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The Impact of Human Capital on International Competitiveness and Trade Performance of Manufacturing Sectors

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Contents

Chapter 1

Introduction: the general framework

The concepts of human capital and international competitiveness are intuitively linked, probably due to the feeling that investing in workers' human capital increases their productivity. Many publications on trade performance seem to reflect the worries of governments about the strength of their countries' international competitiveness.[1] The central aim of the thesis is to establish the mechanisms along which human capital can affect international competitiveness as well as trade performance. The thesis presents, firstly, a theoretical exposition of how human capital affects productivity as a measure of international competitiveness and, secondly, an empirical investigation into the effects of human capital on productivity and trade flows. It is important to note that in the economic literature the relationship between human capital and productivity is the topic of much debate and research (e.g. Blaug, 1976, 1985; Maglen, 1990), whereas the definition of international competitiveness and even the usefulness of defining international competitiveness is controversial among economists (e.g. Francis and Tharakan, 1989; Fagerberg, 1996). Before setting out the supposed links between human capital and international competitiveness in more detail in the following chapters of the thesis, this introduction first briefly discusses the various forms of human capital investments. Next, the choice of productivity as an indicator of competitiveness is justified. Finally, the underlying general framework and the plan of this thesis are presented.

Schultz (1961) distinguishes five forms of human capital investment, namely health facilities and services, on-the-job training (including apprenticeships), formal education, study programmes for adults which are not organized by firms, and the migration of individuals or families to adjust to changing job opportunities. Becker (1975) subdivides human capital investments into on-the-job training (general and specific training), schooling, knowledge about job opportunities, and health and working conditions. According to Blaug (1976, p. 5) the basic idea of the concept of human capital is that "people spend on themselves in diverse ways, not for the sake of present enjoyments, but for the sake of future pecuniary and non-pecuniary returns." An individual decides to invest in human capital if the present value of all future benefits as a result of the investment decision is at least as great as the present value of the costs due to the investment decision.

Although workers accumulate human capital, they are not directly involved in competing internationally for world market shares of goods. The supply of

1. See for example Van Eijk and Van Drimmelen (1989; eds), Francis and Tharakan (1989; eds), Porter (1990), OECD (1992), European Commission (1994), Ministry of Economic Affairs (1995, 1996).

heterogeneous workers with respect to their human capital meets the firms' demand for heterogeneous workers on the labour market. Firms can use the human capital of workers, e.g. to increase productivity and to introduce new production techniques. Rather than workers firms compete on world markets, yet the human capital is incorporated in the workers. Therefore this thesis considers the accumulation of human capital from the point of view of both the worker and the firm. It is useful to describe how firms can acquire human capital, since firms are the smallest units of analysis in international competition. However, the empirical analysis of the thesis is conducted at the sector level due to the availability of international comparable data sets across industrialized countries.

In this thesis we will assume that firms can acquire human capital in two ways. First they can recruit better educated workers and second they can train the workers currently employed (Groot and De Grip, 1991; Cörvers, 1994). Workers have invested in human capital by initial schooling, which stands for all kinds of initial education at primary, secondary and tertiary levels.[2] When students leave school, enter the labour market and become engaged in the production process, they supply the skills that are acquired by their initial schooling. The supply of these skills is therefore largely determined by the country's educational system and by students' choices. Once workers are employed, they can further accumulate their human capital by investment in continuing training, which includes various forms of training like formal training courses, apprenticeships, introductory programmes for young or new workers and learning-by-doing.

This thesis does not primarily aim to explain the decisions of workers and employers with regard to different kinds of human capital investments, but will rather consider the three roles workers' human capital could have in the production process of the firm. Firstly, human capital is regarded as a *factor of production*. Standard economic theory traditionally considers homogeneous capital and homogeneous labour as the only two production factors in a production function. Nowadays it is commonly accepted that human capital is a relevant production factor too. The higher the level of human capital per worker, the higher both the productivity level per worker and the output level of the firm. The reasons for this relationship are twofold (Welch, 1970). Workers with a higher skill level due to investments in human capital are assumed to be more efficient in working with the resources at hand, i.e. these workers produce more physical output.[3] This is called the *worker effect*. Moreover, the *allocative effect* points to the greater (allocative) efficiency of better skilled workers in allocating all input factors to the production process between the alternative uses. Microeconometric studies on the estimation of the production function of the firm show the relevance of human capital as a production factor by allowing for different educational categories of labour input (e.g. Broer and Jansen, 1989; Hebbink, 1992). Furthermore, studies explaining national economic growth also reveal that human capital is an important

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2. Schooling and education are used interchangeably. However, Pencavel (1991) states that education and schooling are not synonymous, because education takes place not only in schools, but also out of schools, i.e. in families, communities and work places.

3. Physical output may also include services like hairdressing or transportation of goods.

factor input (e.g. McMahon, 1984; Rasmussen and Kim, 1992).

Secondly, human capital is considered to be of crucial importance for the *diffusion of new technologies* (e.g. Nelson and Phelps, 1966; Bartel and Lichtenberg, 1987). To introduce new technologies, thus achieving productivity growth, firms require skilled workers. This is called the *diffusion effect* of human capital. Thirdly, human capital is an important *input factor in research and development* (R&D) activities, which is in particular emphasized by endogenous growth theory (e.g. Van Cayseele, 1990; Romer, 1990; Den Butter and Wollmer, 1992). In most countries more than half of the R&D expenditures are wage costs of highly-skilled workers in particular (NOWT, 1994). Since R&D expenditures are a key factor to developing new technologies and thereby establishing productivity growth (e.g. Mairesse and Sassenou, 1991), human capital is considered to be of crucial importance for achieving productivity growth. This is called the *research effect* of human capital.

From the above effects of human capital on productivity, it follows that accumulating human capital by investing in workers increases the output per worker, i.e. labour productivity. The competitiveness of a country improves if average labour productivity increases, although there is no agreement on how competitiveness ought to be defined (see for example Francis, 1989). The World Competitiveness Report (World Economic Forum, 1995) regards productivity as only one of the many indicators of countries' international competitiveness, apart from labour costs, product quality, infrastructures, government debt, exports. Moreover, indicators of price competitiveness can be distinguished from indicators of non-price competitiveness. The former is determined by the nominal wage, the productivity level of labour and the exchange rate to measure relative movements in competitive position of sectors or countries. Decreasing the nominal wage, increasing the productivity level or depreciating the exchange rate improves the competitive position of sectors or countries since the unit costs of products decrease. Also a decrease of the real returns on other production factors than labour, like the real return on capital, increases the price competitiveness of sectors or countries. Non-price competitiveness is measured by quality measures like product characteristics and after-sales services.

Despite the controversies on the concept of international competitiveness, few would disagree that productivity is an important indicator of international competitiveness. This thesis will primarily stick to the importance of productivity as the indicator of competitiveness. The choice of productivity is founded on two reasons. Firstly, human capital theory explicitly refers to the consequences of human capital investments for labour productivity. By distinguishing between different forms of human capital and considering the effects on productivity, this thesis analyses the links between human capital and international competitiveness in a direct way. Human capital investments are here regarded as an important *source* of international competitiveness, because they are supposed to increase the productivity of workers. Therefore the *human capital model* plays an important role in this thesis to analyse and understand the relevance of human capital investments in international competition.

