the shares of technology intensive, capital intensive and labour intensive products in the import and export of manufactured products are examined. Only these dimensions of trade structure are considered because of their relevance to the technological progress.

Average import and export intensity is computed for three time periods, 1985-90, 1990-95 and 1995-98, using trade data obtained from Trade and Production Database compiled by the World Bank[5]. In this database, import and export, collected from UN COMTRADE, are reported in three and four digit classifications of International

[5] The appendix to this chapter gives details of this database.

Standard Industrial Classification Revision 2 (ISIC rev 2). Output figures are obtained from the Annual Survey of Industries (ASI) [6]. To compute import and export intensity,

Table 2.1 Average Import intensity by Industry (In per cent)

	Industry group	1985-90	1990-95	1995-98
1	Professional and scientific measuring and controlling equipment	91.8	88.0	81.8
2	Basic Industrial chemicals and chemical products	34.4	42.4	51.1
3	Photographic and optical goods	227.7	129.1	43.1
4	Products of petroleum and coal	10.4	30.1	41.3
5	Office computing and accounting machinery	29.4	26.0	40.7
6	Industrial machinery and other machinery	33.1	28.1	40.6
7	Radio, television and communication equipment	28.0	19.0	25.8
8	Metal products	33.2	25.5	23.5
9	Synthetic resins, plastic materials and manmade fibres	36.1	30.9	20.9
10	Paper and paper products	13.9	11.1	15.3
11	Fertilisers and pesticides	13.6	13.3	14.2
12	Watches and clocks	16.1	7.7	13.7
13	Electrical Industrial machinery and apparatus	11.9	9.2	13.3
14	Iron, steel and non-ferrous metal basic industries	12.5	8.9	12.1
15	Glass and glass products	12.9	11.3	12.1
16	Transport equipment	10.3	10.9	9.3
17	Wood products	3.8	3.3	7.4
18	Electrical appliances and house hold goods	2.1	2.8	7.2
19	Leather and leather products	2.1	6.6	6.9
20	Drugs and medicines	6.4	7.1	6.5
21	Food products	5.5	2.6	4.5
22	Rubber and plastic products	1.9	2.5	4.1
23	Pottery, china and earthenware	2.5	2.7	3.2
24	Textiles products	1.4	2.0	2.1
25	Agricultural machinery and equipment	0.7	1.0	1.4
26	Paints, varnishes and lacquers	1.0	1.0	1.3
27	Soap, perfumes and other toilet preparations	0.8	0.8	1.0
28	Beverages and Tobacco	0.4	0.2	0.5
29	Cement, lime and plaster	0.5	0.0	0.0
30	**Total manufacturing**	**11.4**	**12.3**	**15.6**

Note: For details of industry classifications see Table 2A.5 in the appendix to this chapter

we have harmonised the classifications of trade and output data using a concordance table between ISIC rev 2 at four-digit level and ASI at three-digit level. These measures

[6] Here it should be noted that ASI covers output of the registered manufacturing only. Since continuous time series data on the output of the unregistered manufacturing industry at three-digit level are not available, we are using ASI output to measure the size of import and export in relation to output.

are computed for the whole manufacturing industry and for 29 industries[7]. The results are presented in Table 2.1 and Table 2.2.

Table 2.2 Average Export Intensity by Industry (In per cent)

	Industry group	1985-90	1990-95	1995-98
1	Leather and leather products	84.0	81.5	77.5
2	Textiles products	22.1	34.6	38.5
3	Basic industrial chemicals and chemical products	8.1	18.9	25.5
4	Office computing and accounting machinery	10.0	13.3	22.9
5	Watches and clocks	0.6	5.5	17.0
6	Metal products	8.9	15.8	16.3
7	Drugs and medicines	8.5	13.0	15.3
8	Food products	8.0	10.4	14.9
9	Glass and glass products	3.6	8.0	14.1
10	Professional and scientific measuring and controlling equipment	9.2	12.2	12.8
11	Radio, television and communication equipment	4.2	4.8	11.1
12	Pottery, china and earthenware, etc.	1.9	6.3	10.8
13	Photographic and optical goods	98.2	49.1	10.7
14	Rubber and plastic products	2.7	7.4	8.2
15	Synthetic resins, plastic materials and manmade fibres	3.1	6.0	7.7
16	Wood products	3.1	6.5	7.5
17	Industrial machinery and other machinery	5.2	6.9	7.5
18	Transport equipment	3.6	7.2	6.8
19	Iron, steel and non-ferrous metal basic industries	1.5	4.3	6.0
20	Electrical appliances and household goods	1.8	4.4	6.0
21	Soap, cosmetics and other toilet preparations	4.2	6.9	5.2
22	Electrical industrial machinery and apparatus	3.4	3.8	5.1
23	Products of petroleum and coal	4.2	5.3	3.8
24	Fertilisers and pesticides	0.9	1.4	2.9
25	Beverages and tobacco	5.1	4.3	2.8
26	Paper and paper products	0.8	1.4	2.5
27	Agricultural machinery and equipment	1.3	1.2	2.1
28	Cement, lime and plaster	0.1	1.6	1.6
29	Paints, varnishes and lacquers	3.0	1.2	0.4
30	**Total manufacturing**	**9.4**	**14.1**	**16.1**

Note: For details of industry classifications see Table3A. 5 in the appendix to this chapter

The average import intensity for the whole manufacturing industry was 11.4 per cent during the first period and 15.6 per cent during the third period. This increase in the import intensity may be attributable to the trade liberalisation policy India has been

[7] This 29 industry group are compiled from the 81 four-digit level industries of ISIC rev 2 after aggregating some of the industries whose products are close to each other. For this classification scheme see Table 2A.5 in the appendix to this chapter.

following more vigorously since 1991. Individual industries that faced increase in import intensity include *Basic industrial chemicals and chemical products, Office computing and accounting machinery, Industrial machinery and other machinery, Agricultural machinery and equipments, Products of petroleum and coal, Electrical appliances and household goods, Wood products, Leather and leather products* and *Rubber and plastic products.* Whereas industries such as *Professional and scientific measuring and controlling equipment, Photographic and optical goods, Metal products, Synthetic resins plastic materials and manmade fibres and Transport equipment* experienced decline in their import intensity.

Export intensity of the whole manufacturing industry increased from 9.4 per cent in the first period to 16.1 per cent in the third period. Industries such as *Textiles products, Basic industrial chemical and chemical products, Office computing and accounting machinery, Watches and clocks, Metal products, Drugs and medicines, Food products, Glass and glass products, Professional and scientific measuring and controlling equipment* and *Radio television and communication equipment* experienced an increase in their export intensity. Industries such as *Products of petroleum and coal, Beverages and Tobacco, Photographic and optical goods* and *Paints, varnishes and lacquers* faced a decline in their export intensity. It is, thus, revealed that almost all the industries, except a few, increased their export intensity during the 1990s.

Analysis of structure of trade requires classification of industries (products) on the basis of technological and factor intensity. The following paragraphs provide details of these classifications.

<u>*Classification on the basis of technological intensity:*</u> By grouping industries on the basis of technological intensity, our objective is to identify a set of industries that are technologically complex and hence offers more scope for learning and innovation. Earlier attempts to classify industries on this basis include Hatzichronoglou (1997) and Lall (2001). These two attempts are based on many criteria, including expert opinion and experience of the researchers in the field of industrial technology. For instance, Lall's (2001) classification is based "on available indicators of technological activity in manufacturing and on author's knowledge of industrial technology" (p.91).

Since developing a satisfactory objective criterion with the available information is quite difficult, our classification of industries into technology intensive group is based on previous studies, particularly[8] on Hatzichronoglou (1997) and Lall (2001). Industries included in this group are of skill and scale intensive technologies in capital goods and intermediate products. They tend to have complex technologies, advanced skill needs and lengthy learning period. A higher priority to make investments in R&D is also characteristics of these industries. The presence of these industries also benefits other industries through technological knowledge externality. The skill and knowledge created in these industries may be useful to generate further technological progress in these and in related industries. Further, most advanced technology industries also have strong linkages with universities and research institutes. The linkages help them to bring about rapid changes in their technology. The technology intensive industries include *Pharmaceuticals, Automobiles, Office accounting and computing machinery including computers,* and *Manufacture of radio, television and communication equipment.* A complete lists of industries included in this group are given in the appendix to this chapter in Table 2A.1.

In the classification of industries into technology intensive group, it should be noted that the available data do not allow us to capture all aspects of technological differences. What is available to us, as we have noted above, is the trade data at four-digit level of ISIC. The data at this level, although reasonably disaggregated, put together activities at different levels of technological complexity under the same category. For instance, Office computing accounting machinery group includes the simple calculator and computers. This problem inherent to the data can be overcome only by using very detailed product categories, but that is not feasible here. Nevertheless, the data available to us give considerable technological differentiation across four-digit industries and can provide insights into the important aspects of the technological structure of trade in manufactures.

[8] Lall (2001) classified products into low technology products, medium technology products and high technology products. "Low technology products tend to have stable, well-defined technologies. The technologies are primarily embodied in the capital equipment; the low end of the range has relatively simple skill requirements" (p.93). "Medium technology products, comprising the bulk of skill-and scale-intensive technologies in capital goods and intermediate products...They tend to have complex technologies with moderately high level of R&D, advanced skill needs and lengthy learning periods" (p.94). "High technology products have advanced and fast-changing technologies, with high R&D investment and prime emphasis on product design. The most advanced technologies require sophisticated technology infrastructure, high levels of specialized technical skills and close interaction between firms, and between firms and universities or research institutions" (p.94). In our classification scheme, technology intensive industries include both medium and high technology industries of Lall (2001).

Labour and Capital intensive groups: Classification of industries into labour and capital intensive groups is based on their capital-labour ratio (capital intensity). For this, we have arranged all the four-digit industries of ISIC on the basis of capital intensity in descending order and grouped top 25 percent (fourth quartile) of industries into capital intensive and bottom 25 percent (first quartile) into labour intensive industries. These two groups consist of industries that are respectively highly capital intensive and highly labour intensive. Although this classification is arbitrary in choosing the cut off point, the industries classified as labour and capital intensive match with those of Nambiar and Tedas (1994). Moreover, capital and labour intensive groups thus classified, as we shall see below, respectively account for a larger portion of manufactured import and export of India. The lists of industries belong to capital and labour intensive groups are given in Table 2A.2 and Table 2A.3 respectively in the appendix to this chapter.

Table 2.3 Share of Technology intensive Products (in per cent)

Year	Imports	Exports
1985-86	45.7	11.2
1986-87	49.7	11.7
1987-88	45.8	12.7
1988-89	48.6	14.4
1989-90	51.1	16.1
1990-91	47.7	15.4
1991-92	49.3	17.3
1992-93	41.4	15.1
1993-94	44.1	15.1
1994-95	45.8	17.2
1995-96	46.2	17.6
1996-97	41.8	19.2
1997-98	43.1	20.3
1998-99	41.5	18.4
1999-00	41.5	18.4

Table 2.3 presents the share of technology intensive products for the period 1985-86 to 1999-00. It shows that export share of technology intensive products is increasing over time, from 11.2 per cent in 1985-86 to 20.3 per cent in 1997-98. On the other hand, the share in import, although high, is showing a declining trend. This rise in the export share and reduction in import share may be signalling the gradually evolving technological mastery of Indian industry. However, compared to other newly

industrialised economies (NIE) and China the share of technology intensive products in India's export is low[9] (Lall 1999).

Table 2.4 Share of Labour and Capital Intensive Products (in per cent)

Year	Labour Intensive Products		Capital Intensive Products	
	Import	Export	Import	Export
1985-86	3.4	41.1	53.4	14.8
1986-87	3.7	42.2	44.9	12.6
1987-88	4.5	39.9	48.3	13.9
1988-89	5.4	42.4	54.0	15.3
1989-90	5.2	38.5	59.2	16.1
1990-91	4.8	34.7	59.5	15.5
1991-92	5.1	32.9	62.8	16.2
1992-93	20.4	32.0	49.5	17.3
1993-94	19.9	32.8	51.8	17.2
1994-95	11.2	31.1	53.2	18.1
1995-96	10.8	33.0	54.2	17.8
1996-97	13.8	27.8	54.4	19.0
1997-98	14.8	28.7	51.8	19.6
1998-99	17.4	34.6	45.3	15.0
1999-00	17.3	34.6	45.4	15.0

Note: Since the two classifications - labour intensive and capital intensive - do not cover whole import or export of manufactured goods, the sum of the shares is not equal to hundred.

The shares of labour intensive and capital intensive products in import and export are given in Table 2.4. Capital intensive products account for 53 per cent of India's import in 1985-86 and it increased to 63 per cent in 1991-92 and thereafter it is showing a declining trend, whereas, its export share is not indicating any definite trend. The export share of labour intensive commodities, although high, is declining and its share in import registered a rapid rise. The trends in the shares of capital and labour intensive products in import and export are suggesting a picture that seems to suit with what one can expect from a labour abundant growing economy. Increased capital accumulation and technological progress may be allowing India, albeit slowly, to reduce its dependence on import for capital intensive products and at the same time enable the country to increase their share in the export basket. The increase in the import share of labour intensive products might be due to the rising wage in Indian industry, making it profitable to import certain products from other low wage countries.

[9] The increase in the export share of technology intensive products could also be due to the export of commodities assembled from the imported parts. This does not require building up of technological capability in the given field. Lall (1999), however, argues that the share of assembled products in India's export is negligible and therefore increase in export reflects improved technological mastery of the Indian industry.

To sum up, the analysis of trade openness, in terms of import and export intensity, shows that for the whole manufacturing industry it has increased during the period considered. Industry-wise analysis reveals that majority of them experienced an increase in the import and export intensity and there exists significant differences in the extent of increase across industries. The analysis of the structure of trade, in terms of import and export shares of technology intensive, capital intensive and labour intensive products, shows that it is changing over time. This might be reflecting the factors such as gradual development of comparative advantage in certain industries and changing relative factors prices. The increase in the trade openness with significant differences across industries as well as the changing structure may be suggesting that the influence of trade can vary from industry to industry, pointing towards a possible effect of trade on the structure of Indian manufacturing industry. Against this background, the next section examines the effect of trade on the structure of the manufacturing industry.

2. 3 Analysis of Structural Change

As we have mentioned in the theoretical section, by the term structural change we mean change in the shares of various sectors/industries in total manufacturing output. In the structural change analysis, we decompose change in the share of a sector/industry into its three proximate sources, namely shift in domestic demand, export and import. Change in share accounted by import and export together is attributed to international trade. Domestic demand includes both final consumption demand and intermediate demand including inventories. The methodology of Chenery, Robinson and Syrquin (1986) as used in Moreira and Correa (1998) is employed to decompose the share change into three sources. This is explained below.

Let,

$$Y_{it} = D_{it} + X_{it} - M_{it} \qquad (2.1)$$

Where,

Y_{it} is the output of the i^{th} industry in year t,

X_{it} is the export of i^{th} industry's products in year t,

M_{it} is the import of i^{th} industry's products in year t,

D_{it} is the domestic demand for the i^{th} industry's product in year t,

If there are n industries, the equation similar (2.1) for the whole manufacturing industry can be written as follows,

$$Y_t = D_t + X_t - M_t \tag{2.1a}$$

Where,

$$Y_t = \sum_{i=1}^{n} Y_{it} \; , \; X_t = \sum_{i=1}^{n} X_{it} \, , \; M_t = \sum_{i=1}^{n} M_{it} \, , \; D_t = \sum_{i=1}^{n} D_{it}$$

We begin by decomposing the output growth rate of i^{th} industry between t and t-k years. That is

$$\frac{Y_{it} - Y_{it-k}}{Y_{it-k}} = \frac{(D_{it} - D_{it-k}) + (X_{it} - X_{it-k}) - (M_{it} - M_{it-k})}{Y_{it-k}} \tag{2.2}$$

$$\frac{\Delta Y_{it}}{Y_{it-k}} = \frac{\Delta D_{it}}{Y_{it-k}} + \frac{\Delta X_{it}}{Y_{it-k}} - \frac{\Delta M_{it}}{Y_{it-k}} \tag{2.2a}$$

Similar equation for the whole manufacturing industry is,

$$\frac{\Delta Y_t}{Y_{t-k}} = \frac{\Delta D_t}{Y_{t-k}} + \frac{\Delta X_t}{Y_{t-k}} + \frac{\Delta M_t}{Y_{t-k}} \tag{2.3}$$

Subtracting (2.3) from (2.2a),

$$\left(\frac{\Delta Y_{it}}{Y_{it-k}} - \frac{\Delta Y_t}{Y_{t-k}}\right) = \left(\frac{\Delta D_{it}}{Y_{it-k}} - \frac{\Delta D_t}{Y_{t-k}}\right) + \left(\frac{\Delta X_{it}}{Y_{it}} - \frac{\Delta X_t}{Y_{t-k}}\right) - \left(\frac{\Delta M_{it}}{Y_{it-k}} - \frac{\Delta M_t}{Y_{t-k}}\right) \tag{2.4}$$

$$\Delta \phi_i = \left(\frac{\Delta D_{it}}{Y_{it-k}} - \frac{\Delta D_t}{Y_{t-k}}\right) + \left(\frac{\Delta X_{it}}{Y_{it-k}} - \frac{\Delta X_t}{Y_{t-k}}\right) - \left(\frac{\Delta M_{it}}{Y_{it-k}} - \frac{\Delta M_t}{Y_{t-k}}\right) \tag{2.5}$$

Where $\Delta\phi_i$ is the change in the share of i^{th} industry between t and t-k years. Multiplying (2.5) by hundred on both sides gives percentage change in share. Equation (2.5) decomposes the change in share into three main sources, namely shift in domestic demand (first term of RHS), relative export coefficient (second term) and relative import coefficient (third term). A positive value for the first term implies that change in domestic demand faced by the i^{th} industry as a proportion of its initial year output is higher than that of the whole manufacturing industry, making a positive contribution to its share change. Likewise, a positive second term suggests that increase in the sector i's export coefficient is higher than that of the whole manufacturing, indicating a share expanding effect of export.

In this context, it is important to keep in mind some limitations of this analysis. The equation (2.5) decomposes the observed change in share into three proximate determinants. It does not tell us anything about the ultimate source of share change. For instance, a reduction in the cost of production due to increasing returns to scale made possible by large domestic demand might enable an industry to expand its export and thereby increase its share beyond that contributed by the domestic demand. Here, domestic demand expansion is the basic cause behind output share increase. The above decomposition formula does not tell us anything about this kind of internal dynamics and to capture this one needs a structural model. Further, we are not considering the indirect influence of trade on industries through backward linkages.

2.3.1 Data

The structural change analysis has been conducted between two time points, 1989-90 and 1994-95. The Indian industry was operating in a more restricted trade policy regime during the first time point compared to the second[10]. This contrast in the trade policy regime between two time points may allow us to get a clear picture of how trade openness affected the structure of the manufacturing industry. Further, selection of these years is also determined by the availability of output data of the unorganised manufacturing sector, which are necessary to implement the structural change equation. Empirical implementation of the decomposition formula (2.5) needs data on output, import and export at disaggregated industry level for the two time points. The output, we use, is the total output of the manufacturing industry, which is the sum of registered and unregistered manufacturing industry output. The registered manufacturing output data are obtained from ASI and that of unorganised manufacturing from 45th and 51st round sample surveys of the unorganised manufacturing sector conducted by National Sample Survey Organisation (NSSO). Import and export data are the same that we have used for computing import and export intensities.

Since the objective is to examine whether trade expanded or contracted the shares of sectors having more potential to generate technological progress, we need first to identify these sectors. In our framework, these sectors are those where learning by doing, R&D investment and investment in plant and machinery are likely to take place more intensively. Two sets of such industries, namely technology intensive and capital intensive industries, have already been compiled in the previous section. In addition to these, industries are also classified on the basis of their R&D intensity. The classification on the basis of different technological criterion not only gives better insights into the pattern of structural change, but also helps us to check whether the results are sensitive to the classification scheme adopted.

[10] Although late 1980s witnessed liberalisation of some of the non-tariff barriers on import, this was accompanied by higher import tariff, nullifying the reduction of non-tariff barriers, see Ahluwalia (1996).

Industries are classified on the basis of their R&D intensity into three groups, namely high R&D intensive, medium R&D intensive and low R&D intensive, using their average R&D intensity for the period 1990-91 to 1996-97. Industry-wise R&D data are obtained from various issues of the *Research and Development Statistics*, published by the Department of Science and Technology, Government of India. This classification scheme is presented in Table 2A.4 in the appendix to this chapter[11]. Here it should be noted that there exists overlapping between technology intensive sector and R&D intensive sectors, particularly high and medium R&D intensive sectors. This one can expect because, as we have already mentioned, most of the high technology industries are also making investment in R&D.

2.3.2 Results

Results of the structural change analysis are presented in Table 2.5 and Table 2.6. Industry-wise results are presented in Table 2.5, in which industries are listed in the descending order of share change. The results show that out of the 29 industries 18 increased their share. The major gainers are *Photographic and optical goods, Office computing and accounting machinery, Synthetic resins, Plastic materials and man made fibres, Professional and scientific measuring and controlling equipment* and *Drugs and medicine*. In all these industries, output share increased due to domestic demand expansion. Further, as shown in the last column, in these industries, except in drugs and medicine, trade negatively contributed to the share change and domestic demand gains were more than offsetting these losses.

Industries that suffered losses in their shares include *Electrical appliances and household goods, Wood products, Soap and cleaning preparations cosmetics and other toilet preparations, Glass and glass products* and *Watches and clocks*. In these industries the loss is mainly explained by the shift in domestic demand. One point to note is that industries, whose shares have been favourably affected by trade, include *Drugs and medicine, Rubber and plastic products, Leather and leather products, Textiles products and Watches and clocks*. In these industries, India has comparative advantage either due to existing weak intellectual property regime as in the case of drugs and

[11]In the Research and Development Statistics, the whole manufacturing industry is classified into 36 industry groups and R&D data are available for these 36 industries. For classifying the industries on the basis of R&D intensity, we have reclassified four-digit ISIC data into this 36 industry group.

Table 2.5 Structural Change by Industry, 1989-90 and 1994-95

No	Industry	Share change (%) A	Sources of structural change (%) Domestic Demand B	Export C	Import D	Trade (C-D)
1	Photographic and optical goods	360.9	493.5	-33.3	99.3	-132.6
2	Office computing and accounting machinery	91.3	106.1	5.5	20.3	-14.8
3	Synthetic resins, plastic materials and manmade fibbers except glass	90.4	120.4	2.9	32.9	-30.0
4	Professional and scientific measuring and controlling equipment.	65.0	129.6	-3.0	61.6	-64.6
5	Drugs and medicines	56.4	47.6	2.1	-6.8	8.8
6	Transport equipment	27.7	31.6	-5.1	-1.3	-3.9
7	Radio, television and communication equipment and apparatus	23.8	38.1	-11.2	3.1	-14.4
8	Fertilisers and pesticides	19.4	33.3	-15.9	-2.0	-13.9
9	Cement, lime and plaster	15.8	12.1	-12.7	-16.5	3.8
10	Rubber and plastic products	13.3	4.2	-2.4	-11.6	9.2
11	Beverages and tobacco	12.4	13.9	-17.5	-16.0	-1.5
12	Electrical industrial machinery and apparatus	12.3	24.1	-14.2	-2.5	-11.7
13	Leather and leather products	10.9	-54.9	57.1	-8.8	65.8
14	Basic industrial chemicals and chemical products	9.9	48.7	19.4	58.3	-38.9
15	Agricultural machinery and equipment	9.6	12.6	-16.5	-13.6	-2.9
16	Pottery, china and earthenware, etc.	5.9	-1.1	-6.7	-13.7	7.0
17	Metal products	2.1	6.9	-3.5	1.4	-4.9
18	Textiles products	1.5	-36.6	25.4	-12.7	38.1
19	Paper and paper products	-4.7	4.8	-15.4	-5.9	-9.5
20	Iron, steel and non-ferrous metal basic industries	-7.1	-1.5	-11.3	-5.8	-5.6
21	Food products	-12.5	-13.3	-8.8	-9.5	0.7
22	Products of petroleum and coal	-12.6	27.9	-14.6	25.9	-40.5
23	Paints, varnishes and lacquers	-19.2	-14.1	-19.3	-14.1	-5.2
24	Industrial machinery and other machinery	-23.4	14.5	-11.6	26.3	-37.9
25	Watches and clocks	-45.9	-60.7	-3.0	-17.8	14.8
26	Glass and glass products	-46.7	-51.4	-0.9	-5.7	4.8
27	Soaps, cleaning, preparations, perfumes, Cosmetics and other toilet preparations	-55.2	-55.3	-15.0	-15.1	0.1
28	Wood products	-74.9	-73.4	-17.1	-15.6	-1.5
29	Electrical appliances and household goods	-101.3	-100.2	-15.5	-14.4	-1.1

Note: A =B+C-D.

medicine or because of resource advantage as in textiles, leather products and rubber and plastic products[12].

Table 2.6 Structural Change, by Technology and Factor Intensity, 1989-90 and 1994-95

Sector	Share change (%) A	Sources of structural change (%)			
		Domestic demand B	Export C	Import D	Trade (C-D)
Technology Intensive	19.9	37.3	-5.6	11.7	-17.4
Capital Intensive	9.1	23.1	-8.0	6.0	-14.0
Labour Intensive	-34.5	-48.1	10.9	-2.7	13.6
High R&D intensive	12.4	22.4	-5.7	4.3	-10.0
Medium R&D intensive	15.4	30.2	-6.6	8.2	-14.8
Low R&D Intensive	-7.7	-14.6	3.4	-3.6	7.0

Note: A = B + C – D

The results presented in Table 2.6 show that technology intensive sector increased its share and this can be fully attributed to domestic demand expansion. The share of this sector would have been increased by 37.3 per cent if trade had a neutral effect. Trade reduced its share by 17.4 per cent, almost by half of what would have been its share if trade had a neutral effect and both import and export moved unfavourably. Similar is the case of capital intensive sector, which increased its share by 9.1 per cent. This share increase was also wholly due to the increased domestic demand and in this case also trade had a negative contribution. The case of labour intensive industries is entirely different from that of the technology and capital intensive sectors. Labour intensive industries suffered a decline of 34.5 per cent in its share. Although trade had a share enhancing effect in this case, with the positive contribution of export higher than that of import, the shift in the domestic demand reduced its observed share. On the basis of conventional trade theory, this effect of trade is quite plausible in a country like India that has abundant labour force. High and medium R&D intensive industries increased their shares. These share changes are fully explained by the domestic demand and trade in this case also contributed negatively. The low R&D intensive sector suffered a reduction in share and the contribution of trade is this case, however, was positive, resulted in a lower observed decline.

[12] One point to note is that in drugs and medicine and watches and clocks, relative decline in import accounts for a larger part of the positive contribution of trade and in textiles, leather and leather products and rubber and plastic products, expansion in exports accounts for the major part of the positive effect of trade.

The results of the structural change analysis shows that trade had an expansionary effect on the labour and low R&D intensive sectors and contractionary effect on technology intensive sectors. These results suit with what one can expect from a developing country with abundant labour force. Nambiar et al. (1999) also reports closely related findings. Using Input-Output Transaction Table, Nambiar et al. examined the effect of trade on value added and employment and found that trade caused shrinking the value added and employment in capital and technology intensive industries. The present study, however, shows that although trade had a negative effect on growth generating sectors, it was not in a position to reduce the observed shares of these sectors.

Despite the negative effect of trade, these sectors were able to increase their shares because of the big and growing domestic demand. In these sectors, the domestic demand expansion, which more than offset the negative effect of trade, acted as a cushion against adverse resource allocation effect of trade. One of the assumptions of the theoretical models analysing the issue of trade-induced resource reallocation and its growth implications is the small economy assumption. Only in an under developed small economy, one can expect a larger share of domestic demand for the products of technology and R&D intensive industries is being met by import and thereby turn the domestic specialisation pattern to industries having lower prospects for technological progress. In addition to this, the already attained level of technological capability, although not very high, along with low wage advantage may have helped these industries to increase their shares. The analysis, however, shows that domestic factors, specifically the domestic demand, can play an important role in determining the extent of effect of trade on the structure of the manufacturing industry and thereby on its prospects of technological progress.

2. 4 Summary and Conclusion

This chapter examined the effect of trade on the structure of the manufacturing industry and its implications for technological progress. The empirical analysis looked at the trends in the extent of trade openness of the manufacturing industry and the structure of trade in manufactures. Trade openness is measured using import and export intensity. The results show that import and export intensity of the whole manufacturing industry increased over time. Industry-wise analysis reveals that majority of them experienced an increase in the import and export intensity, with significant inter-industry variation. The trends in the structure of trade, measured in terms of the shares of technology, labour and capital intensive products in import and export, indicate a changing structure. The analysis of trade openness and structure of trade, thus, signals a possible effect of trade on the structure of the manufacturing industry.