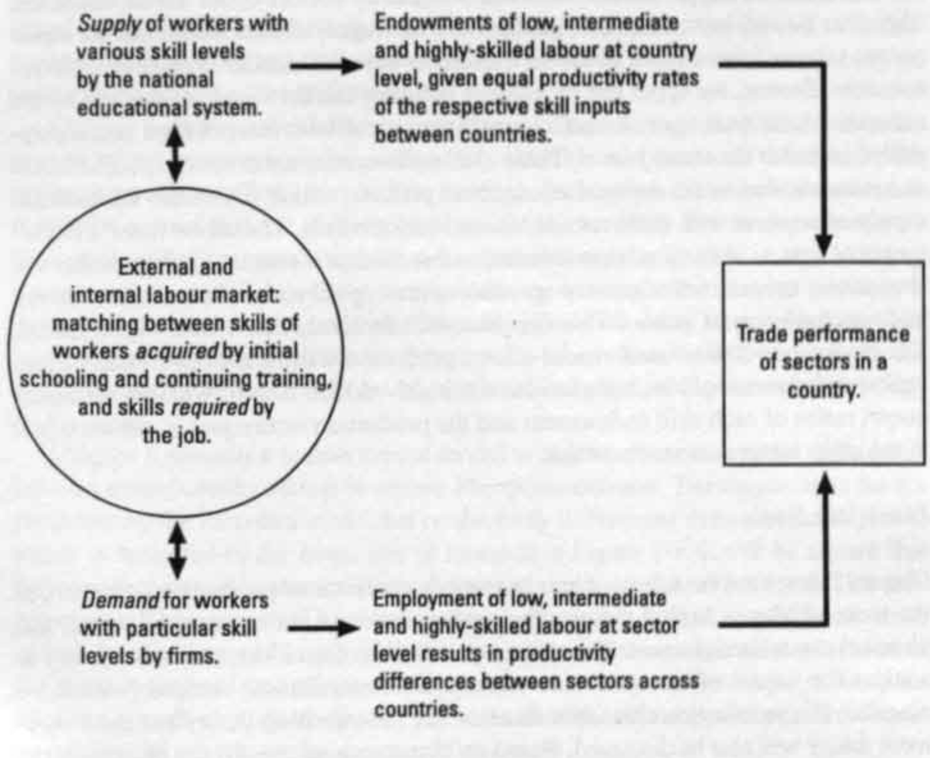
Secondly, according to Porter (1990), "The only meaningful concept of competitiveness at the national level is national productivity." Porter argues that productivity is the prime long run determinant of the nation's income level per capita and the nation's standard of living. Porter also makes it clear that striving for a trade surplus does not increase competitiveness per se. Exporting more low productivity goods for low prices, while having low wages and a weak currency, in order to buy more imported goods produced with high productivity standards does not increase a nation's standard of living so much. Increasing the export of technologically advanced goods produced with high productivity standards, which allows a country to import more low productivity goods, is more favourable since it results both in a higher average productivity level and in a higher standard of living. This implies that a country with a strong export position on the world market is not automatically supposed to be strongly competitive, but displays a good trade performance. To be competitive, the country has to show up with high productivity levels. Since the *Ricardian model* of trade regards labour productivity as an important determinant of trade flows (see e.g. Dornbush et al., 1977), this model will be used in the thesis to underpin the relevance of productivity levels for trade flows. In the Ricardian model productivity differences between countries are due to the use of different technologies. Therefore the human capital inputs for a particular sector may differ across countries, which results in different productivity levels. According to the Ricardian model, the productivity levels of each sector relative to the same sectors in other countries determine the sectoral exports of one country against other countries.

As stated before, competitiveness is often defined by some indicator of trade performance, for example world export shares (see Brouwer and Kleinknecht, 1993; European Commission, 1994). The OECD (1992a) and Fagerberg (1996) too mention the double meaning of competitiveness, i.e. the economic well-being of citizens (related to both the productivity level and the income level) and the trade performance. However, this thesis uses the term 'trade performance' to refer to the *results* of the process of competition, measured by for example the world export share of a particular economic sector or the difference between exports and imports (i.e. net trade) at sector level. In other words, the analysis on trade performance refers to the position of a country's sector in world trade, and leads to the development of indicators of 'revealed comparative advantage' (i.e. revealed by trade flows). In fact the trade performance of countries or sectors has to be considered as the outcome of international competition in which production volumes and market shares are distributed all over the world. In the *Heckscher-Ohlin-Vanek (HOV) model* the sectoral trade performance of goods is dependent on the country's factor endowments of labour, human capital and physical capital. Unlike the Ricardian model in which differences between similar sectors across countries with regard to the use of the available production techniques determine the trade performance, the HOV model assumes that the productivity levels and input-output ratios of a particular sector are equal across countries. These equal productivity levels and input-output ratios are related to the same choice for a production technique in similar sectors across countries. However, in the HOV model the national average productivity levels and the related income levels may differ since some countries have a better educated workforce than other countries, which implies that these countries are specialized in producing and exporting goods that require a relatively high factor input of skilled workers. In this way the average productivity level in these countries is pushed upwards.

The general framework

Figure 1.1 shows the relationships between human capital, international competitiveness and trade performance in the general framework of the thesis. Most theoretical and empirical studies on human capital, international competitiveness and trade performance analyse only part of the general framework described in Figure 1.1. The framework of the thesis makes use of three models that have been mentioned before: the human capital model, the Ricardian model and the Heckscher-Ohlin-Vanek model. The points of view and assumptions in these models are partly different. Nevertheless, the framework intends to provide a complete picture of both the driving forces of human capital as a source of international competitiveness and the resulting impact on trade performance. The relationships of the framework will be briefly discussed below.

Figure 1.1
The general framework of the thesis



As the top and bottom left-hand boxes of Figure 1.1 indicate, references are made to the supply of and demand for workers with different educational backgrounds. The circle in Figure 1.1 refers to the matching of workers' skills acquired by the different forms of human capital investments of initial schooling and continuing training to the skills required to achieve the productivity maximum associated with the jobs performed within the firms. School leavers, unemployed workers and employed workers (who search for another job) with different educational and training backgrounds apply for jobs on the external labour market. To accumulate human capital for achieving higher productivity, firms can either recruit more highly educated workers on the external labour market or train the currently employed workers in the internal labour market.

The figure shows that the human capital stock at the sector and the country level explains international trade along two important lines of research. First, the lower line of research in Figure 1.1 indicates that the employment of workers with particular skill levels by firms results in the human capital inputs at sector level. In the empirical part of the thesis human capital is regarded as a sector-specific factor input that can explain the productivity differences across sectors. To account for the factor input of human capital the thesis distinguishes between workers of three different skill levels: low, intermediate and highly-skilled workers. The arrow from 'Employment of low.......' to 'Trade performance of sectors in a country' indicates that productivity differences between sectors are regarded as the driving force behind the sectoral trade performance. This is in line with the Ricardian model of international trade. Moreover, in the Ricardian model the production techniques in use by sectors differ across countries. Therefore the employment of low, intermediate and highly-skilled labour and the input-output ratios of these types of labour can differ between similar sectors of different countries. Second, the upper line of research indicates that the supply of workers by the national educational system results in endowments of low, intermediate and highly-skilled labour at the country level. These skill endowments are country-specific factor endowments due to the national educational policies, which determine the national supply of workers with different educational backgrounds. The arrow from 'Endowments of low.......' to 'Trade performance of sectors in a country' indicates that the abundances or scarcities of country-specific human capital endowments determine the trade performance of sectors. This is in line with the Heckscher-Ohlin-Vanek model. The Heckscher-Ohlin-Vanek model allows productivity differences between human capital endowments of low, intermediate and highly-skilled labour, whereas the input-output ratios of each skill endowment and the production techniques in use are equal in the same sectors across countries.

Plan of the thesis

Chapter 2 describes the nature of human capital as a factor of production and refers to the roots of human capital theory. The analogy between investments in human and physical capital is discussed. The chapter justifies the use of human capital theory to analyse the impact of investments in education on international competitiveness. To elucidate this justification alternative theories like the screening theory and the assignment theory will also be discussed. Based on human capital theory, the chapter shows that human capital can be measured by distinguishing different educational types of labour. If these educational types of labour are distinguished by their skill level, then the skill structure of the work force indicates the human capital stock of the work force. It is argued that the skill structure rather than the wage structure of the work force represents the human capital stock of a firm, a sector or a country by analysing the productivity and wage consequences of investing in human capital in a standard partial labour market model with emphasis on the supply and demand of human capital.

Chapter 3 discusses the role of human capital in productivity growth. It may be expected that increasing the factor input of human capital does more than just increase output as traditional factor inputs like physical capital and labour do. It will be argued that, firstly, human capital is an important factor input in research and development activities, which in turn stimulate technological progress and economic growth. Secondly, technological progress seems to be skill-biased, which points to human capital as an important requirement to introduce new production technologies.

Chapter 4 distinguishes between the different forms of human capital investments in initial schooling and continuing training. The chapter refers to the circle of Figure 1.1 and describes the matching between skills acquired by workers and required by the jobs that are performed by these workers. It will be argued that in the long run there is no difference between the workers' skills acquired by initial schooling and continuing training on the one hand, and the skills required to achieve the productivity maximum of the job on the other. The chapter explains how the differences between these acquired and required skills usually disappear in the long run due to additional investments in human capital. It will be argued that the workers' acquired skills and the firms' required skills will perfectly match in the long run, apart from the risk of underinvestment in training and skill obsolescence. This result will be used to measure the productivity effects of the skill structure.

Chapter 5 distinguishes between four effects of human capital on the level or the growth of productivity: worker, allocative, diffusion and research. Moreover, the productivity effects of low, intermediate and high skills on productivity are explained. It will be argued that the skill structure of the labour force can be represented by distinguishing between workers that have acquired low, intermediate or high skills by investments in initial schooling and continuing training. The chapter presents a theoretical framework for understanding the effects of skills on productivity and reviews the empirical evidence on this topic. Some reference will be made to the complementarity between skills on the one hand and physical capital and technology on the other.

Chapter 6 presents a human capital model to explain the productivity differences between manufacturing sectors in various European countries. The chapter tests for the prediction by the Ricardian model that productivity differences determine trade flows, which is indicated by the lower line of research in Figure 1.1. It will be argued that these productivity differences result from the skill structure of the work force. This skill structure will be represented by distinguishing between the sectoral employment shares of low, intermediate and highly-skilled labour. The chapter analyses the relevance of the above-mentioned four effects of intermediate and highly-skilled labour on both the level and growth of productivity, and discusses the risk on under- and overinvestment in skills in the manufacturing sectors of the sample.