In the analysis of the effect of trade on the structure of the manufacturing industry, we have examined whether trade has expanded or contracted the shares of sectors having higher potential to generate technological progress by decomposing the change in the shares of these sectors into three sources, namely shift in domestic demand, export and import. The sum of the last two sources is attributed to trade. The results show that trade had a contractionary influence on the shares of these sectors and thereby had a negative effect on the prospects of technological progress. These sectors, however, were able to increase their shares in the total manufacturing output. This is due to the expansionary effect of domestic demand that was more than offsetting the adverse effect of trade. Thus, the results show that big and growing domestic demand acted as a constraint on the ability of trade to displace the growth generating sectors of the manufacturing industry.

As we have found in the previous chapter, changing the specialisation pattern is one of the channels through which trade can affect the prospects of technological progress. Another way it can affect the rate of technological progress is by facilitating diffusion of technology from the advanced trade partner countries. The extent of benefit through this channel, however, depends on the capability of the domestic industry to absorb foreign technology. In the next chapter, we shall examine this aspect of trade and technological progress.

Appendix

A2.1 Note on Trade database

This note provides only a very brief description of the *Trade and Production Database* compiled by the World Bank and further details on it are available from Nicita and Olarreaga (2001). This database merges trade, production and tariff data available from different sources into a common classification: the International Standard Industrial Classification (ISIC), rev.2. Data availability varies, but it potentially covers 67 developing and developed countries over the period 1976-1999.

The source of trade data in this database is the United Nations Statistical Department, which collects data from individual countries and reports them in the Commodity Trade Statistics (COMTRADE). The trade data, reported in Standard International Trade Classification (SITC), have been harmonised into International Standard Industrial Classification (ISIC) rev.2 using a concordance developed by Organisation for Economic Cooperation and Development (OECD). This concordance provides two slightly different concordance tables: one for exports and another for imports and approximates quite effectively SITC codes within the ISIC codes. These two tables do not follow a one-to-one correspondence, but matching is achieved through a method involving a series of carefully estimated weights (Nicita and Olarreaga 2001). Import and export data are reported in 3 and 4 digit of ISIC rev 2 and data on mirrored exports, i.e. exports calculated using import data reported by partner countries, are also reported. The World Bank's World Integrated Trade Solution (WITS) software was used to mirror missing trade data. Indian trade data are available from 1979-80 to 1999-2000 and reported in US $[13].

[13] The exchange rates needed to convert the import and export figures into Indian rupee are available from COMTRADE.

A2.2 Tables

Table 2A.1 Technology Intensive Industries

No	Name of Industry	4 Digit ISIC Code
1	Basic industrial chemicals	3511
2	Manufacture of fertilizers and pesticides	3512
3	Manufacture of synthetic resins, plastic materials and man made fibres except glass	3513
4	Manufacture of paints varnishes and lacquers	3521
5	Drugs and medicines	3522
6	Manufacture of chemical products not classified elsewhere	3529
7	Manufacture of engines and turbines	3821
8	Agricultural machinery and equipment	3822
9	Manufacture of metal and wood working machinery	3823
10	Special industrial machinery	3824
11	Office computing, accounting machinery including computers	3825
12	Manufacture of electrical industrial machinery and apparatus	3831
13	Manufacture of radio, television and communication equipment	3832
14	Manufacture of electrical appliances and household goods	3833
15	Shipbuilding and repairing	3841
16	Manufacture of rail road equipment	3842
17	Manufacture of motor vehicles	3843
18	Manufacture of motorcycles and bicycles	3844
19	Manufacture of air craft	3845
20	Manufacture of scientific and precision equipments	3851
21	Manufacture of Professional and scientific and measuring and controlling equipment	3851
22	Manufacture of photographic and optical goods	3852

Table2A.2 Capital Intensive Industries

No	Industry Name	4 digit ISIC Code
1	Slaughtering, preparing and preserving meat	3111
2	Soft drinks and Carbonated water industries	3134
3	Manufacture of pulp, paper and paper board	3411
4	Manufacture of basic industrial chemicals except fertilisers	3511
5	Manufacture of fertilisers and pesticides	3512
6	Manufacture of synthetic resins, plastic materials and man-made fibres	3513
7	Manufacture of paints, varnishes and lacquers	3521
8	Manufacture of drugs and medicines	3522
9	Tyre and tube industries	3551
10	Manufacture of cement, lime and plaster	3692
11	Iron and steel basic industries	3710
12	Non-ferrous metal basic industries	3720
13	Manufacture of office, computing and accounting machinery	3825
14	Manufacture of electrical apparatus and suppliers not classified elsewhere	3839
15	Manufacture of motor vehicles	3843
16	Manufacture of air craft	3845
17	Manufacture of photographic and optical goods	3852
18	Petroleum and petroleum products	3530+ 3540

Table 2A.3 Labour Intensive Industries

No.	Industry group	4 digit ISIC Code
1	Grain mill products	3116
2	Manufacture of bakery products	3117
3	Manufacture of food products n.e.c	3121
4	Tobacco manufacture	3140
5	Tanneries and leather products	3231
6	Products of leather and leather substitutes except footwear and wearing apparel	3233
7	Manufacture of foot wear except vulcanised or moulded rubber or plastic footwear	3240
8	Saw mills, planing and other wood mills	3311
9	Manufactures of wood and cane containers and small cane wares	3312
10	Manufactures of wood and cork products n.e.c	3319
11	Manufacture of furniture and fixtures, except primarily of metal	3320
12	Manufacture of chemical products n.e.c	3529
13	Manufacture of structural clay products	3691
14	Manufacture of cutlery, hand tools and general hardware	3811
15	Manufacture of electrical appliances and house hold goods	3833
16	Manufacture of rail road equipment	3842
17	Manufacture of jewellery and related articles	3901
18	Manufacture of sporting and athletic goods	3903

Table 2A.4 Classification of Industries on the basis of R&D Intensity

	Industry Group	R&D as % of STO#	Category
1	Scientific instrument	4.79	High R&D intensive sectors
2	Photographic raw film & paper	2.20	
3	Medical &surgical equipment	1.87	
4	Telecommunications	1.56	
5	Machine tools	1.46	
6	Industrial machinery	1.17	
7	Earth moving machinery	1.10	
8	Prime movers	0.94	
9	Transportation	0.91	
10	Food processing industries	0.89	
11	Glue & gelatine	0.87	
12	Ceramics	0.87	
13	Drugs and pharmaceuticals	0.79	Medium R&D Intensive sectors
14	Electronic & electrical equipment	0.71	
15	Industrial equipment	0.70	
16	Boilers &steam generating plants	0.69	
17	Chemicals (other than fertilisers)	0.68	
18	Dyestuffs	0.56	
19	Misc.mechanical engineering industries	0.54	
20	Sugar	0.54	
21	Glass	0.53	
22	Rubber goods	0.48	
23	Agricultural machinery	0.45	
24	Soaps, cosmetics, toilet preparations	0.45	
25	Timber products	0.45	Low R&D intensive sectors
26	Commercial, office household equipment	0.42	
27	Leather, leather goods and pickers	0.36	
28	Cement &gypsum	0.33	
29	Fertilizers	0.28	
30	Metallurgical industries	0.26	
31	Fermentation industries	0.25	
32	Textiles (dyed, printed processed)	0.23	
33	Paper and pulp	0.18	
34	Fuels	0.11	
35	Vegetable oil & vanaspati	0.06	
36	Math. Surveying &drawing instruments	0.00	

STO indicates Sales Turnover. The reported figures are the average R&D intensity during the period 1990-91 to 1996-97.

Table 2A.5 Concordance Table used for aggregating 4-digit industries into different groups

No	Industrial Group	4 digit ISIC rev. 2 Codes
1	Food products	3111, 3112, 3113, 3114, 3116, 3118, 3119, 3121, 3122.
2	Beverages and tobacco	3131, 3132, 3133, 3134, 3140
3	Textiles products	3211, 3212, 3213, 3214, 3215, 3219, 3219, 3220
4	Leather and leather products	3231, 3232, 3233, 3240
5	Wood Products	3311, 3312, 3319, 3320
6	Paper and paper products	3411, 3412, 3419, 3420
7	Manufacture of basic industrial chemicals except fertilisers	3511, 3529
8	Manufacture of fertilisers and pesticides	3512
9	Manufacture of synthetic resins, plastic materials and man-made fibres except glass	3513
10	Manufacture of paints, varnishes and lacquers	3521
11	Manufacture of drugs and medicines	3522
12	Manufacture of soap and cleaning, preparations, perfumes, cosmetics and other toilet preparations	3523
13	Products of petroleum and coal	3530, 3540
14	Rubber and plastic products	3551, 3559, 3560
15	Manufacture of pottery, china and earthenware, etc.	3610, 3691, 3699
16	Glass and glass products	3620
17	Manufacture of cement, lime and plaster	3692
18	Iron, steel and non ferrous metal basic industries	3710, 3720
19	Metal products	3811, 3812, 3813, 3819
20	Industrial machinery and other machinery	3821, 3823, 3824, 3829
21	Agricultural machinery and equipment	3822
22	Office computing and accounting machinery	3825
23	Electrical industrial machinery and apparatus	3831, 3839
24	Manufacture of radio, television and communication equipment and apparatus	3832
25	Manufacture of electrical appliances and household goods	3833
26	Transport equipment	3841, 3842, 3843, 3844, 3845, 3849
27	Manufacture of professional and scientific, and measuring and controlling equipment, not classified elsewhere	3851
28	Manufacture of photographic and optical goods	3852
29	Manufacture of watches and clocks	3853
	Total Manufacturing	**3111 to 3909**

3

Trade, R&D Spillovers and Productivity

This chapter analyses the contribution of trade related R&D spillovers to manufacturing productivity. International trade is considered as one of the important channels facilitating the diffusion of technological knowledge among the trading countries. The new growth theory stresses this role of trade and recognises its importance, especially for the developing countries in the context of their increased trade openness (Grossman and Helpman 1991b, Krueger 1998, Navaretti and Tarr 2000, Keller 2000 and Helpman 2004). As outlined in detail later, majority of the previous studies examining this aspect of trade are in the context of developed countries and most of them use aggregate country level data. Different from them, the present study examines the productivity effect of two types of trade related R&D spillovers separately using firm level panel data. Other aspects we examine include the intersectoral variation in the effect on productivity and the role of firms' investment in R&D, technology import and in plant and machinery in enhancing the contribution of trade related R&D spillovers. The study uses an improved estimation framework. The more open trade policy regime India has been following since 1991 and the larger share of developed OECD countries in India's trade in manufactures make Indian manufacturing industry a suitable case for a detailed analysis of these issues.

The chapter is organised in five sections. Section one provides the detailed theoretical background and also reviews previous empirical studies. Section two presents the methodological framework and discusses related econometric issues. Section three describes data and construction of variables. The fourth section discusses the results and the last one concludes the chapter.

3.1 Trade and R&D Spillovers: The Theory

By R&D spillover, we mean spillover of technological knowledge generated through R&D investment. This spillovers benefit other firms in enhancing their productivity. Analytically R&D spillovers can be classified into two types: (1) rent spillovers and (2) knowledge spillovers (Griliches 1979 and 1992 and Verspagen 1997a). Rent spillovers take place through the purchase of capital goods embodying advanced technology. Using R&D, firms in the capital goods sector introduce better machines and equipment. The purchase of these machines and equipment allows the buyer firms to enjoy the benefits of R&D in the capital goods producing sector. However, this type of spillovers and the subsequent productivity growth occur only when the purchase of R&D intensive goods takes place at a price less than their full 'quality price'. In other words, it takes place only when the innovating firms fail to appropriate the full improvement in the quality of the product in the form of higher price. It is, therefore, called 'rent spillovers'. The failure of the innovating firms to appropriate the full improvement in the quality of the product in terms of higher price might be due to the competitive pressure in the industry[1] (Griliches 1979 and 1992).

Knowledge spillovers take place when the ideas generated by one firm are utilised by other firms. The distinctive feature of knowledge spillovers compared to rent spillovers is that it is not tied to the purchase of any input whose price undervalues its quality. Several channels can facilitate knowledge spillovers among firms. These include personal interaction, familiarity with technologically superior products, information about patents[2], publication in scientific journals, participation in conferences and pure imitation. As we have explained in chapter one, knowledge spillovers arise due to its two important characteristics, namely non-rivalry and partial excludability. Non-rivalry implies that same knowledge can be used in different applications as well as in different locations at the same time and partial excludability means originators of an idea may have difficulty in extracting payments for its use from other users. Firms usually patent the output of their R&D activity and thereby monopolise the production of innovative products or use of innovative processes. However, patenting does not prevent other firms from using the knowledge generated through R&D for further research in that line to improve their product or process. In other words, firms can learn from the innovations made by other firms without exactly copying the innovative product (Romer 1990a). Further, there always exists some knowledge that are either not patented or their patent protection expired. Firms can directly make use of this knowledge.

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[1] Study by Mansfield et al. (1977) of seventeen technological innovations by the U.S. companies revealed that, on average, nearly half of the net benefits from new products and processes were appropriated by innovators, with the rest accruing to the consumers and other entities.

[2] To quote Scherer (1999, p.40) "Companies study the patents and products of rivals and are spurred to improve on them or invent around them."

Trade can facilitate both types of spillovers among the trading partners, especially from the R&D intensive countries to developing countries. Import of capital goods by the developing country producers from the research intensive countries can transfer the benefits of R&D. This is modelled in the endogenous growth model of Grossman and Helpman (1991a). In this, productivity of the final goods production sector increases with the number of varieties of intermediate goods available and R&D is directed to increase the variety of intermediate goods. In this model, trade allows firms to have access to more variety of intermediate commodities than available on the domestic market[3].

Trade can stimulate knowledge spillovers by facilitating the interaction of developing country producers with developed country producers, buyers and products (Grossman and Helpman 1991a and 1991b, Xie 1999, Saggi and Pack 1999 and Connolly 2003). For instance, import of final manufactured products from the developed to developing countries allows the latter country producers to get familiar with technologically superior products[4]. This familiarity gives them useful insights and ideas to improve their products. Further, competition from the import of technologically advanced products may well compel the domestic producers to incorporate qualities of these products, so that they can withstand foreign competition.

Like imports, exports to technological leader countries can also facilitate diffusion of ideas. Exporting gives a chance for the developing country firms to interact with their foreign buyers and learn about new ways to improve the product and production process[5]. Commercial success of firms importing foreign products depends on the quality and price of these products. Importers in developed countries, therefore, usually inform foreign producers about new technology or possible alternations to the product to make it meet the demand in a better way. Further, to sustain exports to developed countries, firms have to keep up with the technological progress taking place in the respective product line in their

[3] Eaton and Kortum (2001) shows that high R&D intensive countries are also the major producers and net exporters of capital equipment in the world and the use of imported capital goods and equipment is a significant source of productivity growth in developing countries. They also show that there exists high positive correlation between share of business sector R&D in GDP and the share of equipment production in GDP, indicating that most R&D intensive countries are also the major producers of equipment.

[4] Frantzen (2000) and Connolly (2003) emphasised the imitation stimulating effect of final goods import.

[5] The case studies by Eagan and Mody (1992) and Schmitz and Knorringa (2000) show that foreign purchasers are an important source of technological information for the developing country producers. For a theoretical exposition of technological externalities through exports, see Saggi and Pack (1999).

export markets. Hence, exporting can have the effect of directing the producers' global search for knowledge to countries to which they export.

It is pointed out that the extent of knowledge spillovers through trade between any two countries depends on the intensity of their commercial interaction, which in turn increases with the volume of bilateral trade. Grossman and Helpman (1991a, p.166-7) brings out this point more clearly.

> It is plausible to suppose that foreign contribution to the local knowledge stock increases with the number of commercial interactions between domestic and foreign agents. That is, we may assume that international trade in tangible commodities facilitates the exchange of intangible ideas...It seems reasonable to assume therefore that the extent of the spillovers between any two countries increase with the volume of their bilateral trade.

It has been highlighted, however, in the literature that R&D spillover is not a passive process, it is an active process in the sense that serious efforts on the part of the firm are necessary for its efficient absorption and assimilation. These efforts can take many forms like investment in R&D and plant and machinery embodying better technology and employment of skilled labours (Teitel 1984 and Cohen; Levinthal 1989 and Keller 1996). For instance, imported machinery containing new technology may help firms to absorb knowledge spillovers. Xie (1999) argues that trade related R&D spillovers can have higher productivity effect in a country that has lower productivity gap with the developed countries. A narrow productivity gap implies higher capability to absorb R&D spillovers. Related to this, Chong and Louis (2002) points out that in developing countries *knowledge spillovers* could be mainly confined to the medium and low technology industries. High technology industries could not gain from knowledge spillovers because of the higher sophistication and tacitness of knowledge in these industries. This signals the possibility of inter-sectoral variation in the effect of R&D spillovers. Let us examine the empirical evidence on the role of trade in facilitating R&D spillovers.

A number of studies examined the role of trade in facilitating R&D spillovers. Table 3.1 presents the details of some of the selected previous studies. It shows that majority of the studies are in the context of OECD developed countries and most of them used aggregate country level data[6]. We have already noted in chapter one that aggregate

[6] Study by Lichtenberg and Potterie (1998) re-examined Coe and Helpman (1995) result by changing the weighting scheme and correcting the indexation bias in their study. This corrected result also confirms the result of Coe and Helpman (1995). Keller (1998) re-examined the study of Coe and Helpman (1995) using random weights, rather than actual trade weights and showed that random weight also perform like trade weights.

country level studies suffer form the dubious quality of data. Studies examining this issue in the context of developing countries are also either use country level data or are case studies confined to a particular industry.

Table 3.1 Summary of Previous studies

Study	Data	Research Issue	Major findings
Eagan and Mody (1992)	Case Study of Indian Bicycle industry	Role of bicycle importers in transferring technological knowledge to producers.	Importers are a major source of information to the bicycle producers in India.
Coe and Helpman (1995)	21 OECD countries plus Israel - Country level data	The role of import in R&D spillovers across countries	Significant effect of import related R&D spillovers on productivity.
Sjoholm (1996)	Firm level data from Swedish industry	Role of trade flows in knowledge spillovers identified as the references in Swedish patents	Knowledge flows are significantly related to trade flows
Coe et al. (1997)	Data of 77 developing countries and 22 developed countries	The role of import in facilitating R&D spillovers from developed to developing countries	Significant effect of import related R&D spillovers on productivity in developing countries.
Xu and Wang (1999)	OECD country level data	Role of import, particularly of capital goods in R&D spillovers	Capital goods import is facilitating technology spillovers.
Keller (2000)	Industry level data of six industries from eight OECD countries	Role of capital goods import in R&D spillovers	Significant productivity effect of R&D spillovers facilitated by capital goods import.
Schmitz and Knorringa (2000)	Case study of foot wear industry	Role of developed country (DC) importers in transferring technical information to developing country producers	Developing country producers are getting technical information from the buyers in DCs.
Funk (2001)	OECD country level data	Role of both import and export in R&D spillovers and its effect on productivity	Export is robust in explaining the trade related R&D spillovers.

Case studies usually concentrate on successful or obvious cases and therefore, their conclusions cannot be generalised. Further, some other important aspects are not addressed in earlier studies. These neglected aspects include: (1) inter-sectoral variation in the contribution of spillovers, (2) relationship between rent and knowledge spillovers and (3) the role of firms' investment in R&D, disembodied technology import and in plant machinery in enhancing the contribution of spillovers. Analyses of these aspects are necessary to have better insights into the issue of productivity effect of trade related

R&D spillovers[7]. This chapter, therefore, focuses on the empirical analysis of these issues.

3.2 R&D Spillovers and Productivity: Methodology

The literature attempting to assess the contribution of R&D to industrial productivity includes two approaches. The first is the case study approach. In this, the introduction of an innovation, its diffusion and growth effects are analysed in detail. This approach enables us to get deeper insights into the process of technology diffusion as well as the various mechanisms involved in. This methodology, however, requires a lot of information about various technical aspects of the innovation and hence is more time and resource intensive. Further, as we have already mentioned above, case studies are always subject to the attack as not being representative, since they tend to concentrate on prominent and successful innovations and fields (Griliches 1979).

The second method is the econometric production function approach. This methodology overcome the problems of case studies by abandoning the interesting details of specific events and concentrating instead on total output as a function of past investments in R&D. While this method is more general than case study approach, it also suffers from all the problems that are beset with the attempts to infer causality from behavioural data on the basis of correlation techniques. Nevertheless, currently it is the only available general way of trying to answer the question about the contribution of R&D to growth (Griliches 1979).

This study uses production function method. This can be explained as follows. A firm is assumed to produce output Q using a bundle of traditional inputs **X,** such as capital and labour, subject to the state of technology **T**. Improvement in the state of technology increases the productivity of traditional factors of production. We assume that the firm can increase its state of technological knowledge through R&D, purchase of capital goods embodying better technology from foreign and domestic sources and import of disembodied technology through licensing. The import of disembodied

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[7] While concluding the simulation evidence from the growth models Lucas (2002, p.9) writes:

> the evidence on trade and growth suggests that the rate of diffusion of technology depends on economic interactions - on trade. To understand how this connection works, and thus to understand the extreme variability of development experience and the policies that lead to successful development, we need to get deeper into the nature of knowledge spillovers.

Here Lucas use the term knowledge spillovers in a broad sense and include both rent and knowledge spillovers.

technology involves purchase of designs, blue prints and technical assistance by paying lumpsum amount or royalty[8].

As we have stated above, firms can purchase capital goods containing recent technology. With the available data, however, it is not possible to determine how much of new technology is contained in a piece of equipment either imported or purchased from domestic producers. A simplification made by many researchers, and the one adopted here also, is to assume that recently purchased capital goods embody newer and better technology than older capital goods (Baily et al.1992 and Bahk and Gort 1993). The embodiment effect is then captured using the share of recent investments in capital goods in the total capital stock[9]. This study distinguishes two types of capital stock made up of recent investment in plant and machinery[10]. The first type is made up of capital goods purchased form domestic sources and second is constructed form investment in imported capital goods. Imported capital goods may contain better technology than domestically produced ones. We, therefore, hypothesize that the effect of these two types of capital goods are different and hence treat them as two separate arguments in the production function. In fact, one of our objective is to examine whether the imported capital goods are more productive than those purchased from domestic sources.

We use a Cobb-Douglas production function that includes technology variables of the firm besides the conventional inputs. For the i^{th} firm in t^{th} year, this can be written as given below,

$$q_{it} = b_0 + b_c c_{it} + b_l l_{it} + b_m m_{it} + b_e e_{it} + b_{sdcg} sdcg_{it} + b_{sicg} sicg_{it} + b_{pk} pk_{it} + b_k k_{it} + b_{sk} sk_{it} + \varepsilon_{it} \qquad (3.1)$$

Where[11]

[8] For a study on the determinants of the probability of foreign technology licensing, choice of foreign partner, etc in Indian context see Evenson and Joseph (1997). It is to be noted that some of the technology transfer in this way is related to foreign direct investment (FDI) (Marjit and Singh 1995).

[9] This approach is adopted in Bregman et al. (1991), Brendt and Morrison (1995) and Hasan (2002).

[10] It is to be noted that if firms maximise profits, producers would allocate investment between various types of capital goods such that *ex ante* rates of return are equal. In such a situation, there is no reason to expect that the composition of firm's capital stock will have an effect on its productivity. On the other hand, if, *ex post*, the marginal product new machinery (or imported) per rupee of service is larger than that of the other capital, the effect of a change in the ratio of the stock of new capital (or imported) to total capital stock will have a positive effect on productivity (Brendt and Morrison 1995).

[11] Since some technology variables can take zero value, 1 has been added to them as in Raut (1995) and Hasan (2002) to avoid the problem of having to take log of zero values.

q	log of gross output of the firm;
c	log of capital sock;
l	log of labour hours;
m	log of raw materials consumed;
e	log of energy consumed;
$sdcg$	log share of recent investments in capital goods purchased from domestic sources in the total capital stock ;
$sicg$	log share of recently imported capital goods in the total capital stock;
pk	log of disembodied technology import stock;
k	log of R&D capital stock;
sk	log of trade related knowledge spillover stock; and
ε	is the error term.

3.2.1 Issues in Estimation

Estimation of a production function is one of the widely discussed issues in the applied econometric literature (see Griliches and Mairesse 1998). One of the major estimation problems is the simultaneity in the input and output decision making, which makes OLS estimates inconsistent. Following paragraphs briefly discuss the problem of simultaneity, various methods suggested in the literature to overcome it and our approach to the problem.

The error term, ε_{it}, in (3.1) can be decomposed into two parts, $\varepsilon_{it} = \omega_{it} + \eta_{it}$. Where ω_{it} is the firm specific productivity differences not accounted by the explanatory variables and η_{it} is a pure random error term. The term ω_{it} includes all the firm specific differences in productivity caused by factors like technological knowledge not captured by the right hand side variables, accumulated experience of the firm, managerial ability, and so on. The major difference between ω_{it} and η_{it} is that the former is a state variable (hence observable to the firm and not to the econometrician) and therefore influences firm's input demand, while the latter has not such effects. A profit maximising firm, having higher productivity, tends to demand more inputs. This correlation between input choice and unobserved productivity of the firm makes OLS estimates inconsistent (Marchak and Andrews 1944 and Griliches and Mairesse 1998). When there are more than two inputs, including quasi-fixed and variable inputs, the direction of bias in the OLS estimates is difficult to trace analytically. However, in a two-input setting, where one input is variable, say labour (l), and the second is quasi-fixed, say capital (c), the direction of bias can be traced as follows.

Let the two input production function specified is as follows,

$$q_{it} = b_0 + b_l l_{it} + b_c c_{it} + \varepsilon_{it}$$

It can be shown that OLS estimate of labour coefficient is

$$\hat{b}_l = b_l + \frac{\hat{\sigma}_{c,c}\hat{\sigma}_{l,\varepsilon} - \hat{\sigma}_{l,c}\hat{\sigma}_{c,\varepsilon}}{\hat{\sigma}_{l,l}\sigma_{c,c} - \hat{\sigma}^2_{l,c}} \tag{3.2}$$

and of capital coefficient is

$$\hat{b}_c = b_c + \frac{\hat{\sigma}_{l,l}\hat{\sigma}_{c,\varepsilon} - \hat{\sigma}_{l,c}\hat{\sigma}_{l,\varepsilon}}{\hat{\sigma}_{l,l}\hat{\sigma}_{c,c} - \hat{\sigma}^2_{l,c}} \tag{3.3}$$

Where $\hat{\sigma}_{a,b}$, in general, denotes the sample covariance between the variables a and b. In the above expressions (3.2) and (3.3), denominator is always positive (by Cauchy-Schwarz inequality); so the sign of the bias is determined by the numerator. One probable situation with most real data can be the case in which capital and labour are positively correlated and both are also correlated with the productivity shock, but labour's correlation is significantly stronger because of its greater flexibility. In this case, the above expressions suggest that $\hat{b}_l$ will tend to be over estimated and $\hat{b}_c$ will be underestimated. When there are more than two inputs, including quasi-fixed and more variable inputs, OLS estimation would lead to upward bias in the coefficient of more flexible inputs and downward bias in the coefficient of less flexible input (see Levinsohn and Petrin 2003).

Since the present study uses panel data, let us examine the various ways of tackling this problem in such datasets.

(i) Within method: In this method, production function is estimated using variables of a firm expressed as deviations from its time mean (within transformation of the data). The basic assumption of this approach is that the unobserved productivity component of the error term is fixed over time (that is ω_{it} is assumed to be ω_i), so transformation of variables removes it from the estimating equation. If this assumption is not valid, the within transformation, as we shall see in this study, not only worsen the simultaneity problem but also exacerbate other problems in the data such as measurement errors (Chamberlain 1982 and Griliches and Mairesse 1998).

(ii) GMM-IV: In GMM instrumental variable (GMM-IV) method, variables are first differenced to remove the constant part of the ω_{it} and appropriately lagged level variables are used as instruments for the equation in differences to estimate the parameters consistently[12]. Further, under certain stationarity assumptions, past differences of the input variables can also be used as instruments for the equation in levels (Arellano and Bover 1995 and Blundell and Bond 1998). One important weakness of this method is that such internal instruments are (past levels for current differences and past differences for the current levels) likely to be quite weak. Many economic variables evolve in a random walk like fashion at the micro level and hence their growth rates (log differences) are only weakly serially correlated with levels. If the input variables are strictly random walk, there would be no power at all in their past levels as instruments for their current differences (Griliches and Mairesse 1998 and Blundell and Bond 2000).