Chapter 7 presents the Heckscher-Ohlin-Vanek model and formulates hypotheses to test for the impact of the country-specific human capital endowments on the trade performance of manufacturing sectors in various industrialized countries. The analysis in the chapter is indicated by the upper line of research in Figure 1.1. The hypotheses are formulated by means of using the four productivity effects of human capital. The country-specific human capital endowments reflect the national skill structure and are represented by the factor endowments of low-skilled, intermediate-skilled and highly-skilled workers and the technological knowledge incorporated in highly-specialized R&D workers.

Chapter 8 further analyses the impact of both country-specific and sector-specific factors on trade performance. Again the Heckscher-Ohlin-Vanek model is used as the starting point for the empirical analysis. This chapter integrates both the country-specific and the sector-specific determinants of trade performance in a factor content analysis of Dutch trade. Instead of including only the manufacturing sectors as in the preceding chapters, the analysis covers all sectors in the Netherlands to test the Heckscher-Ohlin-Vanek model and to analyse the impact of sector-specific factor inputs on trade performance.

Chapter 9 summarizes and concludes the thesis. The chapter reviews the lessons learned from the thesis and recapitulates the country-specific and sector-specific determinants of the trade performance of manufacturing sectors. Finally, some directions for further research are given.

Chapter 2

Human capital as a factor of production

2.1 Introduction

This chapter deals with some simple consequences of the impact of the production factor human capital on output and workers' productivity according to human capital theory. Section 2.2. will first consider the production factor human capital and its analogy with physical capital. Section 2.3 briefly considers the relation between education and labour productivity according to human capital theory, screening theory and assignment theory. Although the screening theory has challenged human capital theory by questioning the productivity enhancing effect of human capital, it will be argued that screening theory can be regarded complementary to human capital theory. Section 2.4 shows how human capital can be modelled in a production function. Therefore a closer view to the measuring of human capital is required. Section 2.5 discusses a partial labour market model to show the relevance of measuring human capital by the skills of the work force rather than by the workers' wages. Section 2.6 concludes the chapter.

2.2 The analogy between human and physical capital

To accumulate capital by investing in machines, buildings or workers, costs are made which are expected to raise profits in future. Adam Smith recognized the necessity of accumulating the stock of fixed capital to increase production. In his *Wealth of Nations* he argues that fixed capital consists not only of machines, buildings and land but also of "the acquired and useful abilities of all the inhabitants or members of the society." (Smith, 1776, reprint 1981, p. 377) Furthermore, Smith appeared to be aware of the concept of human capital as he continues: "The acquisition of such talents, by the maintenance of the acquirer during his education, study, or apprenticeship, always costs a real expense, which is a capital fixed and realized, as it were, in his person. Those talents, as they make a part of his fortune, so do they likewise of that of the society to which he belongs. The improved dexterity of a workman may be considered in the same light as a machine or instrument of trade which facilitates and abridges labour, and which, though it costs a certain expense, repays that expense with a profit."

Two estimation methods for valuing human capital can be revealed from the above quotation (see e.g. Kiker, 1966). According to the first method human capital is measured by the *cost-of-production method*, due to which human capital equals the costs of investing in education and training, for example forgone earnings of studying instead of working, expenses on books and uniforms, travel costs and school fees. This method has the disadvantages of, firstly, not taking into account the depreciation of human capital during the working life of an individual (see Chapter 4 on skill obsolescence) and, secondly, not distinguishing between the individual's investment and consumption motives to spend on education (see Blaug, 1970). According to the second method human capital is measured by the *capitalized-earnings method*, which does not suffer from the above disadvantages. This method measures human capital by the present value of future income streams due to investments in education and training.

However, in Marshall's *Principles of Economics* (1890) the notion of calculating human capital by capitalizing future income flows at an appropriate discount rate is disregarded as 'unrealistic'. Marshall's main reason for his statement was that there is no capital market for investments in human capital. Therefore workers cannot capitalize their earning capacity or trade the rights to future earning power. Marshall's authority is said to be responsible for the complete neglect of the concept of human capital and the investments aspects of education by economists during the end of the nineteenth and the first half of the twentieth century. Kiker (1966, p. 481) states that essentially "the concept of human capital was somewhat prominent in economic thinking until Marshall discarded the notion as 'unrealistic'." According to Blaug (1970) it cannot be justified that Marshall is blamed for the neglect of human capital that lasted till the 1960's, since Marshall accepted both Adam Smith's comparison between an educated man and an expensive machine and the investment analogy of human and physical capital.

Although Marshall did not reject the concept of human capital and even pointed to the danger of underinvestment in education as a result of the individuals' lacking financial means to invest in education (i.e. the imperfect capital market for human capital investments), he rejected the idea of including the acquired skills of people in the measurement of the capital stock of an economy, because economies lack capital markets for labour (Blaug, 1970). However, there are indications for the existence of an (imperfect) human capital market. For example, sportsmen and entertainers sign contracts to work for a number of years in exchange for a capital sum of money, the earnings capacity of a worker determines his or her mortgage agreement and insurance-policy, and student loans are repaid during the working career. Moreover, Blaug illuminates the analogy between physical and human capital by considering heterogeneous workers (with respect to their capital value of abilities and education) in a slave economy, and conducting an analysis as if workers were machines which can be bought and sold, must be depreciated and require maintenance. "All of these considerations show that the absence of a capital market for labour is more a difference of degree between physical and human capital than a difference of kind." (Blaug, 1970)

2.3 Human capital theory and alternative theories

The renewed attention for the human capital concept in the 1960's[1] has laid the foundations of modern *human capital theory*, which are still of current interest. Central to human capital theory is the notion that workers invest in themselves by increasing

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1. The renewed attention for the concept of human capital is illustrated by various articles on human capital that were published in the supplement of *The Journal of Political Economy* in 1962.

the amount of human capital they embody, which raises their productivity. By investing in human capital individuals sacrifice present income for higher expected future income streams. The costs of investing in human capital consist of tuition fees and earnings forgone due to education instead of working, whereas the expected benefits consist of a higher future income as a result of higher productivity. The profitability for individuals' investment in education can be calculated by the net present value method, under which the costs and benefits of education are discounted at the prevalent discount rate. Using this method, Mincer (1974) showed that the percentage increments in annual earnings are linearly dependent on absolute differences in years of initial schooling times the rate of return on one additional year of schooling. Also the profitability of other forms of human capital investments, like on-the-job training (see Chapter 4) can be calculated by the net present value method.

In human capital theory (see also Becker, 1975) the strong positive relation between education and earnings is causal, running from the former to the latter. The abundant research on the relation between workers' education and earnings shows that the average earnings of workers are strongly positively related to their level of educational attainment (see e.g. Psacharopoulos, 1987, ed.). Moreover, age-earnings profiles (see e.g. Blaug, 1970; Mincer, 1974; Pencavel, 1991) show the relationship between earnings and age at different levels of educational attainment. It indeed turns out that the wages of more educated workers are in most cases higher than those of less educated workers of the same age. Unfortunately, however, it is not clear to what extent investments in human capital *cause* earnings and productivity increases (see for a discussion Blaug, 1976 and 1985).

Alternative theories for human capital theory do not presuppose a causal relationship between the level of education and productivity. In *screening theory* employers select workers on certain personal abilities that determine workers' productivity. These personal abilities may be indicated by workers' educational qualifications ('credentials', e.g. diplomas), by their working experience and by their age, gender and social background. There are, however, many versions of screening theory (see for example Winkler, 1987). Both Arrow (1973) and Spence (1973) state that the educational qualifications ('credentials') of workers on the job market are a signal for employers. Signalling by workers and screening by employers are in fact two sides of the same mechanism.[2] One important assumption which Arrow and Spence make in their signalling models is that the costs of acquiring education, for example forgone earnings, tuition fees and physical costs, are lower for individuals with higher productive abilities, because they need less time to acquire an educational credential. For this reason individuals with higher productive abilities will (on average) invest more time in education.[3] If it is assumed that these abilities refer to both school records and the performance at work, then educational credentials signal more productive

2. For this thesis it is does not matter so much whether there is screening by the employer or signalling by the worker. Wherever the term 'screening theory' is used in this thesis it may refer to both screening and signalling.

3. See also Becker (1975) and Hartog (1993) on this topic. Hartog (1993) shows that only under certain conditions will abler individuals undertake more schooling.

workers. Employers, searching for indicators that may be correlated with productivity, use those credentials to sort out more productive individuals. Similarly, in the labour queue model of Thurow (1975) the employer regards educational qualifications as a signal or screening device. Individuals on top of the labour queue are selected first by employers, because these workers have a higher trainability, which reflects a lower cost of training. More highly educated individuals therefore get a higher position in the labour queue. Thurow stresses the selection process on the demand side of the labour market and assumes that employers regard jobs as the elementary demand side entities. Moreover, in Thurow's model job characteristics determine wages and marginal productivities. In screening models the signal or screening device establishes an improved allocation of heterogeneous workers on the labour market and, hence, can increase the production of a firm (and society).