The within and difference transformation have the drawback that they would purge a larger part of the information from the data. This would exacerbate other problems like specification and measurement errors. Empirical evidence shows that these transformations lead to severe underestimation of capital coefficient. One of the reasons for this underestimation is that these transformations reduce identifying variance in the data and increase noise-signal ratio (Griliches and Hausman 1986 and Griliches and Mairess 1998).

(iii) Olley and Pakes' Semi-parametric Method: Another innovative and promising method to solve simultaneity problem is introduced by Olley and Pakes (1996). In this approach, the unobserved productivity of the firm is proxied by a function of the observed variable that monotonically varies with firm's productivity. Olley and Pakes (1996) used investment of the firm to proxy the productivity shock. This choice is based on the solution of a structural model for the optimising firm by Pakes (1996) that (under certain conditions) optimising firms choosing to invest have investment functions that are strictly increasing in the unobserved productivity shock. This method can be explained as follows. In this discussion, for convenience, we suppress the i subscript and writing the production function in log of two inputs,

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[12] In the instrument variable approach, it is assumed that the unobserved productivity term consists of a fixed component and a transitory component. Differencing only removes fixed component and transitory component remains in the data, to which current and future inputs may respond, but not past levels of inputs. Therefore past levels are valid instruments.

$$q_t = b_0 + b_l l_t + b_c c_t + \omega_t + \eta_t \quad (3.4)$$

Inputs are divided into two: freely variable labour (l_t) and the state variable capital (c_t). ε_t is assumed to be additively separable in transmitted component (ω_t) and i.i.d. component (η_t). The major difference between ω_t and η_t, as we have noted above, is that former is a state variable, and hence influences the firm's decision rules, while the latter has no such effects.

Olley and Pakes write investment i as a function of the two state variables in their model,

$$i_t = i_t(\omega_t, c_t)$$

Where ω_t stochastically increasing in past values and investment is monotonically increasing in ω_t. Productivity is stochastically increasing in past values implies that better productivity shock today means better shock in future[13]. Monotonicity means that, given the level of capital, investment is strictly increasing in productivity. The monotonicity condition allows inverting the function $i_t(\omega_t, c_t)$ to express ω_t as a function of investment and capital, that is $\omega_t = \omega_t(i_t, c_t)$. Rewriting the production function (3.4) as follows

$$q_t = b_l l_t + \phi_t(i_t, c_t) + \eta_t \quad (3.5)$$

Where

$$\phi_t(i_t, c_t) = b_0 + b_c c_t + \omega(i_t, c_t)$$

The equation (3.5) is a partially linear model that can be estimated using semi-parametric regression methods. For now note that, by assumption, the error term in the model (3.5), η_t, is uncorrelated with the labour input. Estimation is done in two stages. In the first stage, one can estimate the coefficient of labour input by including $\phi_t(.)$ in the estimation routine[14]. For this, take the expectation of equation (3.5) conditional on i_t and c_t. This is given by

$$E[q_t \mid i_t, c_t] = b_l E[l_t \mid i_t, c_t] + \phi_t(i_t, c_t) \quad (3.6)$$

Because (i) η_t is mean independent of i_t and c_t, and (ii) $E[\phi_t(i_t, c_t) \mid i_t, c_t] = \phi_t(i_t, c_t)$. Subtracting equation (3.6) from (3.5) yields

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[13] The assumption that firm specific productivity shock is stochastically increasing in past values is consistent with many models of firm dynamics like Hopenhayn (1992).

[14] For an excellent introduction into the semi-parametric regression models see Pagan and Ullah (1999).

$$q_t - E[q_t \mid i_t, c_t] = b_l(l_t - E[l_t \mid i_t, c_t] + \eta_t \tag{3.6a}$$

By assumption η_t is mean independent of l_t (and thus of the transformed regressor $l_t - E[l_t \mid i_t, c_t]$), so a no-intercept OLS can be used on (3.6a) to obtain consistent estimate of b_l. Since capital enters $\phi_t(.)$ in two ways, a more complete model is required to identify b_c. In the second stage, Olley and Pakes assume that ω_t follows a first-order markov process and capital does not immediately respond to ξ_t - the innovation in productivity over last period's expectation - as given by

$$\xi_t = \omega_t - E[\omega_t \mid \omega_{t-1}]$$

Defining the q_t^* as output net of labour's contribution, we can write

$$q_t^* = q_t - b_l l = b_0 + b_c c + E[\omega_t \mid \omega_{t-1}] + \eta_t^*$$

Where $\eta_t^* = \xi_t + \eta_t$. Under these assumptions and with a consistent estimate of $E[\omega_t \mid \omega_{t-1}]$, obtained using a candidate value of b_c, regressing q_t^* on c_t produces a consistent estimate of b_c (because both ξ_t and η_t are uncorrelated with c_t).

This approach of attacking the simultaneity problem has important merits and Griliches and Mairesse (1998, p.398) bring them out very clearly[15],

> Trying to proxy for unobserved ω (if it can be done right) has several advantages over the usual within estimators (or the more general Chamberlain and GMM type estimators): it does not assume that ω reduces to a fixed (over time) firm effect; it leaves more identifying variance in l and c and hence is a less costly solution to the omitted variable and/or simultaneity problem, and it should also be substantively more informative.

Levinsohn and Petrin (2003), however, show that there are cases in which investment proxy does not work and therefore unable to solve the simultaneity problem. This is because investment is a control on a state variable, namely capital and hence costly to adjust. This adjustment costs can cause problems to the estimation in a number of ways. Firms that make only intermittent investments will have their zero-investment observations truncated from the estimation routine (the monotonic condition does not hold for these observations). It is quite normal that data on manufacturing firms contain large proportion of firms having zero investment in a year.

[15] In quoting from Griliches and Mairesse (1998), we have changed the notations to conform to our notations.

While the truncation issue relates to only efficiency, non-convex adjustment costs may lead to kinks in the investment function that affect the responsiveness of investment to the productivity shock even when it is undertaken. For example, if $i_t(\omega_t, c_t)$ has some maximal level of investment for all possible outcomes of ω_t. Then $i_t(\omega_t, c_t) = \bar{i}_t(\omega_t, c_t)$ when $\omega_t \geq \bar{\omega}_t(c_t)$ for the kink point $\bar{\omega}_t(c_t)$ and the error term in (3.6a) becomes $\eta_t + (\omega_t - \bar{\omega}(c_t))$, which is correlated with l_t. On the other hand, suppose $\bar{\omega}_t$ is that component of ω_t which is known at the time of the investment decision, and that $i_t = i_t(\bar{\omega}_t, c_t)$ is monotonic in $\bar{\omega}$. Again $(\omega_t - \bar{\omega}_t)$ remains in the error term.

Levinsohn and Petrin (2003) suggests another set of proxies that are freely variable, namely intermediate inputs (materials or energy) to overcome these limitations. This can be explained as follows. Writing the log of output as a function of the log of inputs and shocks we have

$$q_t = b_0 + b_l l_t + b_c c_t + b_m m_t + \omega_t + \eta_t$$

Where m is the log of intermediate input.

The intermediate input's demand function is given as

$$m_t = m_t(\omega_t, c_t)$$

The intermediate input must be monotonic in ω_t for all (relevant) c_t to qualify as a valid proxy[16]. Assuming monotonicity holds, one can invert the intermediate demand function to obtain $\omega_t = \omega_t(m_t, c_t)$. In this setting $\phi_t(.)$ is given now as a function of the intermediate input and capital as given below.

$$\phi_t(m_t, c_t) = b_0 + b_c c_t + b_m m_t + \omega_t(m_t, c_t)$$

The equation for the second stage changes to

$$q_t^* = b_0 + b_c c_t + b_m m_t + E[\omega_t \mid \omega_{t-1}] + \eta_t^*$$

Similar to the investment proxy, for any candidate value of (b_c, b_m) we can estimate $E[\omega_t \mid \omega_{t-1}]$. As we have seen above $\eta_t^* = \xi_t + \eta_t$. While $E[c_t\eta_t^*] = 0$ is still valid for the above second stage equation, $E[m_t\eta_t^*] = 0$ does not hold because the intermediate

16 It is quite plausible to assume that intermediate input consumption is monotonically increasing in productivity shock under firm's profit maximisation behaviour. The picture we have in mind is that when the firm faces large positive productivity shock, it will increase its demand for intermediate inputs and drive down its marginal product until the value of the marginal product is equal to its price. A formal proof of this is given in Levinsohn and Petrin (2003) using a Cobb-Douglas production technology.

input is correlated with η_t^* (it responds to ξ_t). Since the firm choose m_{t-1} before either component of η_t^* is realised, it should be uncorrelated with η_t^*. And m_{t-1} should be correlated with m_t (via, for example size correlation over time due to irreversibility in capital investment and/or the persistence in ω_t), so one can use the moment condition $E[m_{t-1}\eta_t^*] = 0$ to identify the coefficient of the proxy intermediate input.

In this study, we estimate the production function given in (3.1) using Levinsohn-Petrin (LP), OLS and Within methods. This allows us to compare the estimates across different methods and thereby checks their sensitivity to simultaneity problem.

3.3 Data and Construction of Variables

3.3.1 Data

The basic database for the estimation of the model includes firm level panel data of 19 industries in International Standard Industrial Classification revision 2 (ISIC rev.2) for the period 1988-89 to 2000-2001, obtained from the Centre for Monitoring Indian Economy's (CMIE) electronic database PROWESS[17]. After removing observations having implausible values for variables in the specification, the sample consists of 17760 observations on 2101 firms[18]. The sample provides information on a number of variables that include value of output, gross and net fixed assets and their components, costs of raw materials and energy, wages and salaries, expenditure on R&D and money spend on the import of disembodied technology and capital goods.

Other data sets include: (1) industry level R&D expenditure of fifteen OECD countries for the period 1978 to 2000, obtained from the Analytical Business Enterprise Research and Development Database (ANBERD) of OECD; (2) industry level information from Annual Survey of Industries (ASI), and (3) data on the bilateral trade of India in manufactures with fifteen developed OECD countries, obtained from Trade and Production database of the World Bank. Table 3.2 lists the names of industries

[17] For more details on PROWESS data see Shanta and Raja Kumar (1999) and Veeramani (2001).
[18] The procedures adopted for the data cleaning are given in the appendix to this chapter.

included in the study[19] and Table 3.3 gives the names of the countries of trade related knowledge spillovers into Indian manufacturing industry[20].

Table 3.2 Lists of Industries covered by the Study

	Industry	ISIC rev.2 code	Short Name
1	Food, Beverages & Tobacco	31	FBT
2	Textiles, Apparel & Leather	32	TAL
3	Wood Products & Furniture	33	WPF
4	Paper, Paper products & Printing	34	PPP
5	Chemicals, excluding drugs	351+352-3522	CHE
6	Drugs and Medicine	3522	PHA
7	Petroleum Refineries and Products	353+354	PRP
8	Rubber & Plastic Products	355+356	RPP
9	Non metallic Mineral Products	36	NMP
10	Basic metals – Iron & Steel	371	BIS
11	Non ferrous Metals	372	NFM
12	Fabricated Metal Products	381	FMP
13	Non electrical Machinery	382-3825	NEM
14	Manufacture of Electrical Machinery excl. Communication equipment.	3830-3832	MEM
15	Radio, TV & Communication Equipment	3832	RTV
16	Office Accounting and Computing Machinery	3825	OAC
16	Manufacture of Motor Vehicles	3843	MMV
17	Other Transport Equipment	3842+3844+3849	OTE
18	Manufacture of Professional goods and Scientific instruments	385	MPG

Note: For this classification scheme see OECD (2000)

Table 3.3 Lists of Countries

No	Countries	No	Countries
1	Australia	9	Japan
2	Canada	10	Netherlands
3	Denmark	11	Norway
4	Finland	12	Spain
5	France	13	Sweden
6	Germany	14	United Kingdom
7	Ireland	15	United States
8	Italy		

[19] R&D statistics of OECD countries, which are needed for the study, are given in the classification presented in Table 3.2 (see OECD 2000). So we reclassified all other data (firm level data and trade data) into the industrial classification presented in the Table 3.2 for the purpose of analysis.

[20] As shown in Figure 3A.1 in the appendix to this chapter, these countries account for around 50 percent of India's trade in manufactures during the period of study.

3.3.2 Construction of variables

Output (Q): Output is measured in 1993-94 prices, using price indices obtained from the *"Index Numbers of Wholesale Prices in India, base 1993-94 = 100"* published by the Economic Adviser Ministry of Commerce and Industry, Government of India. To mitigate the discrepancy between firm level price deflator and industry level price deflator, price indices are taken at a more disaggregated level of ASI 1987 classification and not at the level of aggregation[21] presented in Table 3.2.

Raw materials (M): Raw material costs are measured in 1993-94 prices. For this we have constructed raw materials price indices for each industry (this is also at more disaggregated level) using weights obtained from the *Input-Output Transaction Table of India for 1993-94*, published by the Central Statistical Organisation (CSO) and appropriate price indices collected from *Index Numbers of Wholesale Prices in India, base 1993-94 =100.*

Capital (C): Capital stock of the firm is measured in 1993-94 prices. The database reports the Gross Fixed Asset (GFA) of the firm in historical cost. Capital stock is constructed using perpetual inventory method by taking 1995-96 as the base year. For this, we have converted the reported GFA of the base year 1995-96 into replacement cost on the basis of a revaluation factor computed using the procedure suggested in Srivastava[22] (1996). We use gross fixed asset of the firm rather than the net fixed asset. Construction of the net fixed asset needs information on the economic rate of depreciation of the capital stock, which is not available for the Indian manufacturing industry[23].

Labour (L): The labour input is measured in terms of hours. This is constructed using wage rate per hour obtained from the corresponding industrial classification of ASI and reported total wages and salaries in the firm level data. If the variation in the wage bill across firms also reflects the variation in the quality of labour they employ, our measure would also capture the quality aspect of labour input.

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[21] This deflation procedure is more appropriate in perfectly competitive market situations, where the law of one price exists. All firms, therefore, face same price. In our setting, there is always a discrepancy between the firm level price deflator and industry level price deflator. Since we do not have data on the firm level price deflator, we are not in a position to address this issue.

[22] Details of the capital stock construction are given in the appendix to this chapter.

[23] Further, there is also a theoretical reason to use the gross fixed asset rather than the net fixed asset. Dennison (1967) argues that the correct measure of capital stock falls some where between gross and net stock of capital, advocating the use of a weighted average of the two with higher weight for the gross asset as the true value is expected to be closer to it.

Energy (E): The variable energy is measured in 1993-94 prices. The reported energy cost is deflated by an energy price index. Price deflator is constructed using weights obtained from the *Input-Output Transaction Table of India for 1993-94* and appropriate price indices.

R&D Capital Stock (K): Measurement of the knowledge stock generated through R&D investment is quite difficult and involves many conceptual and measurement issues. These issues are dealt in detail in Griliches (1979). In this study, the stock of technological knowledge generated through R&D investment is approximated by the R&D capital stock[24]. It is constructed from the R&D investment flows using perpetual inventory method, assuming that R&D investment affects productivity with one year lag. R&D capital stock of i^{th} firm in year t can be written as follows.

$$K_{it} = (1-\delta)K_{it-1} + RD_{it-1}$$

Where RD is the real R&D expenditure in the year $t-1$ and δ is the rate of depreciation of technological knowledge, assumed to be 15 percent[25]. The real R&D expenditure is obtained from the reported nominal expenditure using an R&D deflator, which is a weighted average of the capital and wage deflators related to the manufacturing industry. The weights are the average shares of current and capital expenditure in the total R&D expenditure[26]. Implementation of the perpetual inventory method needs information on the initial year value of K_{it} for each firm. Since we do not have information on firms' pre sample years' R&D investment, this has been approximated in the following way. In the case of firms, which do not report any R&D expenditure in the first three years of their time series, we have assumed that they did not made any R&D investment during the pre sample years[27]. This is based on the presumption that when a firm is not reporting any R&D consecutively for three years the probability of it having previous R&D investment is very low.

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[24] Previous studies using this approach include, among others, Hall and Mairesse (1995), Raut (1995), Hall and Mairesse (1996), Basant and Fikkert (1996), Bernstein and Mohnen (1998) and Hasan (2002).

[25] One year lag in the effect of R&D and 15 per cent depreciation rate are taken on the basis of the previous studies in the context of India (see Raut 1995, Basant and Fikkert 1996 and Hansen 2002).

[26] Here it is assumed that R&D current expenditure mainly includes wage bill of the R&D employees and capital expenditure includes the purchase of equipment required by the R&D unit. The database reports the current and capital expenditure of R&D separately.

[27] Patibandla (2004) also observes in a sample of firms belonging to twelve industries of technology intensive nature that most of the firms started R&D during the middle of 1990s.

Construction of the initial year R&D stock of firms that report R&D expenditure during the first three years of their time series requires information on the number of pre sample years of R&D investment and its growth rate. If the number of pre sample years of R&D investment is s, the rate of depreciation is δ and the growth rate of pre sample R&D investment is g, the initial year R&D stock K_{it} can be expressed as follows,

$$K_{it} = RD_{t-1} \sum_{a=0}^{s} \left(\frac{(1-\delta)}{(1+g)} \right)^{a}$$

The above method is used to compute the initial year R&D capital stock by approximating g by the growth rate of real R&D expenditure per R&D unit during the period 1985-86 to 1996-97 and RD_{t-1} by the average R&D expenditure of the firm during the first three years. We are taking an average, because it is expected to give a better estimate of the R&D expenditure pattern of the firm[28]. The number of pre sample years of R&D investment is assumed to be five[29].

Disembodied Technology Import Stock (PK)[30]: The disembodied technology import stock (PK) is constructed from the flows of technology payments using perpetual inventory method and assuming one year lag in its effect on productivity, as shown below.

$$PK_{it} = (1-\delta)PK_{it-1} + P_{it-1}$$

Where P_{it} is the real expenditure on disembodied technology import. Following the previous studies in the context of India, it is assumed that rate of depreciation δ is 15 percent. Since USA is the largest seller of technology to India, the real expenditure is obtained by deflating the nominal expenditure using US R&D deflator after making adjustment for the change in rupee-dollar exchange rate.

As in the case of R&D stock, the major problem here also is to arrive at the initial year stock of the firm. Here, we follow the procedure adopted in Basant and Fikkert (1996)[31]. This involves two basic steps. First, identification of the years in which the firm entered into a licensing agreement with a foreign firm during the period starting

[28] Hasan (2002) also takes an average of three years' R&D expenditure.

[29] Here, the assumption that age of the R&D unit is five years is arbitrary, for want of better information on this. The extent of error due to the deviation from the actual number of years can be very low and is mainly confined to the initial year R&D stock.

[30] We use PK as an abbreviation for the purchased knowledge stock.

[31] Hasan (2002) also adopted the same procedure.

from 1982-83 onwards[32]. For this we have used the publication *Foreign Collaborations in India*, published by the Council for Scientific and Industrial Research, India. In the second step, using sample information, an industry level average of the ratio of technology expenditure to sales was estimated for the initial year of the firm that imported technology in the past. These ratios were then multiplied by the firm's initial year sales to get an estimate of per year technology flows, assuming that technology flows form a collaboration agreement last for four years, as revealed in Kapur (1989, cited in Basant and Fikkert 1996). These payments are then deflated and depreciated to obtain technology import stock of the initial year.

Stock of recent investment in imported capital goods (SRICG): The reported expenditure on capital goods import is deflated using the unit value index of the imported capital goods with base 1993-94 = 100 to arrive at real investment in imported capital goods (I^M). The unit value indices are collected from the *Statistical Abstract of India*, published by the Central Statistical Organisation, New Delhi. The recent five years' investments have been used to construct the stock of recent investment in imported capital goods (SRICG), as given below[33].

$$SRICG_{it} = \sum_{s=0}^{4} I^{M}_{it-s}$$

The initial year stock of recent investment in imported capital goods (SRICG) is estimated using the following procedure. Let $SRICG_{i0}$ denotes the initial year stock of recently imported capital goods, it can be written as follows[34],

$$SRICG_{i0} = I^{IM}_{i0} \sum_{s=0}^{4} \left(\frac{1}{(1+g)} \right)^{s}$$

Where I^{IM}_{i0} is the initial year real investment in imported capital goods and g is the growth rate of real investment in imported capital goods. I^{IM}_{i0} is approximated using an average of firm's investment in imported capital goods during the first five years. An average is taken, instead of initial year value, because it is likely to be a more representative indicator

[32]We have considered the past foreign technology collaborations of firms from 1982-83 onwards to reduce the enormous amount of work involved due to the large number of firms in our sample. Since we use this information only to construct initial year stock, we hope that the extent of error entering into the variable construction by not considering the collaborations prior to 1982-83 would be very low.

[33]Hasan (2002) also uses recent five years' investment in plant and machinery as recent investment in a context similar to the present study.

[34] Hasan (2002) also adopted the same procedure to estimates initial year stock of these variables.

of firm's pattern of investment. The growth rate g is approximated by the growth rate of real capital formation through imported capital goods.

The share of the recent investment in imported capital stock (SICG) in the total capital stock is $SRICG/C$.

Stock of Recent Investment in Domestically Purchased Capital Goods (SRDCG): The stock of recent investment in the domestic capital goods is obtained from the stock of recent investment in plant and machinery after subtracting the stock of recent investment in the imported capital goods, as given below.

$$SRDCG_{it} = \sum_{s=0}^{4} I_{it-s} - SRICG_{it}$$

Where I is the real investment in plant and machinery. The initial year stock of SRDCG is estimated using a procedure similar to the estimation of the initial year SRICG by approximating 'g' by the growth rate of real investment in plant and machinery in manufacturing. The share of the capital stock made up of recent investments in capital goods purchased from domestic sources in the total capital stock (SDCG) is defined as SRDCG/C.

Trade Related Knowledge Spillover Stock (SK): The available data permit us to construct only an industry level variable to capture the trade related knowledge spillovers. Hence in what follows the subscript i denotes industry and not firm. This variable is constructed on the basis of the conceptual and methodological framework suggested in Griliches (1979). In Griliches, the extent of knowledge spillovers between firms or industries depends on the economic and technological distance between them. A lower economic and technological distance would generate more knowledge spillovers. In the present study, it is assumed that the amount of spillover knowledge that an Indian industry receives from the same industry operating in an OECD country depends on the extent of its trade interaction with that country as well as on the knowledge stock of the corresponding foreign industry. Let SK_{it} be the spillover knowledge stock received by the i^{th} Indian industry from the same industry operating in the fifteen OECD countries, we can write SK_{it} as follows,

$$SK_{it} = \sum_{j=1}^{15} w_{ijt} FK_{ijt}$$

Where FK_{ijt} is the R&D capital stock of the i^{th} industry in country j in year t and w_{ijt} is a "weighting" function, showing the extent of trade interaction of i^{th} Indian industry with country[35] j in year t. The weighting function w_{ijt} gets a higher value, if the trade interaction through export and import is higher. The extent of trade interaction of the i^{th} domestic industry with j^{th} country is measured by its trade intensity with that country. This can be explained as follows. Here, it is assumed that knowledge obtained through last years' trade interaction affects current year productivity. Let X_{it} be the total export of the i^{th} Indian industry's products to the fifteen OECD countries and M_{it} be the total import of the i^{th} industry's products from the same countries and Q_{it} is the output of the i^{th} Indian industry. The trade related knowledge spillover stock (SK) of the i^{th} industry in year t is written as follows.

$$SK_{it} = \left(\frac{(X_{it-1} + M_{it-1})}{Q_{it-1}} \right) \left(\sum_{j=1}^{15} w_{ijt-1} FK_{ijt-s} \right), \qquad s = 1,2,3.$$

Where w_{ijt-1} is defined as,

$$w_{ijt-1} = \frac{M_{ijt-1} + X_{ijt-1}}{X_{it-1} + M_{it-1}}$$

Where X_{ijt} is the export of the i^{th} industry's product to j^{th} country and M_{ijt} is the import of i^{th} industry's product from country j. The weighting function can be considered as the probability of obtaining knowledge spillovers by the i^{th} industry from the same industry in j^{th} country through trade. The weighting function is clearly in tune with the theoretical literature that we have noted above, which argue that extent of knowledge spillovers depends on the volume of bilateral trade[36]. In the computation of the knowledge spillover stock, we have normalised the w_{ijt}, so that the sum of w_{ijt} across j (trade partner countries) is equal to one. Multiplying the weighted sum with trade intensity of the industry is to adjust for the differences in the trade openness of industries[37].

[35] Obviously, by taking the same industry in both countries we kept them technologically similar. Knowledge spillovers, however, take place only if they are interacting closely through trade; w_{ij} measures the extent of this interaction.

[36] Earlier studies that used this kind of weighted aggregation of R&D stocks on the basis of economic/technological closeness, to examine the channels, include Scherer (1982), Coe and Helpman (1995), Basant and Fikkert (1996), Coe et al. (1997), Funk (2000), Frantzen (2000) and Keller (2000).

[37] This adjustment to the trade intensity of industries is necessary. This can be illustrated by the following simple example by taking the case of export only. Consider two industries, 1 and 2 and assume that each industry is producing 1000 units of output. Industry one exports 10 units of output; five units to country A and five units to country B. Industry two exports 900 units; 450 units to country A and 450 units to country B. In this case the value of the weighing function w_{1A}, w_{1B}, w_{2A} and w_{2B} are all equal to 0.50. However, the involvement of industry two in foreign trade is higher and therefore trade related knowledge spillovers can have wider (hence higher) effect in the industry two than in industry one.

The various values that s takes in the above expression indicates different assumptions about the lag length in the effect of foreign R&D on domestic productivity. It seems reasonable to assume that producers in India get information about new products or processes through trade interaction only after these products or processes become to some extent standardised at least in the developed countries. Since we do not have any clear idea about the time lag involved in the process of R&D investment, invention and innovation, we construct three trade related knowledge spillover stock that respectively assume one, two and three years lag in the effect of foreign R&D on domestic productivity.

The foreign R&D capital stocks (FK) are constructed using the industry level R&D expenditure data of fifteen OECD countries collected from *Analytical Business Enterprise Research and Development Database (ANBERD).* The R&D expenditure in this database is reported in current purchasing power parity (PPP) US$. The real R&D expenditure series is constructed using the US R&D deflator obtained from the same database. Perpetual inventory method is used to construct foreign R&D capital stock, assuming a rate of depreciation of 15 percent. The initial year R&D stocks are estimated using Hall and Mairesse (1995) procedure. This uses the procedure that we have used to estimate the initial year R&D capital stock of the firm with the assumption that the industry has infinite years of R&D experience. In this, historical growth rate of R&D expenditure is approximated by the growth rate of real R&D expenditure during the whole period. The foreign R&D stocks are constructed from 1980 onwards and therefore, errors in the initial year stock estimation can have only a negligible influence on the estimates.

3.3.3 Summary measures of variables

Table 3.4 presents summary measures of variables. The highest number of observations is in the textiles and leather industries (TAL), followed by chemicals (CHE). Radio, T.V and Communication Equipment (RTV), Office Accounting and Computing Machinery (OAC) and Textiles and Leather Products (TAL) industries have higher average share of recently imported machinery to total capital stock. The mean stock of disembodied technology import is highest in Petroleum Refineries and Products (PRP), followed by Non-electrical Machinery (NEM) and Basic metals-Iron and Steel (BIS). The average R&D capital stock is highest in Petroleum Refineries and Products (PRP), followed by pharmaceutical (PHA) and transport equipment industries (MMV and MOT).

Table 3.4 Summary Measures of Variables

Industry	No. Observations	Q	C	L[a]	M	E	SDCG	SICG	SK[b]	K	PK
BIS	920	290.55	645.90	147.58	114.79	25.97	0.27	0.03	382.4	2.18	4.56
CHE	1988	157.61	245.84	41.86	67.11	17.38	0.26	0.03	7629.2	1.03	3.37
FBT	1260	99.93	71.53	72.10	48.79	3.17	0.26	0.02	739.8	0.32	0.50
FMP	635	71.96	50.21	30.41	33.81	2.94	0.23	0.06	931.5	0.28	0.61
MEM	819	123.92	83.76	41.97	53.30	3.05	0.21	0.07	2125.8	1.46	1.21
MMV	1098	176.99	159.67	57.67	106.43	4.11	0.25	0.08	4350.1	3.18	3.80
MPG	199	61.91	56.21	32.97	27.74	0.69	0.19	0.10	16054.4	0.22	0.62
NEM	1514	120.21	86.00	77.76	58.73	2.50	0.21	0.06	5462.8	2.65	6.36
NFM	234	236.76	665.58	103.96	80.87	41.92	0.24	0.06	458.1	1.52	4.47
NMP	1037	98.78	156.59	58.95	24.31	20.89	0.20	0.05	220.1	0.46	0.52
OAC	94	129.75	40.81	13.47	43.24	0.45	0.15	0.12	263059	1.57	1.52
OTE	297	308.12	224.78	200.19	164.45	6.19	0.18	0.05	13459.6	3.02	3.62
PHA	798	81.46	65.64	38.44	36.02	2.68	0.26	0.03	3123.0	3.59	0.36
PPP	683	67.55	116.95	38.31	24.30	11.38	0.25	0.05	417.0	0.12	0.19
PRP	128	5011.09	2304.81	207.96	1544.21	64.59	0.21	0.01	1947.1	5.53	6.63
RPP	965	84.12	82.49	32.20	45.18	3.77	0.24	0.10	505.7	1.00	0.99
RTV	478	154.77	95.37	45.98	69.93	1.61	0.15	0.14	13715.8	1.30	1.31
TAL	2420	84.11	111.18	53.62	41.50	6.69	0.24	0.11	440.1	0.49	0.42
WPF	92	44.44	56.04	36.60	17.48	2.73	0.22	0.082	85.10	0.09	0.01

Notes:

(1) All values are mean over the observations, except in column two.