Nevertheless, for both workers and employers the reason for the positive correlation between education and productivity (or earnings) does not matter. An individual will invest in human capital as long as the marginal benefits (higher future earnings) exceed the marginal costs (earnings forgone by not working and tuition fees). An employer screens individuals on their productive ability and offers a wage which reflects this ability. However, for society as a whole, the question above does matter. According to screening theory the educational system merely signals the ability and potential productivity of applicants, but does not enhance the productivity of individuals. Students' skills are not improved by initial schooling, since most of the skills required to be productive are learnt on the job. Arrow (1973) uses a model in which workers, independent of their level of education, are perfect substitutes in production. He shows that the resources devoted to education may be wasted from the societal perspective. However, using a more complicated model in which workers vary in productivity Arrow (1973) shows that screening by the educational system provides valuable information for employers with regard to workers' productive ability. This may improve the allocation of workers on the labour market and therefore social output.

In Spence's and Arrow's models, as described above, education does not enhance productivity. This is called the 'strong' version of screening theory. The principal difference between human capital and screening theory is the question of whether or not education increases the productive ability of individuals during the time they attend school. According to human capital theory the productive abilities of individuals have been increased when they leave school (i.e. the *ex post* abilities), whereas according to screening theory schools select students on their innate abilities (the *ex ante* abilities) without having increased these abilities. "What is debatable is whether schools screen for some *ex ante* innate ability or for some *ex post* ability which includes the productivity-augmenting effects of education." (Winkler, 1987)

Empirical research has found no evidence for the assertion of the 'strong' version of screening theory that education has no direct effect on productivity (Woodhall, 1987). According to Layard and Psacharopoulos (1974) the worker will be paid according to his or her productive ability when the employer gains more first-hand experience with the worker. In the strong version of screening theory this implies that the returns to initial schooling will diminish during the working career and that employers systematically overestimate the productivity of newly employed workers with more initial schooling. Based on a survey of empirical literature on longitudinal earnings data Layard and Psacharopoulos conclude that earnings differentials between, for example, high-school graduates and college graduates increased during the working career, which at first sight is contradictory to the implications of screening theory. This result however, does not really deny screening theory, since better educated workers may be screened on their ability and therefore receive, in addition to a higher starting wage, more on-the-job training. In turn, differences between workers participating in on-the-job-training can be an important determinant of the increased earnings differentials (see Chapter 4).

To test the strong version of the screening theory Riley (1979) uses the above empirical result that the variance of earnings at every level of initial schooling is greater as worker experience (and age) increases and the employer obtains more information on the actual productivity of the worker. If an individual's level of initial schooling is a screening device for employers then this effect is expected to be greater for workers in screened occupations than for those in unscreened occupations, like farmers and other self-employed workers. Although Riley finds the measure of variance to be greater for screened than for unscreened occupations, the difference is not statistically significant. This indicates that, contradictory to the implications of the strong version of the screening theory, the level of initial schooling is more than just a screening device. Moreover, Wolpin (1977) follows Riley when he tests the implication of the screening theory that nonprofessional self-employed (i.e. unscreened) workers acquire a larger amount of initial schooling than nonprofessional salaried (i.e. screened) workers. He finds that, contradictory to the implication of screening theory, both groups of workers acquire the same amount of initial schooling.

Kroch and Sjoblom (1994) test whether human capital theory or signalling theory is the predominant explanation for the value of initial schooling. If the effect of workers' years of schooling on earnings is significantly positive, this implies evidence for human capital theory. If employers use an educational rank order of individuals to infer the position of a worker in the distribution of abilities and to reward the worker accordingly, this implies evidence for signalling theory. Kroch and Sjoblom find that years of schooling has a consistently significant positive effect on earnings, whereas the rank measure rarely does. They conclude that human capital theory gives a better explanation for the value of education than signalling theory.

However, 'weak' versions of screening theory do not deny that education enhances productivity by providing knowledge and skills. Therefore screening theory could be considered complementary to human capital theory in that it states that educational qualifications also indicate abilities, aptitudes and altitudes of individuals and that those are partly shaped and developed by the educational system. In other words, education may be a good proxy (a screening device) for the joint effect of all other relevant determinants of labour input, such as ability[4] and socio-economic background[5] (see Fallon, 1987). Riley (1979) finds some evidence for the proposition that screening is relevant without denying the human capital effect of education. He estimates an

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4. See Griliches (1996) for a discussion on the 'ability bias'.

5. Bowles and Gintis (1976) argue that the socio-economic background determines to a large extent the personal characteristics.

earnings function and finds that the earnings of the screened workers better fit the earnings function than the earnings of the unscreened workers. "The reason why the screening hypothesis is important is that it has focused attention on the precise way in which education or other forms of investment in human capital influence productivity, and has served as a reminder that education does far more than impart knowledge and skills." (Woodhall, 1987, p. 24)

The *assignment theory* or job matching theory (see e.g. Tinbergen, 1956; Jovanovic, 1979; Sattinger, 1993) combines the explanations of the productivity enhancing explanations oriented to the demand side, as in Thurow's model, and supply side explanations such as the human capital model. It follows that workers' productivity is determined by both job characteristics and the level of education. Workers with a given education may be more productive in one job than in another. This feature of the assignment model emphasizes the importance of an optimal allocation of workers for the total output of a firm or a country (see Hartog, 1988). Hartog (1992) finds evidence for the hypothesis that both the job level, measured on a scale of job complexity, and the level of education determine workers' earnings. Again, earnings are supposed to reflect marginal productivities. Thus, the screening or signalling function of education can lead to a better match of workers to a particular job, and therefore a higher productivity of workers in a firm.

It follows that the positive empirical correlation between education and productivity can be explained by three alternative theories, i.e. human capital theory, screening theory and assignment theory. We regard these theories to an important extent as complementary, since they are based on different arguments that do not exclude each other. Better educated workers have not only acquired more human capital which increases their productivity, but have also got diplomas which may be used as a screening or signalling device. Diplomas may refer to both innate and acquired skills. These diplomas may be used as a device to improve the quality of the match between workers' acquired skills and the skills that are required by their jobs (see also Chapter 4). If diplomas increase labour market transparency they are an efficient screening device or matching tool. Then the functioning of the labour market on a more aggregate level (sector- or country-level) is improved due to the more efficient distribution of workers' skills over the available jobs. In line with Arrow's model, which has been discussed above, the average productivity of workers at the sector- or country-level may increase as a result of screening.[6]

In the empirical analysis of this thesis the skill level of workers is the most important variable to explain both productivity levels (as an indicator of international competitiveness) and trade performance. The skill level of the work force is measured by the level of educational attainment of workers at the sector- or country-level. The innate abilities of workers are assumed not to play an important role, since the innate abilities are probably similarly distributed across countries. Although the screening of

6. Although the productivity enhancing effects of screening due to a better functioning of the labour market are not denied, they are not taken into account in the empirical analysis of the thesis. If it is assumed that the productivity effects of screening do not differ between the sectors and countries, then screening does not seriously bias the empirical results of Chapters 6, 7 and 8.

workers by diplomas may be based on the workers' innate abilities instead of the real skills workers have acquired during their initial schooling period, it is not likely that productivity differences between countries are based on cross-country differences of the workers' innate abilities. For example, if workers in some countries have higher productivity levels than in other countries, it is not likely that the innate abilities of workers in countries with higher productivity levels are larger than the innate abilities of workers in the other countries. Therefore different productivity levels between countries must be based on the workers' average skill level instead of the workers' innate abilities. The positive causal relation between workers' skills and their level of productivity justifies taking human capital theory as a starting point for theoretical and empirical analyses.

2.4 Modelling human capital input in the production function

Griliches (1970) and Fallon (1987) mention different possible ways of modelling the production factor human capital in a production function. First consider the traditional (i.e. without human capital) production function f of a firm i in a neoclassical environment:

$$Y_i = f(L_i, K_i) \quad ; \frac{\partial f}{\partial L_i} > 0, \ \frac{\partial^2 f}{\partial L_i^2} < 0 \tag{2.1}$$

Variables Y_i, L_i, and K_i refer to the total net output, the number of workers and the stock of physical capital, respectively. The first and second order partial derivatives of output with respect to labour in equation (2.1) indicate that the marginal product of labour is positive but diminishing. When the stock of physical capital is constant the second order partial derivative is negative because of the law of diminishing marginal returns of labour. Our aim is to incorporate human capital in the traditional production function of equation (2.1). This can be done firstly by using a measure for effective labour, L_i* (instead of the number of workers L_i), which accounts for the heterogeneity of workers, and secondly by including a separate production factor that measures the human capital input.[7]

With regard to the first method, the effective labour input is defined as the number of workers L_i times the average amount of human capital per worker H_i:

$$L_i^* = L_i H_i \tag{2.2}$$

Fallon (1987) gives an overview of possibilities to combine the various educational categories L_{ij}, with j representing the types of labour in the total work force of firm i, into a single labour quality measure L_i*. We can correct for human capital by adding up the various educational categories after weighting them for their marginal productivities. Therefore it is assumed that the various types of labour are perfect substitutes for each other, i.e. the elasticity of substitution between any pair of

7. Other possibilities mentioned by Griliches (1970) and Fallon (1987) concern the impact of education on the various parameters of a standard production function.

educational categories is infinite. This assumption implies that the relative marginal productivities of the different educational categories of labour are constant. However the marginal productivity of workers is often unknown, contrary to data on wages. If it is also assumed that real wages equal marginal productivities, then the different educational categories of labour can be weighted by their respective mean wages which gives the single labour quality measure:

$$L_i^* = L_i H_i = L_i \left(\frac{\sum_j \omega_j L_{ij}}{L_i}\right) = L_i \sum_j \omega_j \left(\frac{L_{ij}}{L_i}\right) \tag{2.3}$$

In an empirical analysis variable ω_j can be approximated by the real mean wage of labour type j of the firms in the sample, which equals the marginal productivity of labour type j if perfect competition holds.[8] Reviewing empirical research Fallon (1987) concludes that the perfect substitutes function of effective labour (equation 2.3) is, despite the theoretical concern with regard to the perfect substitutability of labour categories, a good first approximation for investigating the contribution of production factors to economic growth.

Nevertheless, the assumption of perfect substitutability of different types of labour, i.e. the infinite elasticity of substitution between these types of labour, seems to be rather unrealistic. To meet this difficulty L_i^* can also be calculated by combining the different educational categories into a constant elasticity of substitution function (CES) or into a Cobb-Douglas function. An example of the latter is given in equation (2.4).

$$L_i^* = L_i H_i = L_i \left(\frac{\prod_j L_{ij}^{\theta_j}}{L_i}\right) = L_i \prod_j \left(\frac{L_{ij}}{L_i}\right)^{\theta_j} \tag{2.4}$$

In a Cobb-Douglas function the elasticity of substitution of two labour categories is unity. The coefficients θ_j sum up to 1 and are assumed to be equal across all firms within one sector. In case of perfect competition the coefficient θ_j equals the optimal wage share of L_{ij} in total wages.[9] Contrary to the perfect substitutes function of effective labour, the marginal product of each labour category is diminishing in the Cobb-Douglas function of effective labour. This is more realistic than the assumption of constant marginal productivities in the perfect substitutes function.

Instead of using wages to incorporate human capital of the various labour categories in a production function, the effects of the labour categories on output or productivity can be estimated. Both the perfect substitutes version and the Cobb-Douglas function of effective labour have the advantage that the coefficients ω_j and θ_j, respectively, can

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8. Since wages represent the current and future benefits of investing in human capital, in a multi-period analysis the wage variables in this chapter should be divided by the discount rate (see e.g. Griliches, 1970). This does not change the results of the analysis in this chapter.

9. This can be shown by differentiating to L_{ij}.

be relatively easily estimated when using a Cobb-Douglas production function. This is in particular useful if wage shares of each labour category j are unknown, or if the assumption of perfect competition on the labour market does not hold due to which real wages are not equal to marginal productivities (see the next section). Davies and Caves (1987) estimate a Cobb-Douglas production function which accounts for different categories of labour. The effective labour input in their Cobb-Douglas production function is modelled by the perfect substitutes version of effective labour, whereas Chapter 6 of this thesis estimates a Cobb-Douglas production function with a Cobb-Douglas function of effective labour.

A second method of incorporating human capital in a traditional production function requires the calculation of the total amount of human capital input in the production process, which is considered as a separate input factor in the production function. This implies that for each educational type of worker the human capital input is distinguished from the uneducated labour input ('raw labour'). Human capital can be considered as a (non-observed) homogeneous substance, S_i, measured by the sum of the differences between the marginal productivity or real wage of each educational category, ω_j, and the marginal productivity or real wage of uneducated labour (for example a minimum wage), ω_0, across all educational categories (Fallon, 1987).

$$S_i = \sum_j (\omega_j - \omega_0) L_{ij} \tag{2.5}$$

The two methods described above lead to a different specification of the production function. For example, if the production function is Cobb-Douglas, equations (2.6) and (2.7) show how human capital is incorporated in the standard production function of equation (2.1) according to the first and the second method, respectively. Note that the variable H_i in equation (2.6) represents the average amount of human capital per worker, whereas the variable S_i represents the total amount of human capital across all labour categories. Variable H_i can be constructed by the perfect substitutes version of effective labour (equation 2.4) or the Cobb-Douglas version of effective labour (equation 2.5).

$$Y_i = A\bar{K}_i^{\alpha} L_i^{\beta} H_i^{\beta} \tag{2.6}$$

$$Y_i = A\bar{K}_i^{\alpha} L_i^{\beta} S_i^{\gamma} \tag{2.7}$$

The variable A indicates the given efficiency parameter, whereas α, β and γ represent the elasticities of output with respect to physical capital, labour and human capital, respectively. Griliches (1970) shows that one is unlikely to be able to discriminate empirically between the above two specifications of the Cobb-Douglas production function if the human capital variable, H_i, in equation (2.6) is modelled by the perfect substitutes version of effective labour (equation 2.4). In the Cobb-Douglas form of effective labour, when incorporated in the production function of equation (2.6), each educational type of labour j has its own elasticity of output, which depends on both β

and θ_j.[10]

One has to note that combining different types of labour into one measure of effective labour or human capital, which has been described above, assumes that the ratio of the marginal products of any two types of labour or the marginal product of human capital is independent of the stock of physical capital. This assumption is called homothetic separability (Fallon, 1987).[11] If the assumption is not met, the input of physical capital in the production process does matter for the relative marginal productivities of labour and thus for the labour quality measure. In that case the input factors of the various types of labour cannot be aggregated into a single labour quality measure without correcting for the factor input of physical capital. Empirical studies such as Clark et al. (1988) suggest that the separability assumption is in general not fulfilled and that physical capital has more complementarity with highly educated labour than with less educated labour.[12] This is called the *capital-skill complementarity hypothesis*. Empirical research does reveal fairly strong evidence for this hypothesis,[13] although the complementarities are estimates of parameters that are defined differently in empirical studies.[14] For some authors the capital-skill complementarity has become close to a stylized fact (see for example McMahon et al., 1992). On the one hand, the non-separability of factor inputs is particularly relevant in empirical studies that explain or predict changes in the skill and wage structure by changes in the production technology (see e.g. Goldin and Katz, 1996, and Machin et al., 1996). On the other hand, the Cobb-Douglas production function is still widely used, since it is a convenient tool to estimate the contribution of production factors on output and productivity (see e.g. Davies and Caves, 1987, and Mairesse and Sassenou, 1991).

2.5 A partial labour market model

In this section we will further discuss the measurement of workers' human capital by the equilibrium wage level, which is determined both the demand and supply elasticities on the labour market and the market structure. It will be argued that the skill level of workers is a better way to measure human capital than the workers' wages. For

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10. See Chapter 6 for the derivation of the elasticities of output.

11. Note that this condition has consequences other than the assumption that the capital stock is fixed, since if capital stock is fixed and the total effective labour input increases, the ratio of marginal productivities may change.

12. See for a critical discussion on the specification of production functions with skilled labour De Koning, et al. (1990), in particular Chapter 6.

13. See for example the empirical studies by Griliches (1969), Fallon and Layard (1975), Broer and Jansen (1989), Hebbink (1992) and Draper and Manders (1997). See for comprehensive overviews Hamermesh and Grant (1979) and Hamermesh (1993).

14. See for a critical evaluation Hamermesh (1993), who has a differentiated approach to review the results from empirical research. In particular he refines the interpretation of the results by stating that there is fairly strong evidence that capital and skill are *p*-complements, which implies that an increase (decrease) in the price of physical capital reduces (increases) the input of skilled labour.

the analysis in this section labour demand and supply will be considered in a partial framework at the firm as well as the sector level. It is assumed that the firm's demand for workers encounters the supply of homogeneous workers in a particular segment of the labour market. In order to keep the analysis as simple as possible we assume that a firm has a demand for homogeneous workers with human capital per worker H. Human capital is incorporated by the effective labour input function of equation (2.2). Moreover, the labour demand is a derived demand, i.e. it can be derived from the production function and from supply and demand in a market for homogeneous goods. Next the analysis will show the effect on employment, real wage and productivity of, firstly, an increase in the supply of homogeneous workers with a fixed level of human capital and, secondly, an increase in the level of human capital per worker.