(2) a: numbers are in lakhs; b: in millions of US $ in 1993-94 price.

(3) Reported SK uses one year lag in the foreign R&D.

(4) All others are in Rs. crores (in 1993-94 prices)

3.3.4 Technological Classification of Industries

We have already noted in section one that productivity effect of R&D spillovers depends on the technological opportunity and complexity of industries. This is also true for other types of technological investments like R&D. So one can expect inter-sectoral variation in their effect on productivity. Analysis of this aspect needs classification of industries on the basis of their technological intensity or complexity. We have already noted in the last chapter that, given the available information, no objective criterion is available for this. We, therefore, follow the classification schemes of previous studies that considered this aspect, specifically that of Griliches and Mairesse (1984) and Hasan (2002).

Griliches and Mairesse (1984) classified firms into scientific and non-scientific firms, the former group consists of firms belong to the Chemical, Pharmaceutical, Electronics and Instruments. Firms belong to the rest of the industries are classified into non-scientific sector. Scientific sector is not only technologically sophisticated, but also has higher innovation opportunities. Following this classification, Hasan (2002) classified firms from Chemical, Pharmaceutical and Electrical machinery industries into scientific sector. This classification scheme, however, is more suitable in the case of developed countries, where technological opportunity is greatest in the field of chemical, electrical, including electronics and pharmaceutical industries (Hasan 2002). Our data show that firms in the Non-electrical and Transport equipment industries are also doing more R&D and import of disembodied technology. In Indian context, these industries also enjoy greater opportunities for innovation and adaptation of foreign technology[38].

Since no single classification scheme is satisfactory, in the present study two alternative ones are adopted. In the first one, industries are classified into scientific and non-scientific sector and in the second scheme into technology intensive and low technology intensive sectors. Table 3.5 presents these two classification schemes. Regarding the classification scheme, what we can say, in general, is that scientific and technology intensive sectors are more technologically sophisticated compared to the other two sectors.

[38] On the basis of this argument Hasan (2002) provides one more classification, besides the scientific and non-scientific sectors, which is called technology intensive sector, the present study also adopt the same approach.

Table 3.5 Classification of Industries

	Classification Scheme 1		Classification Scheme 2	
	Technology Intensive Sector	Low Technology Intensive Sector	Scientific Sector	Non-scientific Sector
1	Chemicals, excluding drugs (CHE)	Food. Beverages & Tobacco (FBT)	Chemicals, excluding drugs (CHE)	Food. Beverages & Tobacco (FBT)
2	Drugs and Medicine (PHA)	Textiles, Apparel & Leather (TAL)	Drugs and Medicine (PHA)	Textiles, Apparel & Leather (TAL)
3	Non electrical Machinery (NEM)	Wood Products & Furniture (WPF)	Electrical Machinery excl. Communication equipment (MEM)	Wood Products & Furniture (WPF)
4	Electrical Machinery excl. Communication equipment (MEM)	Paper, paper products & Printing (PPP)	Radio, TV & Communication Equipment (RTV)	Paper, Paper products & Printing (PPP)
5	Radio, TV & Communication Equipment (RTV)	Petroleum Refineries and Products (PRP)	Professional goods and Scientific instruments (MPG)	Petroleum Refineries and Products (PRP)
6	Office Accounting and Computing Machinery (OAC)	Rubber & Plastic Products (RPP)		Rubber & Plastic Products (RPP)
7	Motor Vehicles (MMV)	Non metallic Mineral Products (NMP)		Non metallic Mineral Products (NMP)
8	Other Transport Equipment (OTE)	Basic metals - Iron & Steel (BIS)		Basic metals - Iron & Steel (BIS)
9	Professional goods and Scientific instruments (MPG).	Non ferrous Metals (NFM)		Non ferrous Metals (NFM)
10		Metal Products (FMP)		Metal Products (FMP)
11				Non Electrical Machinery (NEM)
12				Office Accounting and Computing Machinery (OAC)
13				Motor Vehicles (MMV)
14				Other Transport Equipment (OTE)

3.4 Estimation and Results

This section presents the estimation and results of the study. The steps involved in the production function estimation using Levinsohn and Petrin (LP) method are explained in the first part of this section. Results are discussed in the second part. In the estimation of production function using LP method, two intermediate inputs, namely raw materials and energy, are available as proxies for firms' unobserved productivity. We use raw materials as the proxy. However, production function is also estimated using energy as another proxy and the estimates, given in the appendix to this chapter, are similar to those obtained using raw materials. The following paragraphs present the details of the estimation procedures, which involves two stages.

First stage:

The production function for estimation, after replacing ε with the sum of firm specific productivity term ω and pure random error term η, is

$$q_{it} = b_0 + b_c c_{it} + b_l l_{it} + b_m m_{it} + b_e e_{it} + b_{sdcg} sdcg_{it} + \\ b_{sicg} sicg_{it} + b_{pk} pk_{it} + b_k k_{it} + b_{sk} sk_{it} + \omega_{it} + \eta_{it}$$

and

$$\omega_{it} = \omega_t(m_{it}, c_{it})$$

Rewriting the above production function by proxying the productivity term and after suppressing the i subscript.

$$q_t = b_l l_t + b_e e_t + b_{sdcg} sdcg_t + b_{sicg} sicg_t + b_{pk} pk_t + \\ b_k k_t + b_{sk} sk_t + \phi_t(m_t, c_t) + \eta_t \qquad (3.7)$$

Where $\phi_t(m_t, c_t) = b_0 + b_c c_t + b_m m_t + \omega_t(m_t, c_t)$

In the first stage, we estimate conditional moments $E(q_t \mid c_t, m_t)$, $E(l_t \mid c_t, m_t)$, $E(e_t \mid c_t, m_t)$, $E(sdcg_t \mid c_t, m_t)$, $E(sicg_t \mid c_t, m_t)$, $E(pk_t \mid c_t, m_t)$, $E(k_t \mid c_t, m_t)$, $E(sk_t \mid c_t, m_t)$ by regressing respective variables on c_t and m_t using a third order polynomial regression with full set of interactions. Subtracting the expectation of (3.7) conditional on c_t and m_t from (3.7) we get the following.

$$q_t - E(q_t \mid c_t, m_t) = b_l(l_t - E(l_t \mid c_t, m_t)) + b_e(e_t - E(e_t \mid c_t, m_t)) + \\ b_{sdcg}(sdcg_t - E(sdcg_t \mid c_t, m_t)) + b_{sicg}(sicg_t - E(sicg_t \mid c_t, m_t)) + \\ b_{pk}(pk_t - E(pk_t \mid c_t, m_t)) + b_k(k_t - E(k_t \mid c_t, m_t)) + b_{sk}(sk_t - E(sk_t \mid c_t, m_t) + \eta_t \qquad (3.8)$$

A no-intercept OLS is used to obtain estimates of the parameters, b_l, b_e, b_{sdcg}, b_{sicg}, b_{pk}, b_k, and b_{sk} on (3.8).

Second Stage:

We use two moment conditions to identify b_c and b_m. The first moment condition identifies b_c by assuming that capital does not respond to the innovation in productivity, ξ_t. The second moment condition identifies b_m using the fact that last period's raw material choice is uncorrelated with the innovation in productivity in the current period.

These two population moments are

$$E[(\xi_{t+1} + \eta_{t+1})c_{t+1}] = E[\xi_{t+1}c_{t+1}] = 0$$

and

$$E[(\xi_{t+1} + \eta_{t+1})m_t] = E[\xi_{t+1}m_t] = 0$$

An estimate of the residual is obtained from the following relationship:

$$\xi_{t+1} \hat{+} \eta_{t+1}(b^*) = q_{t+1} - \hat{b}_l l_{t+1} - \hat{b}_m e_{t+1} - \hat{b}_{sdcg} sdcg_{t+1} - \hat{b}_{sicg} sicg_{t+1}$$
$$- \hat{b}_{pk} pk_{t+1} - \hat{b}_k k_{t+1} - \hat{b}_{sk} sk_{t+1} - b_c^* c_{t+1} - b_e^* m_{t+1} - E[\omega_{t+1} \hat{|} \omega_t] \quad (3.9)$$

Where residuals are explicitly expressed as a function of two parameters $b^* = (b_c^*, b_m^*)$. Estimate of $E[\omega_{t+1} | \omega_t]$ is obtained using the assumption that ω_{t+1} follows a first order markov process. This allows us to express ω_{t+1} as follows,

$$E(\omega_{t+1} | \omega_t) = f(\omega_t) \quad (3.10)$$

A fourth order polynomial regression is used to get an estimate of $E[\omega_{t+1} | \omega_t]$ on (3.10), from the estimates of ω_t and ω_{t+1} obtained respectively from (3.11) and (3.12).

$$\hat{\omega}_t = \hat{\phi}_t - b_c^* c_t - b_m^* m_t \quad (3.11)$$

$$\omega_{t+1} \hat{+} \eta_{t+1} = q_{t+1} - \hat{b}_l l_{t+1} - \hat{b}_m e_{t+1} - \hat{b}_{sdcg} sdcg_{t+1} - \hat{b}_{sicg} sicg_{t+1}$$
$$- \hat{b}_{pk} pk_{t+1} - \hat{b}_k k_{t+1} - \hat{b}_{sk} sk_{t+1} - b_c^* c_{t+1} - b_e^* m_{t+1} \quad (3.12)$$

In (3.11) and (3.12), we have used the estimates obtained form first stage and candidate values for (b_c^*, b_m^*). The candidate values for (b_c^*, b_m^*) are the OLS estimates of (3.1).

The $\hat{\phi}$ in (3.11) is estimated by regressing output net of inputs, whose coefficients have been obtained in the first stage, on capital and material using a third order polynomial regression with full set of interactions[39]. Since the input demand function $m_t = m_t(\omega_t, c_t)$ is not indexed by other variables (like input prices), $\hat{\phi}$ in (3.11) is estimated separately for the three sub-periods[40] 1989-90 to 1992-93, 1993-94 to 1996-97 and 1997-98 to 2000-01. These sub-periods correspond to the three different growth phases of the manufacturing industry as can be evidenced from the Figure 3A.2 given in

[39] Olley and Pakes (1996), Pavcnik (2002) and Schor (2004) also use polynomial regression to estimate $\phi(.)$ function.

[40] See Levinsohn and Petrin (2003), p. 323.

the appendix to this chapter. The estimation procedure also allows us to implement two specification tests to verify the appropriateness of the model with the data. These two tests are explained below.

Specification tests:

The first specification test verifies the monotonicity assumption with the data. In this, we plot raw materials and capital stock of firms against estimated ω to see whether the material consumption is monotonically increasing in estimated productivity, given the level of capital.

The second specification test checks for the unbiasedness of the coefficient estimates of the choice variables of the firm (or inputs), namely capital (c), labour (l), materials (m), energy (e), disembodied technology import stock (pk) and R&D capital stock (k). Since firm chooses the levels of these inputs, it is quite possible that simultaneity can bias their estimation. This test is implemented as follows. If the estimate of the labour coefficient $\hat{b}_l$ differs from b_l, the equation (3.9) contains the error $(b_l - \hat{b}_l)l_{t+1}$. The error term in equation (3.9) is $\xi_{t+1} + \eta_{t+1}$, where $\xi_{t+1} \equiv \omega_{t+1} - E[\omega_{t+1} \mid \omega_t]$. We expect l_{t+1} is determined in part by ξ_{t+1} and therefore, l_{t+1} would be correlated with the error term in (3.9), whether estimated labour coefficient is biased or not. However, if our model is correct ξ_{t+1} should be mean independent of l_t and therefore, the following moment condition should be valid.

$$E[\xi_{t+1} l_t] = 0$$

On the other hand, if the estimated labour coefficient is biased, the error term in equation (3.9) would contain $(b_l - \hat{b}_l)l_{t+1}$. In this case, the above moment condition does not hold good, because l_t and l_{t+1} are highly correlated in the data. This argument can be extended to other inputs, giving the following moment conditions.

$$E[\xi_{t+1} c_t] = 0,$$

$$E[\xi_{t+1} m_{t-1}] = 0,$$

$$E[\xi_{t+1} e_t] = 0,$$

$$E[\xi_{t+1} pk_t] = 0,$$

$$E[\xi_{t+1} k_t] = 0.$$

In the estimation of capital and materials coefficient, we include these six over identifying restrictions also, yielding in total eight population moment conditions given by the vector of expectations

$$E[(\xi_{t+1} + \eta_{t+1})Z_{t+1}]$$

Where Z_{t+1} is the vector given by $Z_{t+1} = \{c_{t+1}, m_t, c_t, m_{t-1}, l_t, e_t, pk_t, k_t\}$

Finally, we estimate b_c and b_m by minimizing the following GMM criterion function

$$Q(b^*) = \min b^* \sum_{h=1}^{8} \left(\sum_i \sum_{t+1}^{T} (\xi_{i,t+1} \hat{+} \eta_{i,t+1}(b^*)) Z_{i,h,t+1} \right)^2$$

Where i indexes firms, h indexes eight instruments, and T is the last period firm i is observed.

The above estimation procedure involves several steps and therefore, measuring the precision of the estimates requires us to account for the variances and covariances of every estimator that enters into the estimation routine. This is a quite difficult task. Following Levinsohn and Petrin (2003), we also bootstrap the estimates for drawing inferences.

Inference using bootstrap:

In bootstrapping, we (re)sample the empirical distribution of the sample and generate bootstrapped samples. The value of the statistic is estimated from each bootstrapped sample and thus generates the empirical distribution function (EDF) of the parameter of interest. This empirical distribution function provides a bootstrap approximation of the sampling distribution of the statistic. Bootstrap provides asymptotic refinements for asymptotically pivotal statistics like the ones in our case[41]. In addition, the difference between the nominal and true coverage probabilities of the confidence interval can be reduced using critical values obtained from the bootstrap distribution (Horowitz 2001).

Our resampling procedure treats time series observations on each firm as an independent and identical draw from the population of firms. In the drawing of bootstrap samples, thus, we use what is called block bootstrapping method, that is sampling with replacement and with equal probability from the sets of firm observations in the original

[41] Improvements upon the first order approximations of the sampling distribution are called asymptotic refinements.

sample[42] (see Horowitz 2001). The size of bootstrap sample is equal to the number of firms in the original sample. The number of bootstrap replications is fixed at five hundred[43].

The normal bootstrap procedure needs a slight modification when the number of instruments is more than the number of parameters to be estimated (as we do in the test of over-identifying restrictions). When the over-identifying moment restrictions are valid, the GMM function value is equal to zero in the population (i.e. when the over-identifying restrictions are valid $Q(b^*) = 0$ in the population). In the sample, on the other hand, the GMM function value is always greater than zero, when over-identifying restrictions are imposed. Bootstrap treats the original sample as the population and samples from it, implying that estimates obtained from the bootstrap samples implement a moment condition that does not hold in the population from which bootstrap samples (the original sample). As a result, the bootstrap estimator of the distribution of the statistic for testing the over-identifying restrictions is inconsistent (Brown et al. 1997 and Horowitz 2001). This problem can be solved by basing the bootstrap estimation on the recentred moment condition. This recentring of the moment condition can be done using the estimated values of the moments (at the GMM function minimum value) form the original data. This makes sure that bootstrap samples implement a moment condition that is valid in the population (the original sample). The procedure for the recentring of moment condition can be explained, in matrix notation, as follows.

Let Z_b is the matrix of instruments in the bootstrap sample, U_b is vector of residuals in the bootstrap sample, Z is the matrix of instruments in the original sample and $\hat{U}$ is the vector of residuals estimated from the original sample at the function minimum. The recentred GMM criterion function to be minimized in the bootstrap sample can be written as follows.

$$Q_b(b^*) = (Z_b'U_b - Z'\hat{U})'(Z_b'U_b - Z'\hat{U})$$

[42] Since time series observations on each firm is not independent (errors terms may be correlated) resampling from the observations scrambles the relationship between adjacent error terms.

[43] See Hall (1986) for encouraging results on the number of bootstrap replications necessary to obtain reasonable coverage probabilities of confidence intervals.

The recentring makes sure that the value of $Q_b(b^*)$ is equal to zero in the population (original sample) from which bootstrap samples. The bootstrap with recentring provides asymptotic refinements for confidence intervals (Horowitz 2001).

3.4.1 Results

Table 3.6 and Table 3.7 present the production function estimates for all industries and different sectors respectively. The first part of this section discusses the two specification tests of LP estimates and compares the estimates obtained using the three different methods. Discussion of the substantive results follows.

Table 3.6 Production Function Estimates: All Industries

	LP	OLS	Within
l	0.1869*	0.1786*	0.1851*
	(0.008)	(0.008)	(0.013)
e	0.0697*	0.0736*	0.1236*
	(0.006)	(0.007)	(0.010)
sdcg	0.0902*	0.0581*	0.0553*
	(0.028)	(0.031)	(0.022)
sicg	0.2040*	0.1177*	-0.0645
	(0.047)	(0.051)	(0.061)
pk	0.0019*	0.0022*	0.0008
	(0.001)	(0.001)	(0.001)
k	0.0026*	0.0015*	0.0012*
	(0.001)	(0.001)	(0.001)
sk	0.0421*	0.0407*	0.0227*
	(0.006)	(0.007)	(0.009)
c	0.1648*	0.1249*	0.0654*
	(0.012)	(0.010)	(0.013)
m	0.6043*	0.6068*	0.6123*
	(0.011)	(0.010)	(0.013)
P(Q)	0.274		
R^2		0.961	0.958
Number of observations		15659	

Notes:
(1) Bootstrap standard errors of the estimates are given in parentheses; number of replications 500.
(2) P(Q) is the P value of over-identification test.
(3) * indicates significant at 5 percent level implied by the bias corrected bootstrap confidence interval.

The first specification test simply graphs the smoothed $\omega_t = \omega_t(c_t, m_t)$ against raw materials and capital stock. For monotonicity condition to hold, this function should be increasing in materials, given the level of capital. Since this function is allowed to be different in three sub-periods of the sample, there are fifteen such functions to graph. So, to save space, here we report only the three graphs related to all industries. Figure

Table 3.7 Estimates of Sectoral Production Function

	Technology Intensive Sector			Low Technology Sector			Scientific Sector			Non-scientific Sector		
	LP	OLS	Within	LP	OLS	Within	LP	OLS	Within	LP	OLS	Within
l	0.2147*	0.2160*	0.1236*	0.1648*	0.1424*	0.2373*	0.2463*	0.2434*	0.0858*	0.1629*	0.1457*	0.2180*
	(0.013)	(0.014)	(0.018)	(0.009)	(0.009)	(0.017)	(0.015)	(0.015)	(0.027)	(0.007)	(0.008)	(0.014)
e	0.0467*	0.0457*	0.1222*	0.0909*	0.1008*	0.1257*	0.0371*	0.0380*	0.1121*	0.0853*	0.0968*	0.1093*
	(0.009)	(0.009)	(0.017)	(0.008)	(0.009)	(0.014)	(0.013)	(0.014)	(0.019)	(0.008)	(0.009)	(0.011)
sdcg	0.0680	0.0656	0.0496	0.1252*	0.0755*	0.0654*	-0.0053	-0.0111	-0.0191	0.1209*	0.0804*	0.0743*
	(0.054)	(0.055)	(0.042)	(0.031)	(0.036)	(0.025)	(0.057)	(0.057)	(0.044)	(0.029)	(0.034)	(0.025)
sicg	0.3821*	0.3957*	-0.1693	0.1378*	-0.0468	0.0309	0.4409*	0.4718*	-0.0802	0.1423*	-0.0019	-0.0452
	(0.082)	(0.082)	(0.130)	(0.055)	(0.066)	(0.052)	(0.101)	(0.105)	(0.092)	(0.049)	(0.058)	(0.071)
pk	0.0008	0.0007	0.0018	0.0019	0.0029	-0.0005	0.0022*	0.0022	0.0022	0.0049	0.0234	0.0102
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.01)	(0.001)	(0.002)	(0.014)	(0.012)	(0.009)
k	0.0032*	0.0018*	0.0009	0.0005	0.0002	0.0009	-0.0012	-0.0017	0.0015	0.0042	0.0138	0.0116
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.0009)	(0.001)	(0.001)	(0.001)	(0.013)	(0.011)	(0.008)
sk	0.0740*	0.0807*	0.0285*	0.0461*	0.0409*	0.0319*	0.0027	0.0059	0.0787*	0.0549*	0.0536*	0.0298*
	(0.023)	(0.026)	(0.011)	(0.013)	(0.021)	(0.014)	(0.016)	(0.016)	(0.022)	(0.009)	(0.010)	(0.009)
c	0.1409*	0.0974*	0.0815*	0.1755*	0.1529*	0.0594*	0.1141*	0.0838*	0.0734*	0.1763*	0.1505*	0.0884*
	(0.017)	(0.015)	(0.019)	(0.014)	(0.014)	(0.016)	(0.019)	(0.017)	(0.026)	(0.011)	(0.012)	(0.014)
m	0.6231*	0.6269*	0.6558*	0.5787*	0.5875*	0.5716*	0.6463*	0.6462*	0.6760*	0.5905*	0.5834*	0.5902*
	(0.018)	(0.015)	(0.018)	(0.014)	(0.013)	(0.017)	(0.017)	(0.014)	(0.019)	(0.013)	(0.012)	(0.011)
P(Q)	0.798			0.156			0.500			0.236		
R^2		0.964	0.958		0.960	0.956		0.968	0.958		0.959	0.957
No. of Observations	7285			8374			4478			11181		

Notes (1) Bootstrap standard errors of the estimates are given in parentheses; number of replications is 500.
(2) P(Q) is the p value of over identification test.
(3) * indicates significant at 5 per cent level implied by the bias corrected bootstrap confidence interval

Figure 3.2 and Figure 3.3 present these graphs for period one, two and three respectively. These graphs show that productivity is increasing in materials, validating the assumption of monotonicity between the two. This implies that we have exploited a relationship existing in the data, rather than imposing a structure on it, to solve the simultaneity problem.

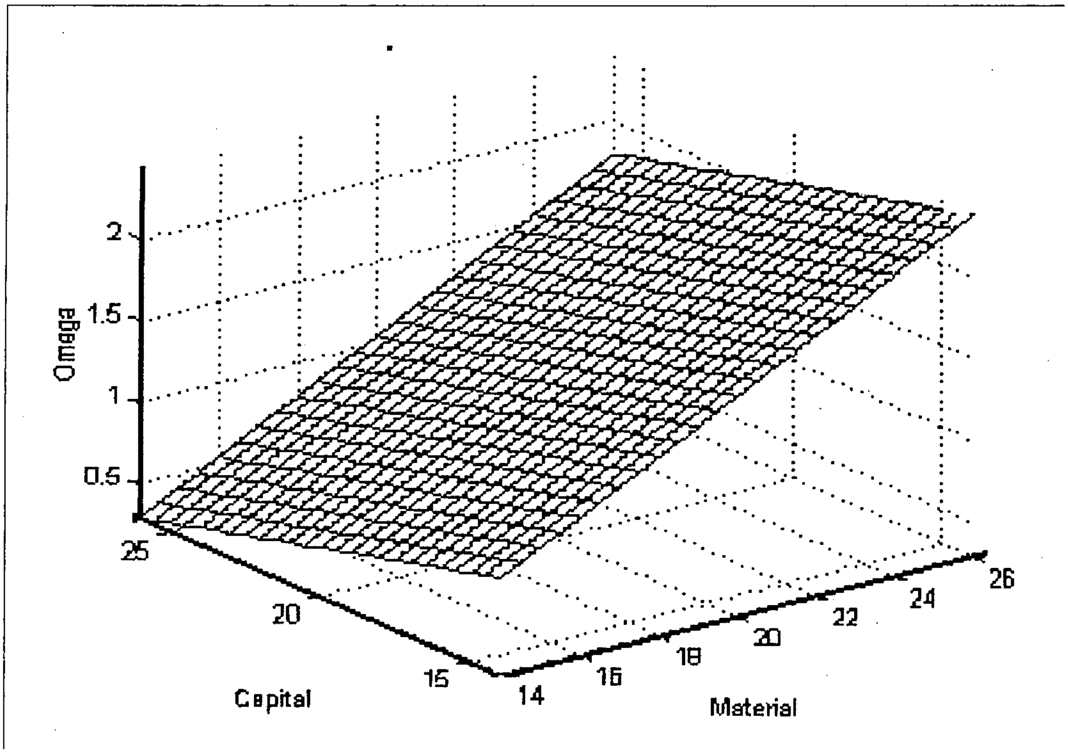

Figure 3.1 Productivity (Omega) as a Function of Capital and Materials-Period 1

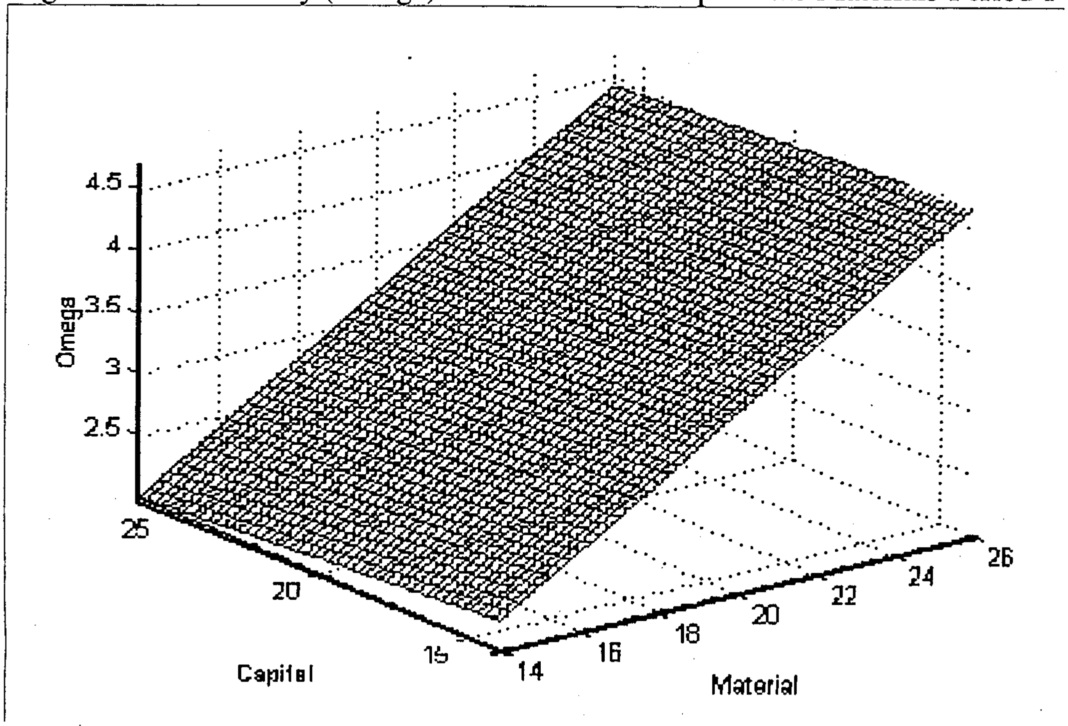

Figure 3.2 Productivity (Omega) as a Function of Capital and Materials-Period 2

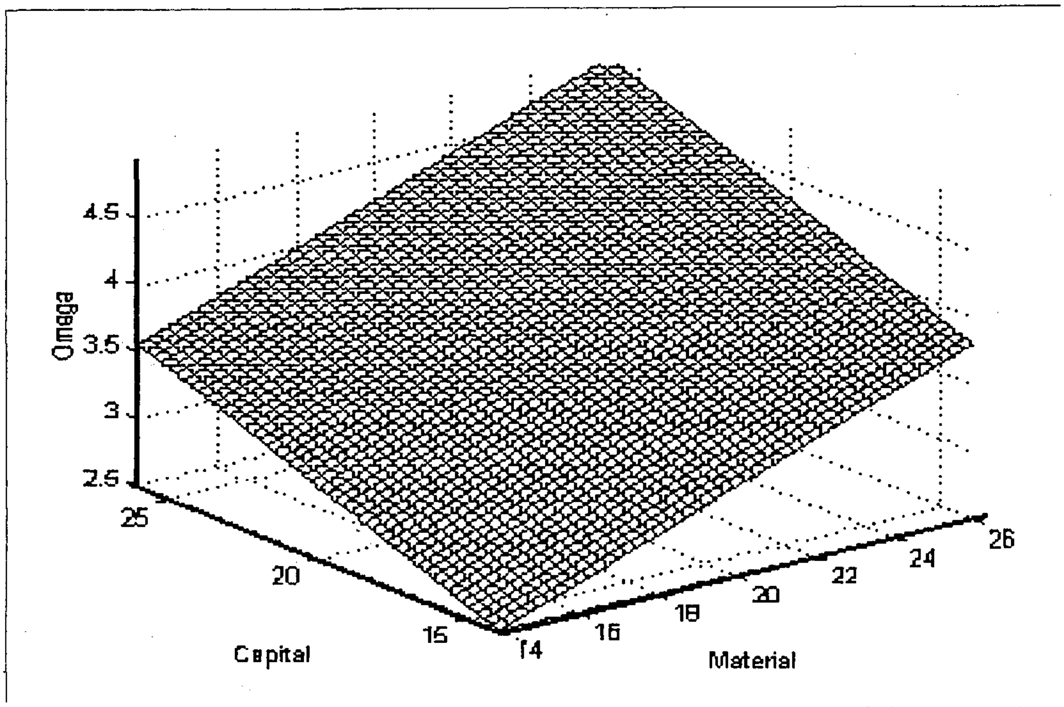

Figure 3.3 Productivity (Omega) as a Function of Capital and Materials-Period 3

The second specification test uses over-identifying restrictions to check the unbiasedness of the estimates. In this, we ask whether the lagged inputs are correlated with the innovation in productivity, which one can expect if the estimates are biased. If the proxy is conditioning out all the variation in inputs that are correlated with the productivity shock, the value of the objective function obtained from the original sample should not differ markedly from that obtained from the bootstrap samples (using recentred moment condition). In Table 3.6 and Table 3.7, the row P(Q) contains the P value of the over-identification test under the null hypothesis that over-identification restrictions are valid[44]. The results show that in all cases the null is accepted at a reasonable level of statistical significance.