From standard labour economics we know that the supply of labour, whether expressed in number of workers or in number of hours, is positively dependent on the wage that is offered (see for example Ehrenberg and Smith, 1994). In other words, the labour supply curve is upward sloping with respect to wages.[15] This implies that the firm is confronted with a given market relationship, in a particular segment of the labour market, between the real wage w per worker and the supply of L_i homogeneous workers.[16] Equation (2.8) in fact represents the inverse function of the common labour supply curve at the firm level.

$$w = w(L_i) \tag{2.8}$$

If the firm has some monopsonistic power on the labour market segment, the real wage increases with the demand for labour. This implies that $\partial w / \partial L_i > 0$, i.e. the labour supply curve slopes upwards. The real wage per worker is constant if there is perfect competition in the labour market segment on which the firm demands labour. This implies that $\partial w / \partial L_i = 0$, i.e. the labour supply curve is horizontal in a labour market segment with perfect competition.

The profit function of the firm is given by

$$\Pi_i = PY_i - L_i W - C_i \tag{2.9}$$

where P is the price per unit of Y_i, W is the nominal wage per worker and C_i is the total fixed costs. The firm can maximize profit Π_i by choosing the optimal effective labour input, here the optimal number of workers.[17] We assume that the amount of human capital per worker H is fixed and therefore excluded from the analysis for the time being. Profit maximization follows by differentiating Π_i with respect to L_i and setting the result equal to zero.

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15. The part of the labour supply curve which bends backward is not considered here (see for example Ehrenberg and Smith (1994).

16. Here the use of the term 'real wage' is not completely correct as it represents the nominal wage divided by the product price of the firm instead of the nominal wage divided by some general (macroeconomic) price index.

17. The number of working hours per worker is assumed to be constant.

$$P \frac{\partial Y_i}{\partial L_i} + Y_i \frac{\partial P}{\partial Y_i} \frac{\partial Y_i}{\partial L_i} - W - L_i \frac{\partial W}{\partial L_i} = 0 \tag{2.10}$$

which can be rewritten as

$$\frac{\partial Y_i}{\partial L_i} = \frac{W}{P} \frac{1 + 1/\varepsilon_W}{1 + 1/\varepsilon_P} \tag{2.11}$$

where

$$\varepsilon_W = \frac{\partial L_i}{\partial W} \frac{W}{L_i} \tag{2.12}$$

$$\varepsilon_P = \frac{\partial Y_i}{\partial P} \frac{P}{Y_i} \tag{2.13}$$

From equation (2.11) it follows that the marginal product of labour equals the real wage corrected for the wage elasticity of labour supply shown by equation (2.12) and the price elasticity of product demand shown by equation (2.13). The firm can determine the level of marginal productivity by choosing the number of workers L_i, since the higher the number of workers the lower the marginal productivity per worker will be. This is a result of the condition added to equation (2.1), stating that the first order partial derivative of output with respect to labour is diminishing. The level of employment at which equation (2.11) is satisfied maximizes the profit of the firm, so that this level of employment represents the labour demand of the firm.

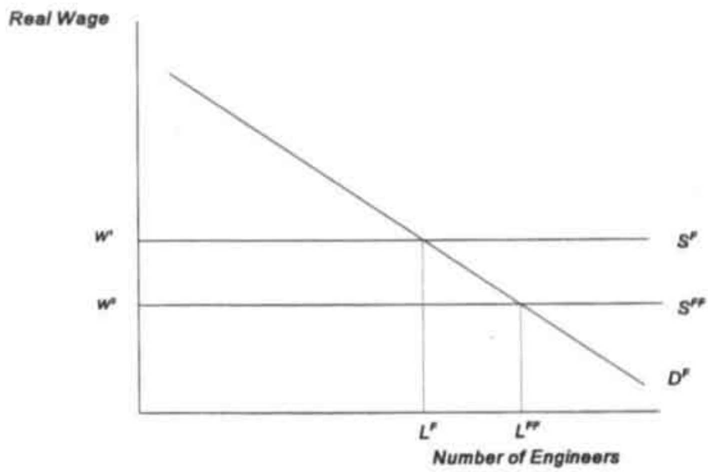
In the case of perfect competition on both the labour and product markets, the elasticities defined above approach infinity and therefore the marginal productivity of labour equals the real wage. In this situation the firm is a price (or wage) taker on both markets. In other cases the real wage and the marginal productivity will probably not be equal. For example, if the firm has monopsonistic power on the labour market and hence is a wage maker on the labour market, it will be confronted with an upward sloping labour supply curve. Therefore, the slope of the marginal labour cost curve will be positive. As can be concluded from equation (2.11), the marginal cost of labour will then exceed the real wage.

However, to analyse the impact of human capital per worker on employment, real wages and productivity, we will at first assume that the firm operates in a perfectly competitive environment in both the labour and the product market. Under perfect competition, equation (2.11) changes into equation (2.14). The real wage is represented by w.

$$\frac{\partial Y_i}{\partial L_i} = \frac{W}{P} = w \tag{2.14}$$

Equation (2.14) is represented by curve D^F in Figure 2.1,[18] showing the firm's demand for labour in a particular labour market segment, for example engineers. The curve reflects the increase in the level of employment in the firm when the real wage costs decrease. The marginal productivity equals the real wage in case of perfect competition. The curve is downward sloping due to the law of diminishing marginal returns (see equation 2.1).[19] The supply of engineers at the firm level is given by curve S^F, which reflects equation (2.8). The supply curve of labour is horizontal because the real wage elasticity of labour supply approaches infinity, i.e. the firm is a price (wage) taker on the labour market segment for engineers.

Figure 2.1
Labour demand and supply for engineers at the firm level, given perfect competition



The equilibrium wage w^1 is determined on the labour market for engineers as shown in Figure 2.2, below. Curve D and curve S^1 show the aggregate demand and supply in

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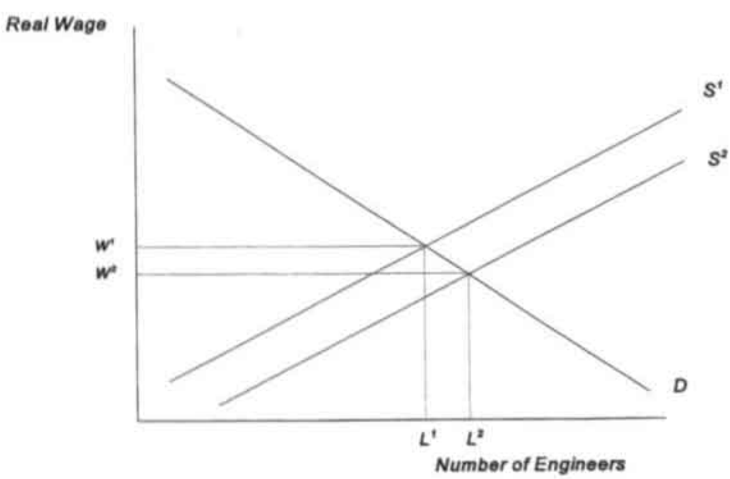
18. The superscript F indicates demand or supply at the *firm* level, whereas a superscript in numbers indicates demand and supply at the *sector* level.

19. In the long run the labour demand curve is downward sloping for other reasons, namely the output (scale) effect and/or the substitution effect. The former effect refers to the increase in product demand due to lower wage costs, since lower wage costs result in a lower product price and a higher level of production. The latter effect refers to the substitution of capital for labour due to lower relative factor costs of labour. Both effects increase the demand for labour in the long run. Here we will not consider these long term effects on the demand for labour.

this labour market segment respectively. The aggregate demand and the aggregate supply of engineers equal the sum of the demand and the supply curves of all firms (horizontally aggregated), respectively. According to one of the Hicks-Marshall laws of derived demand (see, for example, Ehrenberg and Smith, 1994), the wage elasticity of demand for engineers tends to be low when the price elasticity of demand for the good being produced is low. If the price elasticity of demand for good Y at sector level is nil (perfectly inelastic), the wage elasticity of demand for engineers is also nil. The supply of engineers is upward sloping because the higher the wages of engineers, the more attractive it is for individuals to work as engineers (relative to other occupations). It follows that the level of employment in the labour market segment is L^1 number of workers (see Figure 2.2), who are rewarded at the real market wage w^1. At this real wage the firm employs L^F workers (Figure 2.1).

We will now analyse the consequences of *(i)* an increase in the number of workers with a particular type of initial education, such as engineering, and *(ii)* an increase in the human capital per engineer. The former induces a downward shift of the labour supply curve, whereas the latter may induce either an upward or a downward shift of the labour demand curve.