The two specification tests, thus, validate the use of raw materials as a proxy to control for the firms' unobserved productivity. The estimates obtained using this proxy, then, should not be affected by the simultaneity bias as in the case of OLS and Within. Keeping this point in mind, Table 3.8 compares the LP estimates of four principal inputs, namely capital, labour, material and energy, with those of OLS and Within.

[44] Here P value indicates the probability of getting a function value from the bootstrap samples using re-centred moment condition that is equal to or greater than that obtained from the original sample.

Table 3. 8 Difference of OLS and Within Estimates from LP Estimates

Input		All Industries	Technology Intensive Sector	Scientific Sector	Low Technology Sector	Non-Scientific Sector
Capital	β_{OLS}-β_{LP}	-0.0399	-0.0435	-0.0303	-0.0226	-0.0258
	% >0	0.0	0.0	1.4	0.0	0.0
	β_{WITHIN}-β_{LP}	-0.0994	-0.0594	-0.0407	-0.1161	-0.0879
	%>0	0.0	0.0	6.2	0.0	0.0
Labour	β_{OLS}-β_{LP}	-0.0083	0.0013	-0.0029	-0.0224	-0.0172
	% >0	1.0	66.0	14.4	0.0	0.0
	β_{WITHIN}-β_{LP}	-0.0018	-0.0911	-0.1605	0.0725	0.0551
	%>0	49.2	0.0	0.0	99.8	100.0
Material	β_{OLS}-β_{LP}	0.0025	0.0038	-0.0001	0.0088	-0.0071
	%>0	66.4	59.6	44.0	90.4	0.1
	β_{WITHIN}-β_{LP}	0.008	0.0327	0.0297	-0.0071	-0.0003
	% >0	71.4	93.6	88.6	33.8	46.8
Energy	β_{OLS}-β_{LP}	0.0039	-0.0010	0.0009	0.0099	0.0115
	% >0	92.8	45.0	72.0	97.2	99.4
	β_{WITHIN}-β_{LP}	0.0539	0.0755	0.0750	0.0348	0.0240
	% >0	100.0	100.0	100.0	99.4	97.2

Note: Where β_{OLS} - β_{LP} and β_{WITHIN} - β_{LP} respectively denote the difference of OLS and Within estimate form LP estimates. %>0 indicates the percentage of differences greater than zero in the 500 bootstrap estimates

The difference of OLS and Within estimates from those of LP and the pattern of distribution of these differences in 500 bootstrap estimates are reported. The distribution is created by drawing 500 bootstrap samples and estimating production function from each sample using OLS, Within and LP methods. The upper part of each row gives the difference of OLS or Within estimates from LP and the lower part shows percentage of differences having value greater than zero[45].

The table shows that both OLS and Within estimates underestimate the capital coefficient compared to that of LP and this downward bias is more severe in the case of Within estimates. In all industries, the OLS estimate is less by 24 percent of LP and Within is 60 percent less. The distribution of the differences shows that in all cases almost 100 percent of the OLS and Within differences are negative, indicating that underestimation of capital coefficient by OLS and Within is not by chance, but systematic. Regarding the labour coefficient, there is some evidence that OLS systematically underestimates labour coefficient, except in technology intensive sector. OLS estimate of energy coefficients are systematic overestimates in all cases, except in technology intensive sector. In all industries, it is higher by six percent of LP and in

[45] The reported differences in Table 3.8 are computed from the estimates presented in Tables 3.6 and 3.7.

non-scientific and low technology sectors by 13 percent and 11 per cent respectively. The within estimates of energy coefficients are not only systematic overestimates in all cases but the over estimation is more severe also. In all industries, the upward bias is 77 percent of LP, in technology intensive sector it is 162 percent, in low technology sector 38 percent, in scientific sector 202 percent and in non-scientific sector 28 percent.

The performance of OLS and Within estimates compared to that of LP is in tune with the theoretical prediction that in the presence of simultaneity problem OLS and Within methods underestimate the coefficient of relatively more fixed input, namely capital and over estimate the coefficient of relatively flexible input (in the present context it is energy). Further, the results also show that performance of the within estimates is more worse compared to OLS. As noted in Griliches and Mairesse (1998), this can be due to the fact that the within transformation may be purging a larger part of the information from the data and basing the estimates on smaller fraction of information, exacerbating other problems such as simultaneity and measurement errors. The two specification tests and the estimates obtained in the theoretically expected line, as revealed above, may be indicating that LP estimates are free from simultaneity problem. Therefore, the discussion of results is based on LP estimates.

Estimates of returns to scale, which is the sum of capital, labour, material and energy coefficients, are not significantly different from one, signalling the prevalence of constant returns to scale. The estimates are 1.03 in all industries and in technology intensive sector, 1.01 in low technology sector, 1.05 in scientific sector and 1.02 in non-scientific sector.

The estimates for all industries show that imported and domestically purchased machinery shares have significant positive contribution to output, with former having higher elasticity with respect to output. More specifically, a one per cent increase in the share of domestically purchased machinery increases output by 0.09 per cent and the corresponding figure for imported machinery is 0.20 per cent, more than twice the elasticity of domestic machinery share[46]. Sectoral results also show that imported machinery has grater contribution to output. It is interesting to note that in technology intensive and scientific sectors, only the imported machinery share is significant and has

[46] We have tested whether the difference between the two coefficients are equal to zero or not and found that imported machinery has statistically significant higher elasticity.

higher elasticity of 0.44 in scientific sector and 0.38 in technology intensive sector. Whereas, in the low technology and non-scientific sectors, elasticity of imported machinery is only marginally higher than that of the domestic machinery[47].

The results indicate that imported machinery has higher contribution to output than domestically purchased machinery only in technology intensive sector. A possible reason for the higher elasticity of imported machinery in technology intensive sector can be that in this sector, imported machinery may be embodying better technology than corresponding domestic machinery. Whereas technological content of the domestic machinery required by the low technology industries may not be significantly lower than that of the corresponding imported machinery. This difference in the technological content of the domestic machinery, required by the different technological sectors, might be due to the Indian machinery-producing sector's differential capability in machine production. It may be able to produce machinery, required by the low technology industries, of same quality as imported ones. But when it comes to the machines, required by the high technology industries, it may not have the technological capability to produce machines having quality equal to imported ones.

Another important result is that trade related knowledge spillovers (*sk*) is showing positive and statistically significant contribution to output in all sectors, except in the scientific sector[48]. This suggests that knowledge spillovers, facilitated by trade, are contributing to industrial productivity. Since *sk* is an industry level variable, one could argue that it might be correlated with left out industry specific effects and hence reflecting the effect of these left out variables rather than that of knowledge spillovers. To check this possibility, production function has been re-estimated using industry dummies to account for the industry fixed effects. The results are reported in Table 3.9. It shows that in all the sectors, except in low technology sector, the over identification test rejected the null hypothesis, indicating some mismatch between model and data. It shows, however, that the coefficient of knowledge spillover variable (*sk*) is positive and statistically significant in all the sectors, except in technology intensive sector. It, thus, shows that trade related knowledge spillovers have robust positive effect only in the low

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[47] Since low technology industries and non-scientific industries contain almost same industries, we can expect same results in both sectors.

[48]The reported results are based on the spillover knowledge stock constructed using one year lag in the effect of foreign R&D stock and they are not sensitive to the use of two or three years lag.

technology sectors, namely low technology and non-scientific sectors[49]. In other two sectors, statistical significance is sensitive to the inclusion of industry dummies.

Table 3.9 Production Function Estimates with Industry Dummy

Variables	All Industries	Technology Intensive Sector	Low Technology Sector	Scientific Sector	Non-scientific Sector
l	0.2067* (0.008)	0.2199* (0.014)	0.1804* (0.009)	0.2438* (0.016)	0.1850* (0.008)
e	0.0702* (0.006)	0.0573* (0.011)	0.0874* (0.008)	0.0473* (0.015)	0.0808* (0.008)
sdcg	0.1280* (0.025)	0.0982* (0.049)	0.1458* (0.029)	0.0222 (0.049)	0.1526* (0.026)
sicg	0.3092* (0.046)	0.2587* (0.086)	0.3531* (0.057)	0.3127* (0.109)	0.3058* (0.049)
pk	0.0010 (0.001)	0.0010 (0.001)	0.0004 (0.001)	0.0010 (0.001)	0.0089 (0.012)
k	0.0012 (0.001)	0.0027* (0.001)	-0.0004 (0.001)	0.0002 (0.001)	-0.0022 (0.011)
sk	0.0598* (0.010)	0.0305 (0.016)	0.0507* (0.014)	0.0813* (0.027)	0.0624* (0.011)
c	0.1613* (0.011)	0.1372* (0.016)	0.1756* (0.013)	0.1396* (0.019)	0.1733* (0.011)
m	0.6079* (0.010)	0.6269* (0.016)	0.5786* (0.015)	0.6198* (0.018)	0.5938* (0.012)
P(Q)	0.034	0.028	0.068	0.042	0.034

Notes:
(1) Bootstrap standard errors of the estimates are given in parentheses; number of replications 500.
(2) P(Q) is the P value of over identification test.
(3) * indicates significant at 5 per cent level implied by the bias corrected bootstrap confidence interval.

This may be indicating that in technology intensive industries, although they offer grater opportunities for learning, technology may be too sophisticated and tacit to learn anything through trade facilitated interaction. In low technology intensive industries, on the other hand, technology may not be too complex to hinder learning through trade. This may provide empirical evidence to the theoretical argument that high technology industries cannot gain through trade related knowledge spillovers.

The disembodied technology import (pk) is showing significant positive effect on output only in all industries and the lack of sectoral evidence, however, makes this result not robust. R&D, on the other hand, shows significant positive elasticity in all industries

[49]We need to use industry dummies only in the first stage of the estimation, where the coefficient of *sk* is estimated. Since the over-identification test rejected the null hypothesis in majority of the sectors, we are not using these results in further discussion.

and in technology intensive sector. This finding is contrary to that of the previous studies examining this issue using firm level data of 1970s and 1980s period, namely Ferrantino (1992), Raut (1995), Basant and Fikkert (1996) and Hasan (2002). The present study, thus, gives evidence on the positive contribution of R&D to output[50] in the 1990s. Patibandla (2004) also reports positive effect of R&D on firms' technical efficiency in a sample of twelve industries for the period 1989-1999. A possible reason for this could be that in the liberalised policy regime firms might have been investing in more serious R&D in order to improve productivity and competitiveness.

One of our objectives is to examine the relationship among different technology variables with respect to their effect on productivity. This is analysed by estimating production function containing interaction of technology variables. A significant positive interaction term between two inputs, say *k* and *pk* indicates a complementary relationship between the two in the sense that an increase in one enhances the marginal product of the other. For instance, if a significant amount of R&D is needed to utilise imported technology effectively, this would reflect in a positive interaction between the two. On the other hand, if the firm can use either R&D or technology import to achieve technological progress independently of other (they can be substitutes), the interaction term would be small or zero or even negative if diminishing returns are operating in the technological investment.

One problem in estimating the production function containing all the ten interaction variables is that it is creating severe multicollinearity problem, making all the interaction estimates insignificant. We overcome this problem by grouping the interaction variables into two groups in such a way that one group contains only two interactions of a variable and estimating the production function using only one group at a time. Table 3.10 and Table 3.11 present these results respectively for all industries and various sectors.

[50] In Basant and Fikkert (1996), R&D has a significant positive effect on productivity when estimated without time dummies, but when time dummies are included R&D become insignificant. Raut (1995) found that intra-industry R&D spillovers have a significant effect on productivity.

Table 3.10 Estimates with Technology Interaction Variables: All Industries.

Variables	Group 1	Group 2
l	0.1863* (0.008)	0.1863* (0.008)
e	0.0695* (0.006)	0.0698* (0.006)
sdcg	0.1212* (0.035)	0.3281 (0.217)
sicg	-0.4929 (0.257)	0.2393* (0.056)
pk	0.0039* (0.001)	0.0011* (0.005)
k	-0.0121 (0.005)	0.0034* (0.001)
sk	0.0247* (0.006)	0.0471* (0.009)
sdcg*sicg	-0.1378 (0.129)	
k*pk	-0.0002* (0.000)	
k*sk	0.0022* (0.001)	
sicg*sk	0.0997* (0.036)	
sdcg*pk	-0.0041 (0.004)	
sdcg*k		-0.0023 (0.004)
sdcg*sk		-0.0316 (0.031)
sicg*pk		-0.0034 (0.007)
sicg*k		-0.0049 (0.007)
pk*sk		0.0002 (0.001)
c	0.1634* (0.011)	0.1636* (0.012)
m	0.6058* (0.011)	0.6055* (0.011)
P(Q)	0.208	0.318

Notes:

(1) Bootstrap standard errors of the estimates are given in parentheses; number of replications 500.

(2) P(Q) is the P value of over identification test.

(3) * indicates significant at 5 per cent level implied by the bias corrected bootstrap confidence interval.

Table 3.11 Sectoral Estimates with Technology Interaction Variables

	Technology Intensive Sector		Low Technology Sector		Scientific Sector		Non-scientific Sector	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
l	0.2195* (0.013)	0.2175* (0.013)	0.1637* (0.009)	0.1646* (0.009)	0.2446* (0.015)	0.2461* (0.015)	0.1619* (0.007)	0.1619* (0.007)
e	0.0469* (0.009)	0.0469* (0.009)	0.0911* (0.008)	0.0915* (0.008)	0.0382* (0.013)	0.0373* (0.013)	0.0857* (0.008)	0.0856* (0.008)
sdcg	0.1517* (0.074)	0.0176 (1.191)	0.1061* (0.038)	-0.2424 (0.328)	0.0631 (0.077)	0.3251 (0.576)	0.1214* (0.034)	0.1656 (0.333)
sicg	0.4992 (1.399)	0.4423* (0.123)	-1.7163 (0.758)	0.1889* (0.061)	-1.4667 (1.079)	0.3740* (0.139)	-0.3833 (0.329)	0.1827* (0.051)
pk	0.0030 (0.002)	0.0078 (0.023)	0.0023 (0.002)	-0.0082 (0.010)	0.0039 (0.002)	-0.0154 (0.014)	0.0249 (0.019)	-0.0057 (0.061)
k	-0.0163 (0.018)	0.0050* (0.002)	-0.0324* (0.013)	-0.0011 (0.002)	0.0212 (0.014)	0.0018 (0.002)	0.0520 (0.061)	-0.0091 (0.025)
sk	0.0519* (0.024)	0.0748 (0.049)	0.0117 (0.017)	0.0268 (0.019)	0.0079 (0.021)	-0.0067 (0.026)	0.0464* (0.011)	0.0560* (0.015)
sdcg*sicg	-0.4781 (0.309)		0.0599 (0.164)		0.1630 (0.399)		-0.0559 (0.168)	
k*pk	-0.0002 (0.0001)		-0.0003* (0.0001)		0.0001 (0.000)		-0.0339* (0.008)	
k*sk	0.0024 (0.002)		0.0056* (0.002)		-0.0027 (0.002)		0.0022 (0.008)	
sicg*sk	-0.0089 (0.157)		0.3017* (0.123)		0.2181 (0.126)		0.0804 (0.049)	
sdcg*pk	-0.0057 (0.006)		0.0055 (0.005)		-0.0112 (0.008)		0.0060 (0.054)	
sdcg*k		-0.0123 (0.006)		0.0098* (0.005)		-0.0152* (0.007)		0.1687* (0.071)
sdcg*sk		0.0139 (0.139)		0.0568 (0.054)		-0.0277 (0.068)		-0.0099 (0.051)
sicg*pk		-0.0065 (0.012)		-0.0081 (0.009)		0.0098 (0.012)		-0.049 (0.097)
sicg*k		-0.0013 (0.011)		-0.0062 (0.009)		-0.0026 (0.014)		-0.2213 (0.128)
pk*sk		-0.0008 (0.003)		0.0018 (0.002)		0.0020 (0.002)		0.0022 (0.008)
c	0.1409* (0.016)	0.1418* (0.018)	0.1771* (0.014)	0.1761* (0.014)	0.1124* (0.018)	0.1114* (0.019)	0.1759* (0.011)	0.1763* (0.011)
m	0.6231* (0.017)	0.6222* (0.018)	0.5769* (0.015)	0.5781* (0.015)	0.6480* (0.018)	0.6491* (0.017)	0.5909* (0.013)	0.5904* (0.013)
P(Q)	0.834	0.818	0.044	0.216	0.624	0.464	0.134	0.218

Notes:

(1) Bootstrap standard errors of estimates are given in parentheses; number of replications 500.

(2) P(Q) is the P value of over identification test.

(3) * indicates significant at 5 per cent level implied by the bias corrected bootstrap confidence interval.

The results show that interaction between imported machinery and domestically produced machinery is statistically not significant. It can, therefore, be concluded that there is no evidence of a complementary relationship between imported and domestically produced equipments. It contradicts with the assumption made in some endogenous growth models that domestic and imported inputs are complements in production[51] (Romer 1994b and Lee 1995).

R&D and trade related knowledge spillovers are showing a complementary relationship in all industries and in low technology sector, as revealed by the statistically significant coefficient of the interaction between the two. This may be indicating that in-house R&D facilitates the absorption of knowledge spillovers. Similarly, the interaction between share of imported machinery and trade related knowledge spillover has a significant positive coefficient in all industries and in low technology sector. This may suggest that imported machinery helps firms to absorb and utilise foreign knowledge spillovers.

Another significant result is on the relationship between R&D and disembodied technology import. The interaction between the two is significant and negative in all cases, except in scientific and technology intensive sectors. As far as the contribution to output is concerned, this result is suggesting a substitution relationship between the two. The relationship between R&D and technology import is one of the highly discussed issues in the technology literature in Indian context[52]. One strand of the literature has the view that technology import would encourage investment in R&D in order to adapt and assimilate the imported technology. Other strand argues that technology import would act as a substitute for in-house R&D and discourages it. Hasan (2002) and Basant and Fikkert (1996) show that there is no evidence for a complementary or substitution relationship between the two. The present study, however, shows a substitution relationship only in the low technology sector for the 1990s. Further, a substitution relationship in the low technology sector seems quite plausible, because of the low

[51] Hasan (2002) using firm level data for the period 1975-76 to 1986-87 found a complementary relationship between imported machinery and domestically produced machinery. He argues that one can expect this result given the India government's policy of allowing firms to import capital goods only if it could be shown that a domestic substitute did not exist. The liberalised trade policy regime may have changed relation between imported machinery and domestically produced machinery.

[52] A number of studies examined the relationship between the disembodied technology import and firm's R&D investment in Indian context. These studies examined the relation between R&D and disembodied technology import by regressing former on the latter by including other control variables. These studies include Pillai (1979), Katrak (1985, 1990 and 1997), Siddharthan (1988) Kumar and Saqib (1996) Basant (1997). Since both technological inputs are choice variables of the firm this approach is subject to simultaneity bias. Fikkert (1994,cited in Hasan 2002) and Raut (1988) adopted a better approach of using factor demand framework. Fikkert found a negative effect of technology import on R&D and Raut's finding was just opposite. The differences in the estimation procedures and variables construction may be the reason behind the contradictory results.

technology character of the sector R&D may not be required to adapt and assimilate imported technology.

In the low technology and non-scientific sectors, the results reveal a complementary relationship between R&D and investment in domestic machinery. This may be suggesting that, due to some features of industries in these sectors, investment in the new machinery purchased from domestic sources may be helping them to effectively implement results of their in-house R&D[53]. This interaction variable is negative and significant in the scientific sector. The possible reason for this may not be the existence of substitution relationship, but can be the incompatibility between the two. In this high technology sector, domestic machinery may not be suitable to implement R&D results.

3.4 Summary and Conclusion

This chapter have examined the effect of trade related R&D spillovers on manufacturing productivity. The study improves upon previous studies in many respects. First, conceptually R&D spillovers are distinguished into two types, namely, rent spillovers and knowledge spillovers. The first type takes place through the purchase of capital goods that embody better technology and the second one is through the trade facilitated interaction of domestic producers with products, markets and producers of technology leader countries. In the empirical part, the study examined the productivity effect of both types. Second, the study analysed the inter-sectoral variation in the contribution of spillovers and the role of firms' investments in R&D, technology import and plant machinery in enhancing it. Third, unlike most of the earlier studies, the present study has used firm level panel data. We adopt production function approach and use an improved estimation method to estimate it in the presence of simultaneity problem.

In the empirical analysis, the study examined whether the productivity effect of imported machinery is higher than that of domestically purchased machinery. The results show that imported machinery has higher contribution to output and it is greater in technology intensive sector. It also shows that, although the effect of trade related knowledge spillover is significant, it is mainly confined to low technology industries.

[53] The low technology and non-scientific group consists mainly of industries using materials that have higher geographic specificity such as food products, textiles, metals, wood products, rubber, etc. Because of this geographic specificity of the materials, machinery designed for the Indian conditions may be required to utilise improvements made through in-house R&D. In this context domestic machine producers can be the major suppliers of machinery that suits to Indian conditions.

The study, thus, gives evidence on the existence of inter-sectoral variation in the effect of trade related R&D spillovers and also shows that pattern of this sectoral variation depends on the type of R&D spillovers. Further, the results also indicate that firms' R&D and imported capital goods enhance the productivity effect of trade related knowledge spillovers.

In the present chapter, we have examined the role of trade in transmitting technology from the developed trade partner countries and its effect on productivity. The empirical analysis shows its importance in enhancing industrial productivity. As we have found in chapter one, trade can also influence the domestic generation of technology through R&D investment. This is one of the highly debated issues, not only due to the importance of R&D in creating new industrial technology but also because of the ambiguity in the effect of trade. A fuller understanding of how trade influenced the process of technological progress of the manufacturing industry needs an analysis of the effect of trade on R&D. The next chapter is an attempt in that direction, where we examine the effect of trade on firms' R&D investment.

3. Appendix

3A.1 Data Cleaning Rules

To identify and remove observations having implausible values for variables, we have adopted procedures similar to Hall and Mairesse (1995). The cleaning of the firm level data has been done on the basis of following two rules.

1. Removed all observations for which output growth rate was less than –60 percent or greater than 250 per cent.
2. Removed all observations for which growth rate of labour, capital stock, raw materials and energy was less than –50 per cent or greater than 200 per cent.

3A.2 Measurement of Capital Stock

The database gives information on gross fixed asset (GFA) and its various components such as land and building and plant and machinery. Capital stocks of some firms are revalued and this revaluation portion is reported separately in the database. First, we subtracted the value of capital under construction and revaluation portion, if any, from the reported GFA. Taking the difference between the current and lagged values of GFA thus obtained gives the actual investment that enters into the production process. This enables us to use perpetual inventory method to construct capital stock, as given below

$$C_{t+1} = C_t + I_{t+1}$$
$$C_t = C_{t-1} + I_t$$
$$C_{t-2} = C_t - I_t - I_{t-1},$$
and so on

Where C_{t+s} and I_{t+s} are the capital stock and the real investment respectively at time $t+s$. The implementation of this method, however, requires a base year capital stock C_t, which is valued at replacement cost. The reported GFA is measured in historical cost, therefore we have to choose one base year and revalue that year's capital stock. In this study, we took 1995-96 as the base year for the estimation of capital stock. The rationale for taking 1995-96 as the base year is the availability of largest number of observations for this year.

Capital Stock at Replacement Cost in the base year

Since we don't have capital stock at replacement cost in the base year, the base year capital stock needs to be revalued so as to obtain its value at replacement cost. Given the available information, there is no perfect way of doing this and any method adopted is an approximation. The method, we use, is based on the following assumptions.

1 No firm has any capital stock in the base year (1995-96) of a vintage earlier than 1976-77. The year 1976-77 itself is chosen because the life of machinery is assumed to be twenty years, as noted in the report of the Census of Machine Tools (1986) of the Central Machine Tool Institute Bangalore ('National Accounts Statistics: Sources and Methods' New Delhi: Central Statistical Organisation, 1989). For firms incorporated after 1976-77 it is assumed that the earliest vintage capital in their capital mix dates back to the year of incorporation. Clearly, as stated by Srivastava (1996) the year of incorporation and the vintage of the oldest capital in the firm's asset mix may not coincide for some firms, but the assumption is made for want of a better alternative.

2 The price of capital has changed at a constant rate, π

$$\pi = \frac{P_t}{P_{t-1}} - 1$$

from 1976-77 or from the date of incorporation of the firm (which ever is later) up to 1995-96 (base year). Values for π were obtained by constructing capital formation price indices from the series for gross fixed capital formation in manufacturing obtained from various issues of the National Account Statistics of India. The constant inflation rate π is not firm specific but it varies with the year of incorporation, provided the firm was incorporated after 1976-77.

3 Investment has increased at a constant rate for all firms and the rate of growth of investment (g) is

$$g = \frac{I_t}{I_{t-1}} - 1$$

Here the rate of growth of gross fixed capital formation in manufacturing at 1980-81 prices is assumed to apply to all firms. Again different average annual growth rates are obtained for firms established after 1976-77.

Making these assumptions the revaluation factor R^G for the base year gross fixed capital stock can be obtained as described below. The balance sheet value of assets in the base year is scaled up by the revaluation factor to obtain an estimate of the value of capital stock at replacement costs.

Replacement Cost of Capital = R^G x [Value of Capital Stock at Historic Cost]

The revaluation factor can be obtained as follows

Revaluation Factor for Gross Fixed Assets (R^G)

Let GFA_t^h and GFA_t^r are gross fixed asset at historical costs and replacement costs respectively and I_t and P_t denote real investment and price of capital respectively at time t. By definition and making the assumptions mentioned above.

$$GFA_t^h = P_t I_t + P_{t-1} I_{t-1} + P_{t-2} I_{t-2} + \dots$$

$$= P_t I_t \left(\frac{(1+g)(1+\pi)}{(1+g)(1+\pi) - 1} \right)$$

And

$$GFA_t^r = P_t I_t + P_t I_{t-1} + P_t I_{t-2} + \dots$$

$$= P_t I_t \left(\frac{(1+g)}{g} \right)$$

Defining R^G

$$R^G = \frac{GFA_t^r}{GFA_t^h}$$

Then

$$R^G = \frac{(1+g)(1+\pi) - 1}{g(1+\pi)}$$

If it is assumed more realistically that the capital stock does not dates back infinitely, but that the capital stock of the earliest vintage is t period old, then we can derive the revaluation factor as follows.

$$R^G = \frac{[(1+g)^{t+1} - 1](1+\pi)^t [(1+g)(1+\pi) - 1]}{g\{[(1+g)(1+\pi)]^{t+1} - 1\}}$$

We have used GFA thus obtained, after deflating it with the wholesale price index for machinery and machine tools with base 1993-94 =100, in the estimation of production function.

Figure 3A.1 OECD Countries' Share in India's Trade in Manufactures

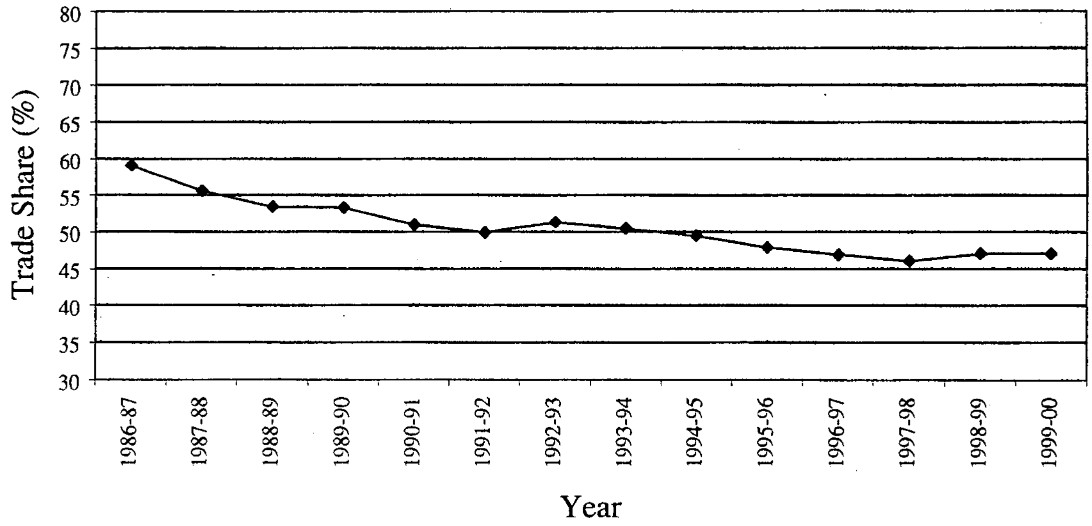

Figure 3A.2 Log of Manufacturing Output

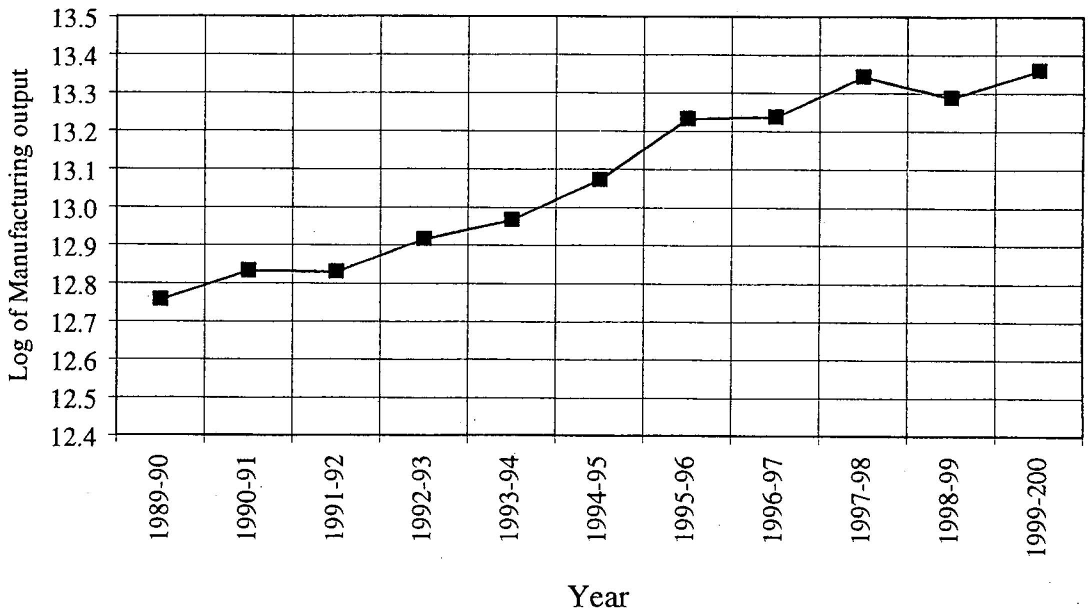

Table 3A.1 Coefficient Estimates using Energy as Proxy Variable

	All Industries	Technology Intensive Sector	Low Technology Sector	Scientific Sector	Non Scientific Sector
l	0.1810* (0.008)	0.2199* (0.014)	0.1466* (0.009)	0.2394* (0.015)	0.1552* (0.009)
m	0.6151* (0.009)	0.6323* (0.015)	0.5958* (0.012)	0.6546* (0.014)	0.5941* (0.012)
sdcg	0.0770* (0.029)	0.0683 (0.054)	0.1070* (0.033)	0.0008 (0.058)	0.1180* (0.036)
sicg	0.1612* (0.049)	0.3762* (0.085)	0.0547 (0.060)	0.3909* (0.106)	0.1204* (0.055)
pk	0.0021* (0.001)	0.0007 (0.001)	0.0021 (0.001)	0.0019* (0.001)	0.0014 (0.001)
k	0.0020* (0.001)	0.0023* (0.001)	0.0004 (0.001)	-0.0009 (0.001)	0.0014* (0.0009)
sk	0.0385* (0.006)	0.0719* (0.026)	0.0358* (0.017)	-0.0003 (0.017)	0.0553* (0.010)
c	0.1562* (0.010)	0.1429* (0.016)	0.1543* (0.013)	0.0984* (0.017)	0.1483* (0.012)
e	0.0426* (0.009)	0.0185* (0.011)	0.1009* (0.011)	0.0279* (0.015)	0.0659* (0.011)
P(Q)	0.446	0.288	0.332	0.928	0.422

Note:

1) * indicates significant at 5 per cent level implied by the bias corrected bootstrap interval; number of bootstrap is 500.

4

Trade and R&D Investment

This chapter examines the effect of trade on R&D investment of firms. Specifically, we examine the impact of import competition, export, technology import and trade related knowledge spillovers. Empirical analysis of this issue assumes significance because, as we shall see below, the theoretical results on the influence of some of these dimensions of trade are ambiguous and contingent on many industry and firm specific factors. The present study considers the importance of one such industry specific feature, namely market structure, in shaping the impact of import competition.

The chapter is organised in five sections. Section one, as a background to the empirical analysis, examines the trends and composition of R&D expenditure in India, particularly of industrial sector. Next section reviews the theoretical literature on various channels thorough which trade can affect R&D investment. This section also contains a review of selected studies on the determinants of R&D in Indian manufacturing industry. The third section specifies the econometric model and describes the data and construction of variables. The fourth section discusses the results and the last one concludes the chapter.

4.1 Industrial Sector R&D in India-Trends and Composition

Realising the importance of scientific and technological knowledge for the development of the nation, the government of India has always given priority to R&D in various sectors of the economy. The promotional measures include establishment of own research institutes in different fields of science, promotion of research units in the public sector firms and provision of several incentives for establishing such units in the private sector, like tax exemption to the money spend on research and concessional import of equipment needed by the R&D units.

To understand the importance given to research in an economy, R&D expenditure is one of the most widely used measures. This study also uses the same indicator to examine the trends and composition of innovation effort. The R&D expenditure data are obtained from various issues of *Research and Development Statistics*, published by the

Department of Science and Technology, Ministry of Science and Technology, Govt. of India.

An examination of the National R&D expenditure indicates that it has increased from rupees 760.52 crores in 1980-81 to 1761.84 crores in 1990-91 (in constant 1980-81 price). Table 4.1 presents the trends in the national expenditure as a per cent of GNP and its break-up by central sector, state sector and private sector is also given. The central sector includes expenditure of the central government through its research institutes and that of the central public sector enterprises. State sector contains expenditure incurred by the state governments and the category private sector denotes the expenditure of the private sector enterprises. The national research expenditure as per cent of GNP is declining in the 1990s and this decrease is mainly caused by the reduction in the central sector expenditure. This deceleration in government financed R&D expenditure, as pointed out by Kumar and Siddharthan (1997), could be due to the fiscal austerity measures associated with structural adjustment during the 1990s[1].

Table 4.1 Share of R&D Expenditure in GNP (In per cent)

Year	Total	Central Sector	State Sector	Private Sector
1984-85	0.86	0.69	0.06	0.11
1985-86	0.89	0.71	0.07	0.11
1986-87	0.97	0.79	0.06	0.11
1987-88	1.01	0.84	0.06	0.11
1988-89	1.00	0.83	0.07	0.11
1989-90	1.01	0.83	0.07	0.11
1990-91	0.89	0.71	0.07	0.11
1991-92	0.89	0.71	0.07	0.12
1992-93	0.83	0.63	0.08	0.13
1993-94	0.81	0.60	0.08	0.13
1994-95	0.73	0.55	0.06	0.12
1995-96	0.69	0.48	0.06	0.15
1996-97	0.66	0.46	0.06	0.14
1997-98	0.69	0.47	0.06	0.16

Source: *Research and Development Statistics*, Department of Science and Technology, Govt. of India, (various issues).

Another related aspect is the trends in the shares of central, state and private sector in the total expenditure. Table 4.2 presents this feature. In 1985-86 the percentage shares of central, state and private sector respectively are 80, 7.9 and 12.2. By 1997-98 the

[1] Kumar and Siddharthan (1997) argues that the regions that underwent structural adjustment witnessed a decline in the proportion of R&D expenditure (p.28-30).

share of the central sector declined to 68.7 per cent and that of the private sector increased to 23 per cent. It is interesting to note that the rise in the private sector share happened during the 1990s.

Table 4.2 Sectoral Shares of National R&D Expenditure (In per cent)

Year	Central	State	Private
1984-85	79.8	7.1	13.1
1985-86	80.0	7.9	12.2
1986-87	81.7	6.6	11.7
1987-88	83.2	6.3	10.6
1988-89	82.8	6.7	10.5
1989-90	82.6	6.5	10.9
1990-91	79.5	7.9	12.6
1991-92	79.2	7.7	13.1
1992-93	75.7	9.3	15.0
1993-94	74.5	9.8	15.7
1994-95	75.0	8.6	16.4
1995-96	69.5	8.8	21.7
1996-97	69.8	8.7	21.5
1997-98	68.7	8.4	22.9

Source: Same as Table 4.1.

Table 4.3 Industrial Sector R&D Expenditure (Rs in Lakhs in 1993-94 prices)

Year	Private Sector	Public Sector	Total
1984-85	50205.00	40435.38	90640.38
1985-86	50527.56	44130.56	94658.11
1986-87	59405.78	48372.29	107778.06
1987-88	54158.36	54427.45	108585.81
1988-89	66698.84	56085.87	122784.70
1989-90	71340.55	61627.00	132967.55
1990-91	60861.32	55271.11	116132.43
1991-92	63235.99	58359.96	121595.95
1992-93	69289.07	54674.46	123963.53
1993-94	79431.64	54281.14	133712.78
1994-95	90490.75	36155.51	126646.26
1995-96	96350.89	31428.84	127779.73
1996-97	101086.19	38955.49	140041.68

Source: Same as Table 4.1.

The data show that industrial sector accounts for about 22 per cent of the national R&D expenditure in a year during the period 1984-85 to 1996-97. Table 4.3 presents the industrial sector expenditure and that accounted by public and private sector. The reported figures are in constant 1993-94 prices, obtained using R&D deflator, which we have constructed in the last chapter[2]. It can be seen that total industrial sector research outlay increased from Rs. 94658 lakhs in 1985-86 to Rs. 140042 lakhs in 1996-97 and that of the private sector almost doubled during this period.

Table 4.4 Growth Rates of Industrial Sector R&D Expenditure
(Annual growth rate in per cent)

Year	Private	Public	Total
1985-86	0.6	9.1	4.4
1986-87	17.6	9.6	13.9
1987-88	-8.8	12.5	0.7
1988-89	23.2	3.0	13.1
1989-90	7.0	9.9	8.3
1990-91	-14.7	-10.3	-12.7
1991-92	3.9	5.6	4.7
1992-93	9.6	-6.3	1.9
1993-94	14.6	-0.7	7.9
1994-95	13.9	-33.4	-5.3
1995-96	6.5	-13.1	0.9
1996-97	4.9	23.9	9.6

Source: Same as Table 4.1.

Table 4.4 presents the year-to-year growth rates of industrial sector research expenditure. It is interesting to note that public sector outlay always recorded a positive growth rate before 1990-91, but during the 1990s growth rate is negative in all, except two years. This, as we have mentioned above, might be due to the austere budgetary policy of the central government, which might have reduced the funds available to the central public sector units. After 1991, however, the private sector expenditure is showing positive growth rates in every year, enabling it to increase its share in the total industrial sector outlay, as shown in the Table 4.5.

[2] The R&D deflator is the weighted price index of capital goods' price index and wage index with weights are the average shares of capital and current expenditure in the total R&D expenditure of the manufacturing industry.

Table 4.5 Shares of Public and Private Sectors in Total Industrial R&D Expenditure
(in per cent)

Year	Private Sector	Public Sector
1984-85	55.39	44.61
1985-86	53.38	46.62
1986-87	55.12	44.88
1987-88	49.88	50.12
1988-89	54.32	45.68
1989-90	53.65	46.35
1990-91	52.41	47.59
1991-92	52.01	47.99
1992-93	55.89	44.11
1993-94	59.40	40.60
1994-95	71.45	28.55
1995-96	75.40	24.60
1996-97	72.18	27.82

Source: Same as Table 4.1.

Table 4.6 R&D Expenditure per Firm in Private and Public Sector
(Rs in lakhs, in 1993-94 prices)

Year	Private Sector	Public Sector
1984-85	66.0	430.2
1985-86	66.4	469.5
1986-87	78.1	514.6
1987-88	55.1	351.1
1988-89	67.9	361.8
1989-90	72.6	397.6
1990-91	61.9	356.6
1991-92	64.5	329.7
1992-93	71.0	319.7
1993-94	81.4	317.4
1994-95	92.7	211.4
1995-96	97.3	189.3
1996-97	102.1	234.7

Source: Same as Table 4.1.

Another dimension, which reveals the increased innovation effort of the private sector firms during the 1990s, is the rise in their per unit R&D expenditure as shown in Table 4.6. It also shows that per unit outlay of the public sector is always higher than that of the private sector. This is because, as the data reveal, firms belonging to the private sector are small in size and large number of firms are investing. On the other hand, firms in the public sector, though a few in number, are big in size and spend larger amount.

From the above brief discussion on the trends and composition of research expenditure the following points emerge. National R&D expenditure as a per cent of GNP is still very low and, in fact, suffered a decline in the 1990s, mainly accounted by the reduction in the public sector outlay. Private sector expenditure, on the other hand, registered a continuous positive growth during the 1990s compared to the previous decade. This may be suggesting that during the 1990s the private sector becomes more active in innovation effort, might be due to the competitive pressure as well as the opportunities unleashed by the liberal trade and industrial policy regime.

4.2 Trade and R&D Investment: The Theory

Trade can affect R&D investment of firms through several channels and these include import competition, export, technology import and trade related knowledge spillovers. Further, trade can also affect R&D by changing the relative price of factors employed in the research activity. These channels are explained in detail below.

Import Competition: A number of theoretical models have analysed the effect of import competition on innovation effort. These models, however, show that direction of the effect is ambiguous and sensitive to the assumptions made about the domestic market structure, cost structure of firms and so on. Rodrik (1992a) analysed the effect of import competition under two market structures; one in which the domestic market structure is monopoly and another an oligopoly market. Under monopoly, the incentive to invest in R&D is greater, larger the scale of output[3]. In the first model, therefore, import competition, which shrinks the market share of the domestic producer, reduces the incentive to do innovation. In the second model, where the domestic industry is an oligopoly behaving in Bertrand assumption, import competition stimulates R&D effort. As in any oligopoly model, these results, thus, depend on the particular behavioural assumptions about the conduct of firms in the market[4].

Smulders and Klundert (1995) examined the effect of market concentration on innovation effort using an endogenous growth model with the assumption of

[3] Since R&D investment is a fixed cost, rate of return from research depends, among other things, on the scale of output on which the firm can spread this fixed cost. So if the scale of output is large, higher the rate of return from R&D.

[4] To quote Rodrik (1992a, p.166) in this context "it is easy to reverse the results by assuming a different mode of behaviour on the part of firms".

monopolistic competition in the domestic market. This model predicts that incentive of the firm to invest in R&D is greater when the domestic market is highly concentrated and market power of firms is lower[5]. Import competition, in this model encourages R&D by reducing the mark-up as well as by increasing the level of domestic concentration through the exit of the inefficient firms and absorption of their market share by extant ones.

One important assumption of Smulders and Klundert is that the cost structure of the domestic and foreign firms is symmetric. Traca (2002) relaxed this assumption and examined the impact of import competition on domestic monopolist's innovative effort. The effect of import competition on domestic firm's output is divided into two parts, namely *market share effect* and *pro-competitive effect*. The first effect captures the reduction in the output of the domestic firm due to a fall in its market share caused by the import competition. The second one refers to the expansion in output induced by the lower price due to the reduction in mark-up brought out by foreign competition. The impact of import competition depends on the relative strengths of these two effects. When the pro-competitive effect dominates the market share effect, the domestic firm would face a net expansion in output. This along with lower mark-up could provide greater incentive to invest in R&D. This model shows that in mature industries, where productivity gap between domestic and foreign industry is low, pro-competitive effect dominates and firm would enjoy an expansion in the market. Whereas, in infant industries, where productivity gap is high, market share effect dominates and import competition would discourage R&D investment[6].

Another set of theoretical models, which are also relevant in the present context, examined the effect of product market competition on innovation and these include Aghion et al. (2001) and Aghion (2003). It is Schumpeter (1942) who suggested that market structure and innovation effort were related and a competitive one was not conducive for innovation. Here, the argument is that reward for a successful innovator comes in the form of monopoly rents. Intense competition, by lowering the monopoly

[5] When there is high market concentration along with market power, it is not necessary for the firms to invest in R&D to increase profit, they can simply charge higher price.

[6] Krugman (1984) addresses the implications of import protection for competitive advantage when there are increasing returns to scale arising, for example, from R&D. He shows that by increasing the domestic firms' market share, import protection encourages R&D effort and thereby improves their competitive advantage.

rents, reduces the incentive to innovate[7]. Aghion et al. (2001) and Aghion (2003) argue that the incentive to perform R&D depends not on the rents of a successful innovator *per se*, but rather on the innovator's incremental rents, that is the difference between rents of a successful innovator and that of an unsuccessful one. These models assume a duopoly with Bertrand price competition[8] and predict that product market competition and innovation effort have an inverted U shaped relationship. In the extreme case of monopoly, profit is independent of monopolist's technological leadership and therefore, it has no incentive to invest in technological progress. On the other hand, at high levels of competition firms find it difficult to appropriate rents from innovation and therefore, they have lower incentive to be innovative[9]. The above review of the theoretical literature clearly shows that the effect of import competition on innovation effort is ambiguous and depends on many things, such as the nature of domestic market structure, cost structure of the domestic industry and so on. So only an empirical analysis can throw light on this issue.

<u>Export</u>: Export allows firms to produce on a large scale and thereby exploit increasing returns to scale, made possible by fixed investments like R&D. Hughes (1986) argues that export can have a positive effect on innovation effort because elasticity of foreign demand with respect to R&D is likely to be greater than that of the domestic demand. Several reasons can be extended to support this point. For instance, since export market usually consists of several segmented markets and each sub-market varies from others in terms of consumers' preferences, entry barriers and elasticities, the likelihood that R&D will increase demand in some of these markets is higher than that in the domestic market. Secondly, if R&D is leading to product differentiation or the development of a new product, likely to be preferred by a small group of consumers, then export enables the firm to realise economies of scale in the production of this differentiated commodity. In this case, export possibilities allow the firm to make required R&D investment.

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[7] Aghion and Howitt (1992) modelled this Schumpeterian view of innovation and growth. In these models, innovations are made by outside firms who earn no rents if they do not innovate, and who become local monopolists if they do. An incumbent monopolist does not innovate in these models, since it is already enjoying monopoly rents, it has a weaker incentive than outsiders. Further, if the R&D technology exhibit constant returns to scale and incumbent has no advantage in R&D, given the monopoly rents it is enjoying, it will choose not to perform R&D in equilibrium. A new innovator becomes a monopolist in its own industry because of the (implicit) assumption of undifferentiated Bertrand competition within each innovative sector. See Aghion and Howitt (1992) and Aghion et al. (2001).

[8] Aghion (2003) also extends the model to the case of three firms.

[9] In these models, innovative effort is at the maximum when there is an intense competition between neck-and-neck firms, that is, competition between firms having similar levels of productivity. When there is intense competition between neck-and-neck firms, firms will try to escape competition by innovating.

Technology Import: In an open trade policy regime, firms can import foreign technology. This can be either in the form of capital goods embodying new technology or in disembodied form such as blue prints and designs. Technology import can affect incentive of the firm to invest in in-house R&D. The relationship between the two, however, has been a subject of intense debate in the development literature (see Evenson and Westphal 1995 and Kumar and Siddharthan 1997). One view suggests that these two are substitutes to each other, implying that technology import would reduce R&D investment (Pillai 1979 and Mytelka 1987). An opposing view, on the other hand, considers them as complementary (Cohen and Levinthal 1989, Mowery and Oxley 1995 and Bell and Pavitt 1997). It argues that, since most technologies consist of certain portion of tacit knowledge, absorption of imported technology requires some technological capability on the part of the firm and it can take the form of in-house R&D effort (Cohen and Levinthal 1989 and Patel and Pavitt 1994). Likewise, imported plants and machinery may also require adaptations and modifications to suit local conditions, raw materials and usage pattern (Teitel 1984, Mani 1995, Basant 1997 and Mody and Yilmaz 2002).

It has been recognised, however, that the relationship between technology import and local R&D is a complex one and depends on many things. For instance, Kumar (1987) highlights mode of technology import as one factor determining the nature of relationship. Firms importing through a package of foreign direct investment (FDI) may not be induced to invest in R&D because of their continued captive access to the centralised research laboratories of parent firms. On the other hand, unaffiliated licensees may be prompted to invest in R&D not only by the lack of access to the parent's laboratories, but also by the eagerness to absorb the technology during the life of the licensing agreement. Technology imported through FDI, therefore, may not be followed by local R&D, while licensing imports may be complemented by further research. Subrahmanian (1991) argues that the relationship also depends on the policy environment[10]. Firms' strategy to develop their technological capability can be different in a protectionist policy regime and in a liberal one. In the former regime, firms may supplement their technology imports by internal R&D and strengthen their manufacturing capability, although the building-up of design capability needed for continuous updating is neglected because of protection. On the other hand, in a liberal

[10] Aggarwal (2000) also emphasised this point.

economic environment firms may build-up technological capability through continued reliance on technology imports.

Besides substitution or complementary relationship, experience with imported technology can subsequently lead to innovative R&D. This takes place when it helps firms to build its innovation capability or by providing further insights into the technological opportunities[11]. Evenson and Westphal (1995, p.2262) brings out this point more clearly,

> Case studies of technological development in industry at the firm level clearly indicates that many important form of investment in technology are not captured in conventional measures. This is especially true of investments that are made in the course of mastering newly acquired technology. As was previously indicated, most of these investments do not count as formal R&D. Nonetheless, they simultaneously lead to productivity-enhancing technological change and to the accumulation of technological capability. In both respects, they are the means whereby the tacitness of technology and of local circumstances is overcome through experience-based learning and complementary additions of technological elements from outside the firm. Moreover, they contribute the foundations from which the capability effectively to undertake formal R&D evolves, without them there can be no meaning full technological development.

<u>Trade Related Knowledge Spillovers</u>: In the new growth models of Romer (1990a), Grossman and Helpman (1991a) and Rivera-Batiz and Romer (1991) R&D activity makes use of existing stock of scientific knowledge for further research and larger this stock higher the productivity of research effort[12]. In the previous chapter, we have found that international trade facilitates knowledge spillovers from the developed trade partner countries. The knowledge spillovers can increase the productivity of in-house R&D effort by enhancing the innovation and adaptation opportunities faced by the local researchers and thereby encourage R&D investment.

<u>General Equilibrium Effects</u>: Trade can affect R&D through its general equilibrium effects also. A country that imports human capital intensive goods may find that international integration reduces the derived demand for human capital – a prominent input into the innovative activity - and thereby lowers the cost of innovation. Trade might discourage R&D in a country that exports human capital intensive products, because the exportable sector draws human capital away from research activities (Grossman and Helpman 1991a).

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[11] The point that technology import can subsequently lead to more formal innovative R&D is also emphasised in Stewart (1981), Teitel (1984) and Katrak (1989).

[12] In the introduction chapter, we have found that this feature of knowledge production function is sustaining R&D process by keeping the rate of return at a level that makes investment in R&D profitable.

4.2.2 Review of Empirical Literature

In the context of Indian manufacturing industry, a number of studies examined the determinants of firms' R&D investment[13]. Since detailed reviews of the literatures are already available elsewhere, here we consider only some of the selected previous studies, as given in Table 4.7.

The table shows that, though, majority of the studies focused on the effect of technology import, there is no agreement among them on this. Another set of studies examined the influence of market structure and firm's size on innovation. One study that examined the effect of export on firms' R&D investment is Kumar and Saqib (1996). It shows that export has a positive effect on R&D. But the simultaneous relation between export and innovation is not addressed in this study.

Further, the review of the previous studies reveals that majority of them are in the context of protected trade policy regime. Although, some of the studies examined the effect of export and technology import, other aspects of trade are not analysed in any of the earlier studies. Analysis of these aspects, particularly the impact of import competition, is important, not only because of its prominent influence but also due to the theoretical ambiguity in its effect. Against this background in this chapter, we shall examine the effect of import competition, export, technology import and trade related knowledge spillovers on the probability and intensity of R&D investment. *R&D intensity* is defined as the ratio of R&D expenditure to sales of the firm.

The review of the theoretical literature shows that the effect of import competition on R&D is ambiguous and contingent on many things, including the market structure of the domestic industry. In this study, we shall also examine how the effect of import competition is shaped by the domestic market structure. Following the theoretical literature, we hypothesize that import competition has positive effect on innovative effort, when the domestic market structure is highly concentrated. It is possible that import competition in such an industry can provide the required discipline by reducing market power of firms and still leaves them with a scale of output and scope for product differentiation sufficient to make R&D investment viable.

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[13] For a detailed discussion of the literature as well as for a review of the evidence from national and international contexts on the determinants of R&D activity and for other issues involved in the creation of technological capability in developing countries see Kumar and Siddharthan (1997). See also Marjit and Singh (1995).

Table 4.7 Summary view of Major Previous Studies on R&D in Indian Industry

Study	Data	Issues Examined	Findings
Katrak (1985)	Industry level data for the period from 1964-65 to 1969-70 and for some later years.	Effect of technology import and firms' size on R&D effort	Positive effect of technology import and firms' size on R&D.
Siddharthan (1988)	Firm level data consisting of 166 firms for the financial year 1984-85	Hypothesised that private sector firms were doing adaptive R&D, so technology import was expected to have a positive effect on their R&D. Also examined the effect of firms' size and age.	Technology import through lumpsum payments encourages R&D in private sector firms. Age did not turn out to be a significant determinant of R&D.
Katrak (1989)	Two data sets of 300 and 51 firms for the periods 1966-71 and 1980-84 respectively	The relationship between R&D and technology import through collaborations.	Technology import has a positive effect on the probability of investing in R&D and on the amount of investment.
Katrak (1990)	Data consisting of 56 firms for the period 1980-84.	Effect of number of technology collaborations, purpose of foreign technology import, firm's size and the Exclusive Right to Sale (ERS) associated with technology import on firms' R&D expenditure.	Number of foreign technology import has a positive effect on R&D. ERS has a negative effect and technology import to strengthen the R&D capability of the firm has a positive effect.
Kumar and Saqib (1996)	291 firms for the period 1977-78 to 1980-81	Effect of firms' size, competition, technology import, export, appropriability of the innovation, firms' age, and adaptation opportunities on the probability and intensity of R&D investment.	Export intensity has a positive effect on the probability and intensity of R&D and technology import is insignificant.
Katrak (1997)	82 firms from electrical and electronics industries for the year 1990.	Examined (1) Whether the firms are importing technology after achieving in-house technological capability? and (2) Whether the technology import is stimulating further investment in in-house R&D?	Firms' initial technological capability is weakly related to technology import and it has a negative effect on the intensity of firms' technological effort measured in terms of R&D manpower.
Basant (1997)	1089 firms from chemical and industrial machinery for the year 1974-84.	Determinants of technological choices of firms and considers four choices. (1) No in-house R&D and no technology import, (2) importing technology (3) investing in in-house R&D and (4) both importing technology and investing in R&D.	In both industries, firms' size is positively related to the probability of doing either own R&D or import technology or do both. Import of capital goods also has the same effect in both industries.