Figure 2.2
Labour demand and supply in the labour market for engineers



(i) Shifting the labour supply curve

Suppose that the supply of engineers S is increased, perhaps by a government labour market programme. The aggregate supply curve of engineers is shifted to the right (curve S^2 in Figure 2.2) which leads to a decrease in the engineers' marginal productivity and equilibrium wage, to w^2. On the other hand, the larger supply of engineers increases the equilibrium employment at the sector level to L^2. The individual firm will be confronted with a lower wage for engineers (see equation 2.8). This implies that the horizontal labour supply curve at the firm level shifts downwards (see curve S^{FF} in Figure 2.1) and the new equilibrium point at the firm level is represented by (w^2, L^{FF}).[20] This can be illustrated by using equations (2.1) and (2.2) to incorporate the amount of human capital per worker in equation (2.14), which results in the following equation:

$$w = \frac{\partial Y_i}{\partial L_i} = \frac{\partial f(L_i^*)}{\partial L_i} = H\frac{\partial f(L_i H)}{\partial (L_i H)} = Hf^1(L_i H) \tag{2.15}$$

If the real wage decreases from w^1 to w^2 due to the outward shift of the supply curve in the labour market segment for engineers (Figure 2.2), it follows that the firm faces an exogenous decrease in the real wage to w^2. The firm finds itself temporarily at point (w^2, L^F). Since at this point the real wage is lower than the marginal productivity (represented by curve D^F in Figure 2.1), it will be profitable for the firm to increase the number of engineers employed. Due to the law of diminishing returns of labour, the marginal productivity of labour decreases as the firm employs more engineers, i.e. $\partial f / \partial L_i < 0$. The firm will stop employing new engineers when the marginal productivity of an engineer equals the new (lower) real wage level w^2. This implies that the marginal productivity decreases from w^1 to w^2 along curve D^F. Thus, due to the increase in the supply of engineers, the real wage of engineers falls, whereas the employment level increases to L^{FF}. The magnitudes of these changes are dependent on the wage elasticities of the demand and supply of engineers. If, for example, the demand for engineers is perfectly inelastic (i.e. a vertical demand curve), then the increase in the supply of engineers is expressed entirely in a fall in the real wage level, without changing the level of employment. If, on the other hand, the demand for engineers is perfectly elastic (horizontal demand curve), the increase in the supply of engineers is entirely expressed in a rise in the level of employment, without changing the real wage level.

An interesting point of the above analysis is that the human capital level per engineer is assumed to be constant, whereas the real wage may fall due to the increased supply of engineers. Thereby the fall of the real wage depends on the wage elasticity of the demand for engineers. However, in the last section it has been argued that the human capital per worker can be measured by calculating the capitalized value of present and future wages. Therefore the human capital level per worker may decrease due to the increased supply of engineers. Although the supply of engineers may change, the skill level of each engineer, *H*, is assumed to be constant. Since educational programs are in general relatively stable, the level of educational attainment of engineers is also rather stable over time. Measuring the human capital level of engineers by the capitalized-earnings method has the consequence that the human capital level of engineers fluctuates with the supply and demand conditions on the

20. Note that the vertical distances between w^1 and w^2 in Figures 2.1 and 2.2 represent equal wage differences. The differences in the figures are not equal due to the use of different scales in the figures. Also the numbers of workers in Figures 2.1 and 2.2 are represented by horizontal distances with different scales.

labour and the product market rather than with the skills acquired by engineers. Moreover, the real wage level and the level of marginal productivity of engineers are dependent on the market structure, as well. As can be seen from equation (2.11) the equilibrium wage with imperfect competition on the labour and the product market is not equal to the equilibrium wage with perfect competition on both markets. The human capital level per worker depends on the market structure if the capitalized value of present and future wages is used as a measure of human capital. For these reasons we will not interpret the capital value of workers, i.e. their human capital, literally (see also Blaug, 1970). In this thesis the human capital of workers refers to the workers' skill level rather than to their capitalized value of present and future wages. For example, intermediate and highly-skilled labour can be distinguished from low-skilled labour, and the numbers of workers with different skill levels may therefore represent the human capital of firms, sectors or countries (see Chapter 5).

(ii) Shifting the labour demand curve

Suppose that the amount of human capital per engineer, H, increases. Since we want to concentrate only on the demand side of the labour market we assume, for the time being, a perfectly elastic supply of labour in the labour market segment for engineers (i.e. a horizontal labour supply curve). Moreover, we assume that the increase in human capital per engineer is the result of improved productivity of the educational system,[21] without increasing the costs of that education for the engineers (their investments).[22] These assumptions imply that the real wage per engineer, $W/P = w^l$, does not change. The next equation, which is in fact similar to equation (2.15), illustrates two opposing effects which follow from the increase in the human capital per engineer. To indicate these two effects, variable H is written with subscripts *1* and *2*.

$$w = \frac{\partial Y_i}{\partial L_i} = H_1 f'(L_i H_2) \tag{2.16}$$

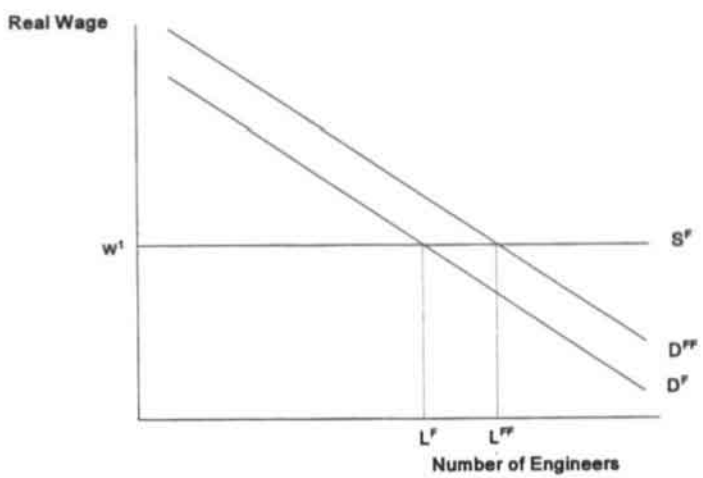
First, each engineer is more productive for the same (fixed) wage w^l, as a result of the increase in human capital per engineer. The increase in human capital per engineer is indicated by an increase of H_1. Since the real wage is fixed, the marginal productivity will be temporarily larger than the real wage. However, this gives the firm the incentive to employ more labour L_i at the same real wage w^l, which lowers the marginal productivity of labour according to the law of diminishing returns. As a result the labour demand curve shifts to the right, which is shown by Figure 2.3. Second, more human capital per engineer, H_2 , decreases the number of engineers L_i needed to achieve the same level of effective labour input (and hence production). In other words, L_i and H_2 are substitutes in the production function. The decrease in the number of

21. A brief introduction to educational production functions is given in e.g. Cohn and Geske (1990). A critical evaluation of educational production functions is given by Hanushek (1987). Here we will not discuss the research on educational production functions.

22. For this reason the amount of human capital per worker H is not included in equation (2.8).

engineers needed shifts the labour demand curve to the left. Of course, H_1 and H_2 represent the same variable H, and the strength of each of the two effects depends upon the specification of the production function. It can be shown that the first effect, i.e. the productivity effect, will always be stronger (given the above assumptions and given the stock of physical capital) than the second, the substitution effect, so that the labour demand curve shifts to the right.[23] In that case the net effect of an increase in the human capital per engineer is a rise in the level of employment at the same real wage level.

Figure 2.3
A shift of the labour demand curve at the firm level, given perfect competition



In Figure 2.3 the improved skill quality of engineers does not lead to a higher wage level, since the labour supply curve in the labour market segment for engineers has been assumed perfectly elastic with perfect competition. It is, however, more realistic to assume an upward sloping labour supply curve in the labour market segment for engineers. Given perfect competition in the labour segment for engineers, the labour supply curve at the firm level is still horizontal. If the equilibrium wage in the labour market segment for engineers rises due to a larger demand for engineers by all firms at sector level, then the horizontal labour supply curve at the firm level shifts upwards. Since the labour supply curve in the labour market segment for engineers usually slopes upwards (the slope depending on the elasticity of the labour supply), the rise in employment at the firm level in Figure 2.3 is less than the difference between L^{FF} and

23. It can be shown that this holds for each usual production function from which a downward sloping labour demand curve results. For a proof of the Cobb-Douglas production function see Cörvers (1994).

L^F, whereas the real wage will become larger than w^l. If the labour market is imperfect with an upward sloping labour supply curve at the firm level, then the real wage increases even more as a result of the improved skill level of engineers, whereas the employment level of engineers increases less. With a perfectly inelastic labour supply (i.e. a vertical labour supply curve) in the labour segment for engineers the increase in human capital (education) per engineer is completely passed on to an increase in the real wage per engineer, without any change in the level of employment.

With regard to the shift of the labour demand curve in Figure 2.3 a similar point of interest can be raised as with the shift of the labour supply curve. The analysis of the shift of the labour demand curve shows that an increase in the human capital per engineer due to the higher skill level of engineers depends very much on the elasticities of labour demand and supply and the market structure. Again this implies that measuring the capital value of workers by the capitalized-earnings method does not necessarily refer to the acquired skills of workers. Therefore it is useful to incorporate the acquired skills of workers in the production function instead of the workers' capital value to measure the impact of human capital on productivity. In this thesis human capital will be represented by the skill structure of the work force, which allows us to distinguish between various skill levels.