4.3 Empirical Model, Data and Construction of Variables

4.3.1 Empirical Model

We use probit and tobit regression models to examine the effect of various dimensions of trade on the probability and intensity of R&D investment. The set of explanatory variables, we use, include those related to trade and other determinants of R&D. The variables related to trade are import penetration rate (IPR), export intensity (EXPOIN), technology import intensity (TECHIN) and trade related knowledge spillover stock (SK). The other determinants include size of the firm (SIZE), age of the firm (AGE), advertisement intensity (ADVTIN), rate of profit (ROP), share of value added in sales (VAS), domestic market concentration (MCON) and a dummy variable (D_FEP) that takes value one if the firm has foreign equity participation and otherwise zero. The selection of other determinants is based on previous studies in the context of Indian manufacturing industry.

In probit regression, we estimate the probability of investing in R&D as a function of above mentioned variables. In this model, the dependent variable Y_{it} takes value one if the i^{th} firm has invested in R&D in t^{th} year, otherwise zero. The probit model can be expressed as follows.

$$Prob(Y_{it} = 1) = F(\boldsymbol{\beta}'\mathbf{x}_{it}) \tag{4.1}$$

Where $F(.)$ is the standard normal distribution function, $\boldsymbol{\beta}$ is the vector of parameters to be estimated and **x** is the vector of explanatory variables; $\boldsymbol{\beta}'\mathbf{x}$ is defined as follows,

$$\begin{aligned}\boldsymbol{\beta}'x_{it} = {} & \beta_0 + \beta_1 SIZE_{it} + \beta_2 EXPOIN_{it} + \beta_3 TECHIN_{it} + \beta_4 ADVTIN_{it} + \\ & \beta_5 ROP_{it} + \beta_6 IPR_{it} + \beta_7 MCON_{it} + \beta_8 AGE_{it} + \beta_9 D\_FEP_{it} + \\ & \beta_{10} IPR_{it} * MCON_{it} + \beta_{11} SK_{it} + \beta_{12} VAS_{it} + \boldsymbol{\delta}'\mathbf{Z}_{it}\end{aligned} \tag{4.2}$$

Where **Z** is the matrix of industry specific dummy variables to capture the inter-industry variation in the innovation and adaptation opportunities and appropriability conditions and $\boldsymbol{\delta}$ is its coefficient vector.

The tobit model, in which the dependent variables is the R&D intensity[14] (RDINS), is expressed as follows,

$$\begin{aligned}RDINS_{it} = {} & \beta_0 + \beta_1 SIZE_{it} + \beta_2 EXPOIN_{it} + \beta_3 TECHIN_{it} + \beta_4 ADVTIN_{it} + \beta_5 ROP_{it} + \\ & \beta_6 IPR_{it} + \beta_7 MCON_{it} + \beta_8 AGE_{it} + \beta_9 D\_FEP_{it} + \beta_{10} IPR_{it} * MCON_{it} + \\ & \beta_{11} SK_{it} + \beta_{12} VAS_{it} + \boldsymbol{\delta}'\mathbf{Z}_{it} + \varepsilon_{it}\end{aligned} \tag{4.3}$$

4.3.2 Data

The study uses firm level data, covering the whole manufacturing industry, for the period 1994-95 to 1999-2000, obtained from the Centre for Monitoring Indian Economy PROWESS database. For the purpose of analysis, we consider a period during which the

[14] R&D intensity is defined as the ratio of R&D expenditure to sales.

Indian industry was operating in a more liberal trade policy regime (see Kusum Das 2003)[15]. The data consist of 15181 observations on 3675 firms, organised in 92 four-digit industries of National Industrial Classification (NIC), 1998. The other datasets, we use include the output data obtained from Annual Survey of Industries (ASI) and import and export data of the manufactured products. The source of trade data is the same as that of chapter two. We have harmonised the classifications in different datasets using two concordance tables, one is between NIC 1986 and 1998 and the second is between NIC 1998 and ISIC rev 2. In this harmonisation process across different classifications[16], we have to merge some of the four-digit industries to get proper matching and finally we left with 59 industry groups[17].

4.3.3 Construction of Variables

The details on the construction of variables and their expected relationship with probability and intensity of R&D investment are explained below.

Import Penetration Rate (IPR): We measure the import competition faced by an industry using import penetration rate. It is an industry level variable and is defined as follows,

$$\text{IPR} = \left(\frac{\text{Import}}{\text{Output} + \text{Import} - \text{Export}} \right)$$

Where export and output respectively denote the export and output of the industry and import refers to import of the industry's products[18]. The output data are taken from Annual Survey of Industries (ASI).

Market Concentration (MCON): The relationship between market concentration and innovation effort is extensively analysed in the theoretical and empirical literature[19]. It is argued that a concentrated market might encourage innovation by allowing firms to differentiate their products as well as by improving the appropriability conditions. It is,

[15] We consider only up to 1999-2000, because trade data are available at a more disaggregated level in readily usable electronic format only up to 1999-00. For more details on the trade database of Indian industry see Veeramani (2001). See also data appendix to chapter two.

[16] The concordance table between NIC 1998 and NIC 1988 is given in the National Industrial Classification-1998, Published by Central Statistical Organisation (CSO).

[17] In the 59 industry groups, a few groups are formed by aggregating two or three four-digit industries together and rest are the four-digit industries of NIC 1998.

[18] Since output figures are taken from ASI, which covers only the registered manufacturing sector, it should be noted that the denominator of this ratio provides only an approximate measure of domestic demand. Data on unregistered manufacturing output at this level of disaggregation are not available for the years of analysis.

[19] For a review of theoretical and empirical literature see Kumar and Siddharthan (1997) chapter 5.

however, also possible that greater market concentration may discourage R&D, if it allows firms to exercise monopoly power. In this situation, it is not necessary for firms to be innovative to reap higher profit. Smulders and Klundert (1995) show that market concentration can have a favourable effect on innovative effort, provided the market power of firms is not too high. This study measures the concentration in the domestic market using Herfindhal index (HI^D), which is defined below.

$$HI^D = \sum_i^n S_i^2$$

Where S_i is the share of i^{th} firm's domestic sale in the total domestic sales of n firms. Domestic sale is arrived at by subtracting exports from total sales of the firm. Domestic concentration is considered as a good indicator of the extent of concentration and market power, if the industry in question is involved in export. If exports constitute a larger portion of sales, index of concentration, which is based on firms' total sales, is a misleading indicator of their actual market power. This is because sale in the foreign market and sale in the domestic market must be distinguished, since the corresponding relevant markets are distinct. Producers are usually price takers in foreign markets. Hence, for that part of the production, which is exported, they are in a competitive market, facing an elastic demand. So export value must be subtracted from the total sales to assess the market power of the producers in the domestic market[20] (Jacquemin et al. 1980).

In this study, the choice of Herfindhal index over other alternative measures of concentration is based on the following reasons[21]. First, Herfindhal index satisfies all the desirable properties required for a concentration index (see Chakravarty 1995). Second, it has good statistical distribution properties and hence, can be estimated from a sample of firms. Hart (1975) shows that, when the size distribution of firms follows log normal distribution, Herfindhal index is a function of the moments of the original and first

[20] Jacquemin et al. (1980) used Herfindhal index of domestic concentration to measure the concentration in an open economy. We have also constructed two other measures of concentration. First is a Herfindhal index of concentration of total sales (include export) (HI^T) and second is the four firm concentration ratio (C^K), which is defined as the share of the largest four firms' sales in the total output of the industry, which is taken as corresponding ASI output. There exists moderately high correlation between these three measures of concentration. The correlation between HI^D and HI^T is 0.98, between HI^D and C^K is 0.46 and between HI^T and C^K is 0.51.

[21] Several alternative measures of concentration are available. For review of these measures and their properties see Hart (1975) and Chakravarty (1995).

moment distributions of the log of the size variable[22]. Third, it can be directly linked with oligopoly theory. For instance, for a given elasticity of demand one can show that the divergence between marginal cost and price (mark-up) is lower when the Herfindhal index is low. For a given elasticity of demand, a higher index, on the other hand, can indicate higher mark-up in the industry (Chakravarty 1995)[23]. Indeed, in an open economy context, Herfindhal index of domestic concentration does not indicate the true market power of firms, for they are subjected to import competition. In these situations, price-marginal cost ratio, which reflects both domestic and foreign competition, is recommended as a better measure of market power (Aghion 2003). In the present study, however, one of our objectives is to examine how import competition is affecting innovation effort, given the domestic market structure. For this, we have to identify the two sources of competitive pressure on domestic firms, namely domestic concentration and import competition, separately.

*Interaction between Import Penetration and Market Concentration (IPR*MCON)*: One of our objectives is to examine how the domestic market structure is shaping the effect of import competition. It is expected that import competition can encourage R&D in those industries that are more concentrated. This implies that these two variables (IPR and MCON) not only have separate effects, but also have interactive effect. We use an interaction variable between import penetration rate (IPR) and market concentration (MCON) to verify this hypothesis.

Firm Size (SIZE): Several reasons can be put forward to expect a positive relationship between size of the firm and its innovation effort[24]. Since R&D costs is a fixed costs, big firms can spread this costs over a greater amount of output than small ones. Firm size, therefore, is likely to exert a positive influence on the decision to innovate. Large firms are also in a favourable position, compared to small ones, regarding the financing of R&D. They usually have more internal resources at their disposal or they can easily mobilise funds from the capital market. Further, big firms often produce a variety of

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[22] Hart (1975) shows that "a wide variety of *ad hoc* measures of concentration or inequality are functions of the sample moments of the original and first moment distributions, so that information required may be obtained from a knowledge of the sample moment" (p. 430).

[23] It is also to be noted that Saving (1970) has established, within the confines of the static price leadership model, that concentration ratios measured by the share of k largest firms (K-firm concentration) can be related to the Learner measure of the degree of monopoly.

[24] For a detailed review of the theoretical and empirical literature on firm size and innovative activity see chapter four of Kumar and Siddharthan (1997).

products, so they benefit more from their innovation activities, if these involve economies of scope. Following the earlier studies, firm's size is proxied by its sales[25].

Rate of Profit (ROP): One of the important sources to finance R&D expenditure is the profit of the firm. Higher profit can increase the internal resources and therefore, one can expect a positive relationship between profit and R&D investment. Braga and Willmore (1991), Kumar and Saqib (1996) and Pamukcu (2003), however, note that one can also expect a negative relationship between the two, if lower profit, which firms might view as a threat to their survival, forces them to be innovative to improve their competitiveness. Further, there exists a two-way relationship between R&D activity and profit. Successful R&D usually results in innovative products or processes and contributes to higher profit. The issues arising from the simultaneous relationship will be discussed below. The rate of profit is taken as the ratio firm's net profit after tax to its sales.

Advertisement Intensity (ADVTIN): Firms usually spend on the advertisement of their products to increase market share. The relationship between advertisement and innovative effort is ambiguous. Advertisement promotes R&D, if it enables the firm to increase its market share and thereby enhance the rate of return on innovation. If the firm, on the other hand, opts for investment in advertisement rather than in R&D to increase market share, one can expect a negative relationship between the two. In this case, both act as substitutes rather than complements to each other. In this study advertisement intensity is defined as the ratio of advertisement expenditure to sales.

Age of the Firm (AGE): If learning by doing exists in production and R&D activity, more experienced firms have accumulated stock of knowledge that gives them greater comparative advantage in research. Hence, experience of the firm is expected to affect the probability and intensity of R&D positively. It is proxied by age of the firm, which is calculated from the year of incorporation. Of course, for some firms the year of incorporation and the year of starting of the production may not coincide, however, we are using this proxy for want of a better alternative.

Value Added Share (VAS): Since information is a commodity having imperfect market, it is argued that firm could better appropriate the returns from knowledge production by internalising its use rather than selling it (Arrow 1962). On this basis, one can expect

[25] Earlier studies using sales to proxy firms' size include Katrak (1990), Katrak (1997), Basant (1997) and Siddharthan and Nollen (2004).

that firms engaged in the larger part of the production chain of a product (higher vertical integration) have better opportunities for the internal application of knowledge and therefore, have higher probability of investing in R&D. In this study, following Kumar and Saqib (1996), share of value added in sales is taken as a proxy for the extent of vertical integration. A positive relationship between *VAS* and probability and intensity of R&D is expected[26].

Foreign Equity Participation (D_FEP): The effect of foreign equity participation on innovation effort is not clear. It can have a negative impact, if foreign participation allows firms to have access to technological knowledge stock of the parent foreign company and thus avoids the need to do in-house R&D. On the other hand, it can have a positive influence, if technology, which is sourced from the parent firm, needs to be adapted to suit local factor prices, usage pattern and so on. It is argued that such innovation and adaptation activities are more likely to take place in joint ventures than in purely local firms, as joint ventures do not have to support the huge search cost of appropriate technologies in the world market, since such information can be provided by the head quarters of the foreign partner (Pack 1982). Dahlman et al. (1987) argue that such positive effect on innovation is probable, if the local partner has the motivation and the ability to learn from the technological competence of the foreign partner. Further, in the context of globalisation of research activities of multinational firms, there is a higher probability that subsidiaries of foreign companies would start research units in India to take advantage of the low cost R&D personal available here.

The database provides only the latest years' information on foreign equity participation of firms. We have, therefore, used information on the dividend payments to foreign partners to identify whether a firm has any foreign equity participation in a year or not[27]. In the regression model, D_FEP is a dummy variable that takes value one if the firm has foreign equity participation, otherwise zero.

[26] It is also argued that value-added to sales ratio tends to be higher in consumer goods industries. Firms in these industries are also more likely to invest in R&D because of the better appropriability and differentiability conditions (Comanor 1967 and Kumar and Saqib 1996). Since we are using industry specific dummies to control for the industry characteristics like extent of appropriability and differentiability, we expect that VAS will capture what it intends to.

[27] One problem in using remittance of dividend to make inference about the foreign equity participation is that the availability of information depends on the declaration of dividend by the firms. If the firm is not declaring dividend in a year, we cannot observe its equity holding pattern. It is, therefore, important to keep in mind that the variable D_FEP is subjected to this problem.

Export Intensity (EXPOIN): Firm's extent of involvement in export is measured by its export intensity. It is defined as the ratio of export to sales. As in the case of profit rate, there exists a simultaneous relationship between export and innovation effort. While export can affect R&D through ways that we have already noted above, innovation can enhance productivity of the firm and thereby its export performance. The issues emerging from this simultaneity and the way we are trying to tackle this problem are taken up in the estimation section below.

Technology Import Intensity (TECHIN): We have already found that firm's technology import can affect its innovation effort. Technology import intensity is used to measure the extent of technology import. It is defined as the ratio of expenditure incurred on the import of capital goods and disembodied technology to sales.

Trade related knowledge spillover stock (SK): As we have noted above, trade related knowledge spillovers can enhance the productivity of the in-house R&D investment. In tobit and probit models, we use the trade related spillover knowledge variable (SK) that we have constructed in the previous chapter to capture the effect of knowledge spillovers on R&D. It is expected that this variable will have a positive effect on R&D investment.

Opportunities for process and product adaptations: The opportunities for innovation and adaptation vary across industries. Innovation and adaptation opportunities depend, among other things, upon the maturity of the technology, the gap between Indian and world standards, the degree of monopoly hold over the technology and the nature of intellectual property protection. In addition, some technologies need adaptation to local conditions[28]. In capital goods industries such as transport equipment, non electrical machinery, and electrical equipment industries product adaptation are often necessitated by the different climatic conditions (as in electronics and telecommunication equipment), poor quality of raw materials (as in the case of coal based thermal power equipment), poor infrastructure (as in the case of transport equipment), difference in the intensity of use (as in the case of telecommunication equipment) and so on. Industry dummies at two-digit level of NIC 1998 are used to capture the inter-industry variation in the opportunities for innovation and adaptation[29].

[28] Kumar and Saqib (1996) argues that in the case of developing countries, where bulk of the R&D is of adaptive type, opportunities for adaptation is more important rather than that for innovation.

[29] Studies that used industry dummies to account for the inter-industry differences in the technological opportunities include Scherer (1965) and Kumar and Saqib (1996)

Table 4.8 Summary Measures of Variables

Variable	Mean	Standard Deviation
RDINS	0.0024	0.0125
SIZE*	161.61	1344.22
EXPOIN	0.1157	0.2259
TECHIN	0.0216	0.1020
ADVTIN	0.0059	0.0195
ROP	0.5256	0.3189
VAS	0.3077	0.3189
IPR	0.1468	0.1955
MCON (HI^D)	0.0987	0.1063
AGE	21.90	19.71
SK#	7918.23	866601.33
Number of observations having R&D investment	3807	--
Number of observations having foreign equity participation	2661	--
Number of Firms	3675	--
Number of Observations	15181	--

Note: * Sales value is in Rs 10 million. # SK is in millions of US $

4.4 Estimation and Results

4.4.1 Estimation

In this section, first we take up the econometric issues involved in the estimation of probit and tobit models specified in (4.1) and (4.3). A discussion of the results follows.

Estimation Issues: In the regression models specified in (4.1) and (4.3), some of the explanatory variables are endogenous. The endogeneity problem can arise in the case of EXPOIN, ADVTIN, ROP and SIZE. So a positive significant coefficient for EXPOIN or for ROP may not be due to their effect on R&D, instead it could also be due to the influence of innovation on these variables or it could be the combined effect of both relationships. This makes drawing reliable inference about their effect from the estimated coefficients difficult[30]. One way to tackle this issue is to use a simultaneous equation model. But due to the computational difficulties we are not resorting to it. Instead, we are also adopting what is prevalent in the very recent empirical literature to estimate probit and tobit regression models consisting of potential endogenous explanatory variables, that is estimating the models using one-year lagged values of the explanatory variables. Studies that have adopted this approach to control for the possible simultaneity

[30] Clearly, there exists a time lag in the effect of R&D on performance variables like export and profit. It takes some time for the firm to introduce an invention by investing in R&D and it takes further time for its commercial implementation. Only after the innovation one can observe the effect of R&D on performance variables, like productivity, profit or export competitiveness.

relationship in binary choice and tobit models[31] include Pamukcu (2003) and Siddharthan and Nollen (2004).

Lagged values of the explanatory variables are predetermined variables and one can also expect a high correlation between these and current values due to the persistence in the trends of many variables, like firm size. This predetermined nature and high correlation with current values allow one to use them as proxies for the current values and estimate the coefficients that are free from simultaneity problem.

Table 4.9 Correlation between lagged and current values

Variable	Correlation
IPR	0.7737
MCON	0.9698
IPR*MCON	0.9602
SIZE	0.9957
EXPOIN	0.9163
TECHIN	0.2238
ADVTIN	0.8197
ROP	0.5568
VAS	0.5788
SK	0.2830
AGE	1.0000
D_FEP#	0.9185

Since D_FEP is a dummy variable, Spearman's rank correlation is reported.

In our dataset, as Table 4.9 shows, for the majority of the variables, there exists a high correlation between one-year lagged and current values. In this study, two versions of the probit and tobit models, presented in (4.1) and (4.3), are estimated. In the first one, (Model1) current values of the explanatory variables are used and in the second version, (Model 2) one-year lagged values are employed.

Another issue is to account for the panel nature of the data. Firm specific effects can influence the R&D effort. Initially we have estimated the probit and tobit models using random effect specification[32]. This estimation uses Gauss-Hermite quadrature to compute the log likelihood and its derivatives[33]. We, however, found that the coefficient estimates are highly unstable and sensitive to the number of quadrature points, making

[31] Aggarwal (2000) used lagged value of R&D investment in an OLS regression of technology import to avoid simultaneity between technology import and R&D.

[32] Tobit and probit regression models are not amenable to fixed effect estimation see Greene (2000) and Wooldridge (2002).

[33] We have used Stata 8.1 for estimation. Another econometric package Limdep 7 also uses Gauss-Hermite quadrature to estimate random-effects probit and tobit models. For more on Gauss-Hermite quadrature procedure see Greene (2000), p.179-180.

quadrature approximation not at all reliable[34]. We have, therefore, adopted the alternative estimation procedure, namely pooled estimation, in which cross-sections of firms are pooled over the years[35]. We use maximum likelihood method to estimate probit and tobit models. Model (4.1) and model (4.2) are also estimated using OLS fixed-effects specification, as in Bernard and Jensen (1999) and Siddharthan and Nollen (2004). These results are given in the appendix to this chapter[36]. The estimates show that, although within transformation removes a larger part of variation from the data and thus exacerbate other problems, important results of the study are still robust to fixed effect estimation.

Marginal Effects in Probit and Tobit models: The estimated coefficients of the probit and tobit regressions are not the marginal effects of variables as in the case of linear ordinary least square (OLS) regression. In these models, the marginal effect of an explanatory variable is conditional on all the independent variables (Ai and Norton 2003). Estimation of marginal effects allows us to find out the change in the independent variable due to a small change in the explanatory variable. More importantly, as we shall see below, the sign and statistical significance of the marginal effect of an interaction variable can be different from those of the corresponding coefficient. So it is important to compute marginal effects for correct inference. The marginal effects (ME) of the independent variables in probit model, except that of *IPR*, *MCON*, IPR*MCON and D_FEP, are estimated as follows,

$$\text{Marginal Effects of } j^{th} \text{ variable} = f(\hat{\boldsymbol{\beta}}'\mathbf{X})\hat{\beta}_j$$

Where **X** is the matrix of explanatory variables, $\hat{\boldsymbol{\beta}}$ is the vector of estimated coefficients, $f(.)$ is standard normal density and $\hat{\beta}_j$ is the estimated coefficient of j^{th} explanatory variable. The marginal effects (ME) of IPR, MCON and IPR*MCON are estimated using the following expressions,

$$\text{M E of IPR} = f(\hat{\boldsymbol{\beta}}'\mathbf{X})(\hat{\beta}_6 + \hat{\beta}_{10}MCON)$$

[34] When quadrature approximation is used to estimate models in which some of the independent variables are constant within groups, as the industry dummies in our case, coefficient estimates usually become highly unstable. If estimates are sensitive to the number of quadrature points, then one alternative is to use pooled estimation. (see Cross-sectional and Time Series Reference (XT) Stata 8, pp.10)

[35] Siddharthan and Nollen (2004) also adopted pooled estimation method to estimate tobit regression.

[36] Estimation of linear probability model using fixed effect specification is appropriate only when very large sample is available (see Bernard and Jensen 1999). So we have estimated the OLS fixed effect model only for Model 1, as it allows maximum number of observations.

$$\text{M E of MCON} = f(\hat{\beta}'X)(\hat{\beta}_7 + \hat{\beta}_{10}IPR)$$

$$\text{M E of IPR*MCON} = \{\hat{\beta}_{10} - [(\hat{\beta}_6 + \hat{\beta}_{10}MCON)(\hat{\beta}_7 + \hat{\beta}_{10}IPR)]\hat{\beta}'X\}f(\hat{\beta}'X)$$

Marginal effect of the dummy variable D_FEP is computed by taking the difference in the predicted probabilities at two values of the dummy variable.

Marginal effects (ME) in tobit model, except that of IPR, MCON, and IPR*MCON, are estimated as follows[37],

$$\text{M E of } j^{th} \text{ variable} = F\left(\frac{\hat{\beta}'X}{\hat{\sigma}}\right)\hat{\beta}_j$$

Where $\hat{\beta}$ is the vector of estimated coefficients of tobit regression, $\hat{\sigma}$ is the standard deviation of the random error term and $F(.)$ is the cumulative normal distribution function.

$$\text{M E of IPR} = F\left(\frac{\beta'X}{\hat{\sigma}}\right)(\hat{\beta}_6 + \hat{\beta}_{10}MCON)$$

$$\text{M E of MCON} = F\left(\frac{\hat{\beta}'X}{\hat{\sigma}}\right)(\hat{\beta}_7 + \hat{\beta}_{10}IPR)$$

$$\text{M E of IPR*MCON} = F\left(\frac{\hat{\beta}'X}{\hat{\sigma}}\right)\hat{\beta}_{10} + \frac{1}{\hat{\sigma}}\left[f\left(\frac{\hat{\beta}'X}{\hat{\sigma}}\right)(\hat{\beta}_6 + \hat{\beta}_{10}MCON)(\hat{\beta}_7 + \hat{\beta}_{10}IPR)\right]$$

In both probit and tobit models, marginal effects and their standard errors are estimated for each observation and averages are reported[38]. The standard errors of the marginal effects are estimated using delta method[39]. Since sign and statistical significance of the ME of IPR, MCON and IPR*MCON can vary from one observation to another, an average may not be a good representative of the effect of these variables (Ai and Norton 2003). So, while making inference on these variables, we also utilise the distribution of the marginal effects and their test statistics (z or t values).

[37] See McDonald and Moffitt (1980) and Greene (2000, p.910)

[38] To compute marginal effects, one can evaluate the expressions at the sample means or at every observation and use sample average of the individual marginal effects. Since the functions are continuous, the theorem of Convergence in Quadratic Means (the Slutsky theorem) applies and in large samples both approaches give the same answer. But in small or in moderate sized samples this is not applicable. Current practice favours averaging the individual marginal effects when it is possible to do so. (Greene, 2000, p.816).

[39] For delta method of computing standard errors of non-linear combination of parameters, see Greene (2000), p. 357-358.

4.4.2 Results

Probit and tobit estimates of Model 1 and Model 2 are reported respectively in Table 4.10 and Table 4.11. The row with name LLF gives the maximised value of the log likelihood function. LR test reports the results of the likelihood ratio (LR) test of the null hypothesis that all the slope coefficients are equal to zero, which is rejected in every case. We first consider the effect of variables that are not related to trade. Estimated marginal effects from the probit model show that size of the firm has a significant positive effect on the probability of investing in R&D. Estimate from Model 2, which uses lagged value of sales, also reveals the same. This evidence supports the theoretical hypothesis of a positive effect of firm's size on innovative effort. In tobit regression also size is significant and positive, indicating that R&D intensity is increasing with firm's size. Numerical value of its marginal effect is, however, extremely low (0.000000242 in Model 1 and 0.000000264 in Model 2) indicating that R&D intensity is increasing very slowly with size[40].

Advertisement intensity (ADVTIN) has a significant positive effect on the probability and intensity of R&D. Probit estimates of Model 1 show that a one point increase in the advertisement intensity, on an average, increases the probability by 1.36 times and the corresponding estimates for tobit is 0.019. These results may be indicating a complementary relationship between the R&D and advertisement. The latter may be helping firms to enhance the market for products (developed through R&D) and thereby increasing the rate of return on innovation.

In probit and tobit estimates of Model 1 and Model 2, rate of profit (ROP) is positive and significant. Estimates obtained from Model 2 show that a one point increase in the rate of profit increases the probability of R&D investment by 0.06 times and intensity by 0.0009 times. The dummy variable, representing the foreign equity participation has a significant positive sign in both probit and tobit estimates. Having foreign equity participation increases the probability of R&D by 0.19 points and intensity by 0.0023 points. One of the possible reasons for this positive effect can be the setting up of R&D centres in India by the subsidiaries of multinational firms in their attempt to take advantage of low cost R&D personal available here.

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[40] Some of the previous studies included square of the size variable also in the regression equation to test the inverted U shape relationship between R&D and size. However, since probit and tobit regression models are already in non-linear form, incorporation of further non-linear structure into the model makes the interpretation of the result difficult (see Norton et al. 2004)

Table 4.10 Estimated Coefficients and Marginal Effects of Probit Model

	Model 1		Model 2 (Lagged Values)	
	Coefficient	Marginal Effect	Coefficient	Marginal Effect
Constant	-1.7459* (-36.52)		-1.7618* (-31.78)	
IPR	-0.2513* (-2.26)	-0.2064 (-0.96)	-0.2578 (-1.83)	-0.0216 (-0.73)
MCON	-0.4152* (-2.00)	-0.0319 (-0.93)	-0.5192* (-2.10)	-0.0631 (-1.22)
IPR*MCON	1.8283* (2.61)	0.4838* (2.55)	1.9015* (2.30)	0.5312* (2.26)
SIZE	0.0006* (16.46)	0.0002* (16.46)	0.0008* (15.56)	0.0003* (15.56)
EXPOIN	0.4307* (7.24)	0.1287* (7.24)	0.3958* (5.63)	0.1289* (5.63)
TECHIN	-0.0190 (-0.15)	-0.0058 (-0.15)	0.1507 (1.14)	0.0491 (1.14)
ADVTIN	4.5628* (7.64)	1.3640* (7.64)	3.5328* (5.10)	1.1509* (5.01)
ROP	0.2474* (5.33)	0.0739* (5.33)	0.1803* (3.55)	0.0587* (3.55)
VAS	-0.0241 (-0.57)	-0.0072 (-0.57)	0.0933 (1.40)	0.0304 (1.40)
SK	4.36e-08 (0.28)	1.30e-08 (0.28)	-1.07e-07 (-0.59)	-3.49e-08 (-0.59)
AGE	0.0140* (23.29)	0.0042* (23.29)	0.0137* (19.50)	0.0045* (19.50)
D_FEP	0.5546* (18.21)	0.1854* (18.21)	0.5242* (15.31)	0.1847* (15.31)
LLF	-7090.38		-5313.89	
LR test	2918.64* (0.00)		2198.38* (0.00)	
Number of Observations	15181		10828	

Notes:

(1) z values are given in parentheses, except for LR test; for LR test Chi-square values are reported and P values are given in parentheses.
(2) All regressions include industry dummies.
(3) * Indicates significant at five per cent level.

Experience of the firm, proxied by its age (AGE), has a significant positive effect on both probability and intensity of R&D. As we have hypothesised, this may be suggesting that firms' accumulated knowledge through production experience is increasing research productivity. The results on the effect of share of value added in sales (VAS), a proxy for the extent of vertical integration, are not robust; it is significant only in the tobit estimates of Model 2.

Table 4.11 Estimated Coefficients and Marginal Effects of Tobit Model

	Model 1		Model 2 (Lagged Values)	
	Coefficient	Marginal Effect	Coefficient	Marginal Effect
Constant	-0.0474* (-33.60)		-0.0391* (-29.47)	
IPR	-0.0169* (-5.90)	-0.0014* (-2.95)	-0.0144* (-4.86)	-0.0015* (-2.65)
MCON	-0.0151* (-2.77)	0.0005 (0.22)	-0.0122* (-2.32)	0.0001 (0.28)
IPR*MCON	0.1066* (5.94)	0.0219* (5.10)	0.0823* (4.77)	0.0191* (4.22)
SIZE	1.18e-06* (6.34)	2.42e-07* (6.29)	1.14e-06* (5.91)	2.64e-07* (5.87)
EXPOIN	0.0133* (8.48)	0.0027* (7.13)	0.0091* (5.97)	0.0021* (5.36)
TECHIN	0.0041 (1.24)	0.0008 (1.23)	0.0109* (4.20)	0.0025* (3.93)
ADVTIN	0.0944* (6.47)	0.0194* (5.70)	0.0666* (4.70)	0.0155* (4.33)
ROP	0.0066* (5.28)	0.0014* (4.85)	0.0038* (3.53)	0.0009* (3.38)
VAS	0.0019 (1.87)	0.0004 (1.82)	0.0042* (3.04)	0.0010* (2.94)
SK	5.73e-10 (0.14)	1.18e-10 (0.12)	-5.06e-09 (-1.33)	-1.17e-09 (-1.15)
AGE	0.0003* (18.23)	0.0001* (11.85)	0.0003* (16.45)	0.0001* (10.89)
D_FEP	0.0111* (14.43)	0.0023* (10.13)	0.0090* (12.93)	0.0021* (19.25)
LLF	4546.43		4390.63	
LR test	1883.71* (0.00)		1431.31* (0.00)	
Number of Observations	15181		10828	

Notes:

(1) t values are given in parentheses, except for LR test; for LR test Chi-square values are reported and P values are given in parentheses.
(2) All regressions include industry dummies.
(3) * indicates significant at five per cent level.

The results show that marginal effect of market concentration, MCON, is not significant in any of the estimates. As we have noted above, the sign and statistical significance of its marginal effect can vary from one observation to another. So one has to look at the distribution of the marginal effects and test statistics to make correct inference on its effect. Table 4.12 presents the distributions of the marginal effects, z and t statistics of MCON, IPR and IPR*MCON. It shows that although majority of the marginal effects of MCON are negative (see part A and C), most of them are not significant (see part B and D). Therefore, the results suggest that market concentration, in general, is not showing any significant effect on innovation effort.

Table 4.12 Distribution of Marginal Effects (ME) and Test Statistics
(As per cent of number of observations in each Model)

A. Distribution of the Marginal Effects (ME)- Model 1

Variable	Probit Estimates		Tobit Estimates	
	ME<0	ME>0	ME<0	ME>0
IPR	78.0	22.0	85.2	14.8
MCON	79.3	20.6	68.2	31.8
IPR*MCON	0.0	100.0	0.0	100.0

B. Distribution of Test Statistics-Model 1

	Probit		Tobit	
Variable	z<-1.96	z>1.96	t<-1.96	t>1.96
IPR	32.4	4.0	68.8	8.5
MCON	8.7	6.4	33.1	22.5
IPR*MCON	0.0	97.6	0.0	98.5

C. Distribution of the Marginal Effects (ME): Model 2

Variable	Probit Estimates		Tobit Estimates	
	ME<0	ME>0	ME<0	ME>0
IPR	77.3	22.7	86.7	13.3
MCON	85.4	14.6	70.5	29.5
IPR*MCON	0.0	100.0	0.0	100.0

D. Distribution of Test Statistics-Model 2

Variable	Probit Estimates		Tobit Estimates	
	z<-1.96	z>1.96	t<-1.96	t>1.96
IPR	0.0	1.8	69.3	5.9
MCON	23.4	0.3	20.4	18.0
IPR*MCON	0.0	97.6	0.0	99.7

Export intensity shows significant positive effect on the probability and intensity of investment. Estimates of its marginal effect in probit regression of Model 1 and Model 2 are very close to each other and indicate that a one-point increase in the export intensity increases probability of R&D by 0.13 times. The results, thus, show that export promotion can have a favourable effect on innovation effort. Contrary to the theoretical hypothesis, trade related knowledge spillovers[41] (SK) is not showing significant relationship with R&D in any of the estimates[42].

The result on the effect of technology import is found to be sensitive to whether we use current values or its lagged values in the regression model. Current technology import intensity is not showing any significant effect on the probability and intensity of R&D. Tobit estimate of Model 2, however, shows a significant positive effect on intensity of R&D investment. The regression models are also estimated by including embodied and disembodied technology import intensities separately to get further insights. The results show that current values of only disembodied technology import intensity is positive and significant in both probit and tobit estimates, while lagged values of both variables are significant in tobit and that of disembodied technology import is significant in probit estimates. The results, thus, show that technology import has a positive effect on R&D investment. As we have noted above, the relation between technology import and R&D is a complex one. It is contingent on many other factors and one can expect a positive relationship on the basis of a number of reasons. So further research is needed to understand the reasons behind the positive effect. Nonetheless, on the basis of the results of the present study, we have the following tentative conclusion on this. In the previous chapter, we have found with respect to the contribution to output that there exists a substitution relationship between disembodied technology import and R&D in low technology sector. Hence, a possible reason for this result, as we have mentioned in the theoretical section, could be that production experience with imported technology might be increasing the capability to do innovative research in future as shown by the significant positive coefficient of lagged values. To reiterate, further research is needed to get a clear picture on this issue.

One of our objectives is to examine the effect of import competition on R&D investment. Probit estimate of the average marginal effect of import penetration rate is not significant in any of the models. The distribution of its marginal effects shows that 78 per cent of them are negative in Model 1 and 77 per cent in Model 2. Majority of them, however, are insignificant, as revealed in part B and D of the table. Different from this, tobit estimates of the average marginal effect is negative and significant in both

[41] The reported results are based on SK constructed assuming one year lag in the effect of foreign R&D on Indian R&D. We have also considered lags of two and three years, however, the results are the same.

[42]One of the reasons for the insignificance of SK could be its collinearity with industry dummies. It is significant when estimated without industry dummies. Another reason could be the its lower variability in the sample, due to the shorter time series and its availability at a greater level of aggregation.

models. Further, for the majority of the observations the marginal effect is negative and significant (see Table 4.12). The results, thus, show that import competition, taken alone, has a significant negative effect on the intensity of investment, whereas it is not showing any effect on the probability of investing in R&D.

One important objective of the study is to examine the role of domestic market structure in shaping the effect of import competition. For this we have included an interaction variable between import penetration rate and market concentration. The average marginal effect of this variable is positive and significant in both probit and tobit estimates of Model 1 and Model 2. Further, its distribution shows that for all observations in both models it is positive and around 98 per cent of them are significant, making the results on interaction effect quite robust. These results may be suggesting that the effect of import competition depends on the domestic market structure. Import competition encourages R&D investment in those industries where domestic market structure is more concentrated.

To understand the variation in impact of import competition with the level of concentration, we have computed its marginal effect, keeping all other variables except IPR and MCON, at their mean values[43]. These estimates from probit and tobit models are plotted against the Herfindhal index in Figure 4.1 and 4.2 respectively.

Figure 4.1 shows that the marginal effect of import penetration rate is increasing with the level of concentration. When the Herfindhal index is around 0.15, marginal effect is almost zero and increases to 0.10 at a Herfindhal index of 0.30. One point to note from the figure is that at very low level of concentration marginal effect is negative. The tobit estimates, plotted in Figure 4.2, also show the same picture. These results, thus, suggest that import competition stimulates R&D investment only when the domestic market structure is more concentrated[44].

[43] Estimates from Model 1 are used for this computation.

[44] It should be noted that the threshold level of concentration (0.15) at which the marginal effect of import competition is changing sign is high when we compare it with 0.10, the mean of the Herfindhal index in the data.

Figure 4.1 Marginal Effect of Import Penetration: Probit Estimates

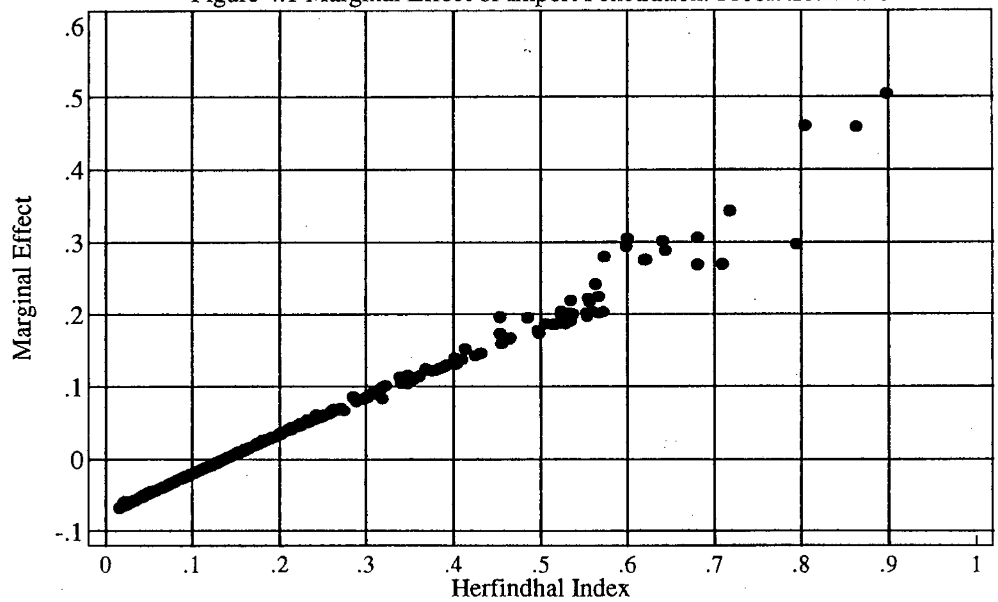
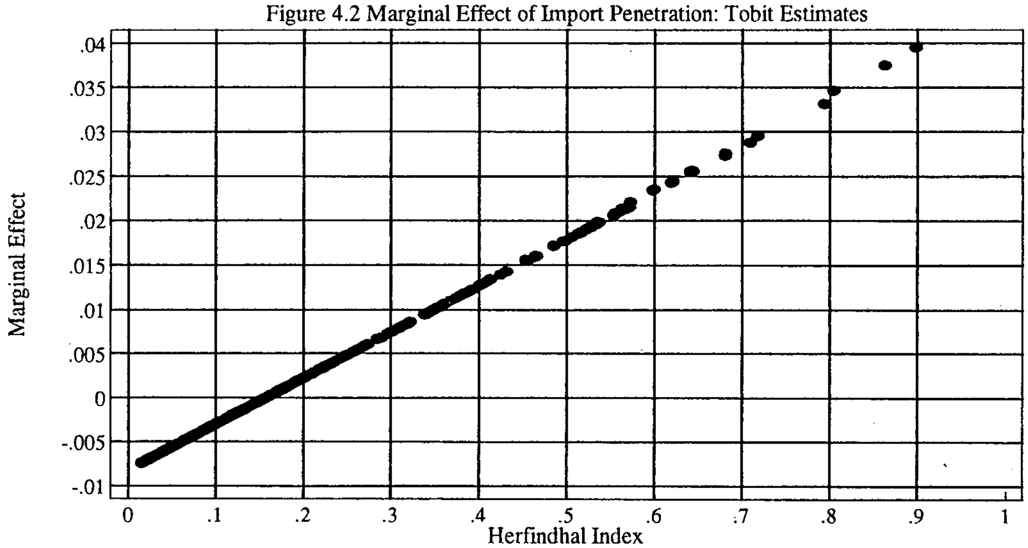


Figure 4.2 Marginal Effect of Import Penetration: Tobit Estimates



In a situation of greater market concentration, import competition may be reducing the market power of firms, leaving them without any option other than investing in productivity enhancing activities like R&D to increase profit. Further, in this case, greater appropriability conditions ensured by the higher market concentration and larger scale output due to less number of firms may also be encouraging R&D investment. On the other hand, in those industries, where the domestic concentration is already lower (competition is higher), import may be further intensifying the competitive pressure, and thereby reducing the incentive of the firm to invest in R&D. This result, thus, seems to be supporting the theoretical argument, as presented in some of the growth models, that both too much competition and too little competition are not conducive for innovation and growth. When there is too little competition in the domestic industry liberal import policy is an option that can be used to discipline the firms and thereby induce them to make productivity enhancing investments.

3.5 Summary and Conclusion

This chapter has examined the effect of international trade on the R&D investment of firms. Trade can affect innovation effort through import competition, export, technology import and trade related knowledge spillovers. The theoretical results on the effect of import competition and technology import on R&D are ambiguous, leaving it as an issue for empirical analysis. This study has examined the effect of export, import competition, technology import and trade related knowledge spillovers on the probability and intensity of R&D investment, using probit and tobit regression models. In this analysis, drawing upon the theoretical literature, we have hypothesised that the effect of import competition on R&D investment depends upon the domestic market structure.

As a background to the empirical analysis, we have examined the trends and composition of R&D investment of the manufacturing industry. It shows that innovation effort of the private sector firms increased during the 1990s. This increased participation of the private sector firms in the R&D activity may be the result of competitive pressure generated by the liberal trade and industrial policy regime. The results of the empirical analysis show that export has a positive effect on the probability and intensity of R&D investment. This is supporting the argument that export promoting trade strategy encourages innovation. Although the effect of technology import on R&D is found to be positive, further research is needed to find out the exact reason for this result. The evidence on the impact of import competition on R&D investment indicates that it is shaped by the domestic market structure. Import competition encourages R&D investment only in those industries, where the domestic market structure is highly concentrated. When the domestic market is less concentrated, import competition, on the other hand, has a negative effect on R&D. This result may be supporting the theoretical argument presented in some of the new growth models that both too much competition and too little competition are not conducive for innovation and growth. If there is too little competition in the domestic industry, liberal import policy is an option that can be adopted to encourage the firms to be innovative. On the basis of empirical evidence, it seems safe to make the following observations on the kind of trade policy that is conducive for innovation and growth. Since export is always found to have a positive effect on R&D investment, export promoting trade strategy can boost the innovation efforts of the domestic industry. However, when it comes to the import liberalisation, an across the board liberal import policy is not desirable, instead the empirical evidence suggests a selective import liberalisation policy depending upon the market structure of the industry.

Appendix

Table 4A. 1 OLS Fixed-effect Estimates

Variables	Dependent variable	
	Y	RDINS
Constant	0.0795* (2.45)	0.0063* (2.87)
IPR	-0.1105* (-2.61)	-0.0072* (-4.39)
MCON	0.0804 (0.82)	-0.0053 (-1.40)
IPR*MCON	0.6657* (2.50)	0.0479* (4.64)
SIZE	6.50e-06 (1.36)	7.45e-09 (0.04)
EXPOIN	0.0557* (2.14)	0.0017 (1.65)
TECHIN	0.0198 (0.86)	0.0013 (1.47)
ADVTIN	0.3081 (1.54)	0.0222* (2.88)
ROP	0.0295* (3.18)	0.0001 (0.13)
VAS	-0.0245* (-2.62)	0.0007 (1.78)
SK	2.16e-08 (0.71)	6.68e-10 (0.57)
AGE	0.0074* (5.42)	-0.0001 (-0.93)
D_FEP	0.0398* (3.08)	0.0008 (1.57)
Over all R^2	0.0802	0.0015
Number of Observations	15181	

Notes:

t values are in the parentheses. * Indicates significant at five per cent level.

5

Summary and Conclusion

5.1 Objectives and the Context of the Study

The present study has examined the effect of international trade on the process of technological progress of Indian manufacturing industry. Technological progress is considered as the source of long run economic growth. In this perspective, the larger objective of the study is to understand the impact of trade on the long run growth prospects of the manufacturing industry, which is considered as the 'engine of economic growth'. An analysis of this sector, therefore, assumes significance from the point of view of the overall economic growth.

There are mainly three factors that led to the present study. First, the recent developments in the growth theory. This literature, while highlighting a number of channels through which trade can affect technological progress, show that theoretical results are ambiguous and sensitive to many country and industry specific factors. Only empirical analyses can throw further light on the issue of the effect of trade on technological progress. Second, lack of convincing empirical evidence on the effect of trade openness on economic growth. A number of studies examined the effect of trade on economic growth, mainly using aggregate country level data. While, these studies, in general, conclude that trade openness encourages economic growth, their methodology and results have been criticised on several grounds, making the question of trade-growth relationship still an unresolved one. The problems of the aggregate country level studies as well as their inability to give deeper insights into the growth effects of trade raised the need for micro level studies based on rigorous analytical framework and better quality data. Third, the more open trade policy regime that India has been following since 1991 to improve growth and competitiveness of Indian manufacturing industry. A study focusing on the effect of trade on the process of technological progress of the manufacturing industry assumes significance in this context.

The empirical analysis of the study is based on the recent developments in the growth theory, namely endogenous growth theory. In this literature, technological progress is endogenously generated. It incorporates trade into growth models and identifies following channels through which trade can affect technological progress: (1) By changing the structure of the manufacturing industry, (2) through trade facilitated technology spillovers from the developed trade partner countries, and (3) by affecting the R&D investment of firms. The present study empirically examines these channels using more disaggregated industry and firm level data. We have also considered the role of factors internal to the economy and industry in shaping the effect of trade.

5.2 Empirical Analysis and Results

In the analysis of trade-induced structural change, the structure of the manufacturing industry is defined in terms of the shares of various sectors in the total manufacturing output. Trade can change the structure by expanding sectors having comparative advantage and contracting others. Its growth implications arise from the fact that sectors vary in their potential to generate technological progress through sources like learning by doing and R&D. If trade expands sectors having higher potential to generate technological progress such as research intensive and technology intensive sectors, the industry as a whole would experience a higher rate of technological progress. Further, the presence of these industries also increases technical progress of other industries through positive externalities. If trade shrinks the shares of these sectors, it would adversely affect the overall technological progress. The study examined whether trade expanded or contracted the shares of growth generating sectors of the manufacturing industry. Industries having better opportunities for technological progress are identified using three criteria, namely technological intensity, R&D intensity and capital intensity.

As a prelude to the structural change analysis, the study examines the trends in the extent of trade openness of the manufacturing industry and the structure of trade in manufactures. It shows that import and export intensity of the manufacturing industry, surrogate measures of trade openness, increased over time, with significant variation across industries. It also revealed a changing trade structure, reflecting the evolving comparative advantage in various sectors. The increase in the trade openness with significant variation across industries and changing structure of trade suggest a possible effect of trade on the structure of the manufacturing industry.

In the structural change analysis, we have decomposed the change in the share of a sector into three proximate sources: due to (1) shift in domestic demand, (2) import, and (3) export. The sum of the last two is termed as change in share due to trade. The analysis is conducted between 1989-90 and 1994-95. The contrast between the two years with respect to the trade policy regime prevailed may have allowed us to get a clear picture of how trade affected the structure of the industry. The results show that trade negatively affected the shares of technology intensive, high and medium R&D intensive and capital intensive sectors. In these sectors, however, the share enhancing effect of domestic demand is more than offsetting the negative contribution of trade, enabling them to increase their observed shares. The study, thus, reveals that although trade negatively affected the growth generating sectors, trade is found to be not in a position to reduce the observed shares of these sectors. The inability of trade to turn the observed structure against the growth generating sectors is the large and growing domestic demand vis-à-vis the volume of import. An important assumption of the theoretical models analysing the growth effects of trade-induced resource allocation is the small economy assumption, only in a small economy import can meet a larger part of the domestic demand and thereby displace the domestic industry. Further, the already achieved technological capability, though not very high, along with lower wage advantage may have also helped these sectors to withstand import competition. Further research, however, is needed on the exact role of wage advantage and technological capability in various industries. The study, however, shows that the policy of import liberalisation in developing countries has to keep in mind its deleterious effect on sectors having better opportunities for technological progress.

In the analysis of the effect of trade related R&D spillovers on manufacturing productivity, we have considered the effect of two types of spillovers separately, namely *rent spillovers* and *knowledge spillovers*. The first type of spillovers takes place through import of capital goods embodying better technology and the second one through trade facilitated interaction of domestic producers with products, markets and producers of technology leader countries. In addition to the productivity effect of these two types of spillovers, we have also examined their inter-sectoral variation and the role of firms' own effort in enhancing their productivity effect. For empirical analysis, we have used firm level panel data of 19 industries for the period 1988-89 to 2000-01. In this respect, the study is an improvement over the previous ones that are based on country level data. Fifteen developed OECD countries are considered as the source of trade related knowledge spillovers. The intersectoral variation in the effect of trade related R&D spillovers is examined using two alternative classification schemes of industries. In the first classification scheme, industries are classified into technology intensive and low technology intensive sectors and in the second one into scientific and non-scientific sectors.

In the empirical analysis, production function approach with Levinsohn and Petrin (2003) methodology to overcome simultaneity problem is employed. The two specification tests and the comparison of estimates obtained using Levinsohn and Petrin (LP) methodology with that of OLS and Within suggest that LP estimates are free from simultaneity problem. The major findings based on LP estimates are as follows.

The results reveals that imported machinery has higher productivity effect than the machinery purchased from domestic producers in technology intensive industries. In low technology industries, both types of machinery have equal contribution. On the other hand, knowledge spillovers are mainly confined to low technology industries. High technology industries are not gaining through knowledge spillovers, may be due to the tacitness of technology in these industries. The results, thus, suggest that there exists inter-sectoral variation in the effect of trade related R&D spillovers on productivity. The pattern of sectoral variation, however, depends on the type of spillovers.

The study also shows that firms' R&D investment helps them to absorb knowledge spillovers. This result supports the argument that knowledge spillovers are not passive process, but active effort on the part of the firm is necessary for its proper absorption. This result may be suggesting that countries having a certain level of R&D would benefit more from knowledge spillovers than those not have any R&D experience. This goes against the assumption made in some of the endogenous growth models that knowledge spillovers are independent of country characteristics. Further, we also found a complementary relationship between imported machinery and knowledge spillovers, indicating that imported machinery is helping firms to absorb knowledge spillovers. This suggests that the benefits of imported machinery go beyond its direct contribution. Another important result is that the study does not find any evidence supporting the assumption of some of the growth models that there exists a complementary relationship between imported and domestically produced machinery. Instead, we find some evidence for a substitution relationship between the two. The study also shows that firms' R&D investment has a significant effect on productivity, contrary to results of the previous studies using 1970s and 1980s data. A possible reason could be that in the liberal policy regime, firms might have been investing in R&D to improve productivity and competitiveness.

In the analysis of the effect of trade on R&D investment, we have examined the impact of import competition, export, technology import and trade related knowledge spillovers on the probability and intensity of R&D investment. Formal theoretical results on the impact of import competition are ambiguous and suggest that final outcome depends on factors like market structure and cost structure of the domestic industry. Similarly, the effect of technology import on R&D is also ambiguous, making an empirical analysis more important. In this analysis, drawing upon the theoretical literature, we have hypothesised that the impact of import competition is shaped by the domestic market structure.

As a background to the analysis, we have first examined the trends and composition of R&D investment of the manufacturing industry. This shows increasing effort on the part of the private sector firms on innovation front during the 1990s. The results of the econometric analysis indicate that export has a positive effect on the probability and intensity of R&D investment, even after accounting for the two-way relationship between the two. This result, thus, supports the theoretical argument that export promoting trade strategy encourages innovation. Empirical evidence on the impact of import competition suggests that direction of the effect depends on domestic market structure. Import competition promotes R&D investment only when the domestic market structure is highly concentrated. Whereas in industries having low market concentration, import competition discourages innovation effort. The possible reason for this variation in the impact of import competition across different market structures could be as follows. In highly concentrated industries, import competition maybe reducing the market power of firms and thereby compels them to be innovative. At variance, in less concentrated industries, import competition may be further intensifying the competitive pressure, leading to lower incentive to invest in R&D because of lower appropriability conditions. These results may support the theoretical argument, as presented in some of the recent growth models, that both too much competition and too little competition are not conducive for innovation and growth. When there is too little competition in the domestic industry, liberal trade policy is an option that may be used to discipline the domestic industry and thereby induce them to be innovative. The result, thus, suggests that liberal import policy in all industries across the board may not promote innovation. The evidence suggests a selective import liberalisation policy depending upon the domestic market structure. Whereas, an across the board export promoting trade strategy appears to be encouraging innovation.

5.3 Concluding Remarks

The empirical analysis of the present study shows that international trade can influence the process of technological progress of the manufacturing industry and its long run growth prospects through several channels. It also corroborates the stance of the theoretical literature that trade can affect technological progress positively as well as negatively and the outcome depends upon many factors that are specific to the economy and industry.

The study shows that the two dimensions of trade, namely import and export, affect technological progress differently. Import can have a favourable effect by making available intermediate commodities that embody better technology as well as by facilitating knowledge spillovers. In addition, import competition can also stimulate innovation effort when the domestic firms are enjoying higher market power, which discourages innovation. Import, however, can have adverse effect on sectors having higher potential to generate technological progress such as technology intensive industries due to weaker comparative advantage in these industries.

Export is found to have positive effect as it encourages learning and innovative effort of firms. By increasing the share of products of industries having greater opportunities for learning and innovation in the export basket, developing countries can increase the rate of learning in these industries. This trade induced learning also helps them acquire technological capability required to move up the technology ladder and produce more sophisticated products. Further, export participation also increases the firms' eagerness to learn new technology, as keeping up with best practice technology is a precondition for success in export market.

The above arguments may suggest that export promoting trade strategy with selective import liberalisation would be conducive for faster technological progress and economic growth. Since technological learning mainly takes place at the firm level and depends heavily on the initiative taken by the firm, export promotion strategy that rewards efficient firms is considered superior to import protection, which is sector specific, to expedite learning and technological progress[1]. Implementation of selective trade policy,

[1] See Romer (1993) and Srinivasan (1993).

however, needs a political and bureaucratic infrastructure that is immune to the pressure of rent seeking interest groups. The quality of the existing political and bureaucratic institutions, therefore, plays an important role in the choice of suitable trade policy[2]. Further research could focus on identifying and formulating innovative political and bureaucratic institutions that are immune to rent seeking pressure groups in a democratic set up.

It is widely recognised in the literature that achievement of certain threshold level of technological capability is essential for the trade induced-learning to takes place. Technological capability depends, among other things, on the availability of skilled labour force, firms' own R&D effort, efficient scientific infrastructure and other institutional facilities and a conducive policy environment. Having a threshold level of technological capability not only speeds up the trade induced-learning, but also helps the industry to withstand the adverse effects of trade. So studies examining in detail the role of various factors like availability of skilled labour, institutions and infrastructure facilities and government policy in shaping the impact of trade are required to have a fuller understanding of the issue of trade and technological progress. Given the limitations of the data, we have not pursued this in full.

[2] More on this see Romer (1993) section III. See also Pack and Westphal (1986).

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