2.6 Conclusions

This chapter has shown the investment analogy between human capital and physical capital. Human capital theory explicitly considers investments in education as accumulated stock of human capital. This stock of human capital is used, analogous to physical capital, as a factor of production. Therefore human capital theory offers the opportunity to link investments in education and the primary indicator of international competitiveness, i.e. productivity, in a general framework.

Although screening theory can also explain the statistical relationship between workers' earnings and their educational background, the productivity enhancing effects of human capital can hardly be denied due to the empirical evidence in favour of human capital theory. Moreover, it has been argued that screening theory and human capital theory are complementary in understanding how investing in workers' education influences their productivity, whereas assignment theory shows that improved matching between workers and jobs due to better screening of these workers may increase the average productivity level of all workers in a country. Nevertheless, ability differences of workers across different countries are probably of minor importance, so that screening theory will not be used to explain sectoral productivity differences between countries in the international context of this thesis.

It has been shown that human capital can be represented in a production function by incorporating an effective labour input function in the production function. The Cobb-Douglas form seems to be a useful specification for the effective labour input function, since this form is relatively easy to estimate in empirical analysis. Furthermore, it allows for diminishing marginal products of labour categories, contrary to the perfect substitutes form of effective labour input.

An important result of this chapter is that human capital, when measuring the effects of human capital on productivity, should be measured by the skills of workers instead of the capital value of workers, since the skills acquired by workers are not dependent on the supply and demand elasticities on the labour and the goods market. On the contrary, the capital value of workers is dependent on the current and future wage that is paid for the workers, whereas the workers' wage in turn is determined by the supply and demand elasticities of the labour and the goods market. Therefore the human capital stock of a sector or a country can usefully be represented by the skill structure of the work force. The use of the skill structure of the work force to indicate the human capital stock of a sector or a country allows for differentiation between various skill types of workers. Finally, an increase in the amount of human capital per worker, when measured by the workers' skill level, generally raises both the productivity and the employment level, but the extent of the raise depends on the supply and demand elasticities and the market structure.

Chapter 3

Human capital as a growth factor

3.1 Introduction

Human capital plays a dual role in the process of economic growth. First, human capital is a stock of skills directly used as a factor of production. It can be combined with physical capital and unskilled labour to produce total output. Increasing these factor inputs results in larger total output and thus economic growth. The previous chapter treats human capital as such a factor input. This chapter focuses on the second role of human capital: the role of human capital in economic growth by stimulating technological change. In growth literature the change in technological change is often regarded as the driving force behind economic growth (see e.g. Verspagen, 1992). Although in growth studies the role of human capital is usually referred to in one way or another, it is far from clear in these studies how human capital induces technological change. Therefore this chapter casts light on the role of human capital in stimulating technological change. To clarify the relevance of technological change and (technological) knowledge for economic growth, we will also make reference to endogenous growth theory.

Section 3.2 distinguishes between human capital and knowledge and discusses the features of knowledge to understand the role of human capital in knowledge generation. It will be argued that human capital consists of both workers' skills and knowledge. Section 3.3 first distinguishes between technological and technical change and next discusses research and development activities and learning as the two forms of knowledge generation at the firm and/or sector level.[1] Section 3.4 presents a simple model to illustrate the role of human capital in both research and development and the diffusion of knowledge. Moreover, it will be discussed why human capital and technological knowledge are complementary. Section 3.5 concludes the chapter.

3.2 Knowledge and human capital

Wood (1994) distinguishes between *direct skills*, which are embodied in workers, and *technology* (i.e. *technological knowledge*), which is embodied in capital goods

1. Learning at the individual level is discussed in the next chapter. In this chapter learning increases the stock of knowledge at the aggregate level of firms and sectors, whereas in the next chapter learning by individual workers improves the match between the workers' skills and the skills needed in their jobs.

(vintages of physical capital) or intermediate goods.[2] Wood argues that the technological knowledge in use represents *indirect skills*, since technological knowledge has been embodied in the material means of production by the prior application of workers' skills. These definitions of knowledge and skills emphasize the relevance of workers' skills in both bearing and exchanging information. Skills are embodied either directly in workers or indirectly by applying workers' skills to all kinds of materials. Wood's definitions imply that the embodiment of knowledge is not possible without direct or indirect interference of workers and the use of their skills.

Although we agree with Wood putting the emphasis on the interference of workers to embody knowledge, we do not agree with his view that (technological) knowledge cannot be embodied in workers. We argue that knowledge can be embodied both in all kinds of materials like machines, books, computers, information systems, etc. and in workers by simply bearing knowledge in their minds. In this respect workers do not differ from other means of production, since they can all be regarded as a medium in which knowledge is embodied. By referring to *technological knowledge* instead of just *knowledge* we intend to emphasize the relevance of the latest available knowledge, which is probably less disseminated than the previously available knowledge. On the other hand, the skills to handle knowledge make workers different from other means of production that embody knowledge. Chapter 5 will further discuss the relevance of workers' skills to gather, interpret and use knowledge efficiently. The skills of workers refer to particular tasks they can perform, whereas the knowledge of workers about the production process is different. Workers may have knowledge about how to perform particular tasks, without having the skills to perform these tasks themselves (within a restricted period of time). Therefore workers' *human capital* consists of the sum of firstly, their skills and secondly, their embodied knowledge.[3]

The definitions of information, human capital and (technological) knowledge are illustrated in Figure 3.1. The figure shows that human capital and knowledge is the subset of information that is economically relevant. The intersection of human capital and knowledge is *knowledge in embodied workers*. As far as knowledge is not embodied in workers it is here referred to as *knowledge embodied in materials*, since it can be embodied in for example machines and computers.[4] In the previous chapter human capital was treated as a stock of skills without considering the embodied (technological) knowledge of workers.

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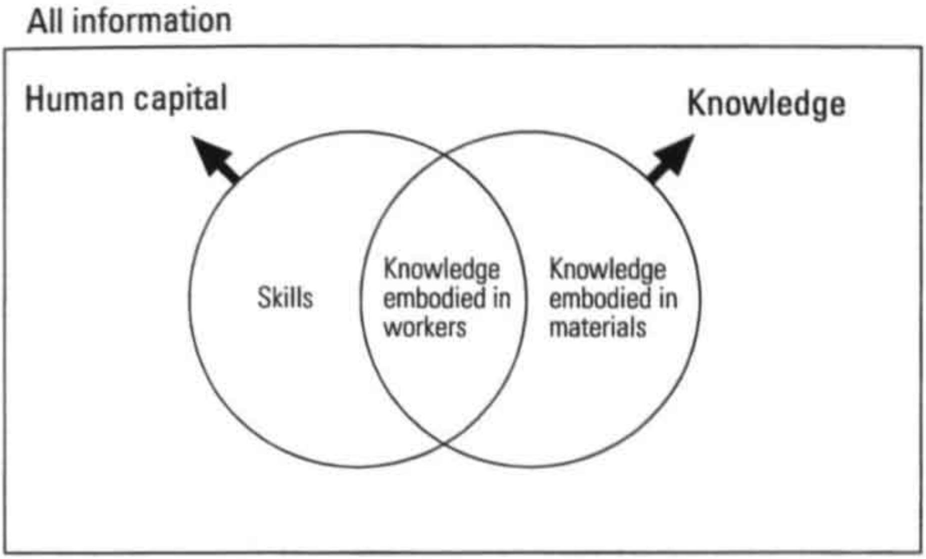
2. Wood's definition of knowledge is not in line with the usual distinction between knowledge and skills, which is used in this thesis. We will, however, focus on the ideas behind the relationships between human capital and technological knowledge rather than the definitions as such.

3. The human capital of workers may also include their physical condition, which can be improved by investments in health, working conditions, etc. (see Chapter 1). This thesis does not account for variations in the physical condition of workers across different sectors or countries.

4. We do not refer to disembodied knowledge, since it is assumed that all kinds of knowledge are somehow embodied in either workers or materials.

Figure 3.1
The relationship between human capital and knowledge



Technological knowledge is often regarded as a principal source of economic growth. This can be explained by two features of technological knowledge (see Romer, 1990). First, technological knowledge is a nonrival good or input factor. One example of technological knowledge is a blueprint (design) of a new good, which can be used as often as desired once the blueprint is created. Input factors such as labour, physical capital and skills are usually assumed to be rival, because their use by a firm precludes any other firm from using it during the same period. Other examples of nonrival goods or inputs are a scientific law, a principle of mechanical, electrical, or chemical engineering, a mathematical result, software, a patent and a mechanical drawing (Romer, 1990). Although these kinds of knowledge may in one or another form be embodied in workers as well as materials, they were first invented by highly-specialized workers in research and development activities. So these kinds of technological knowledge were originally embodied in these workers only. Afterwards the embodied technological knowledge spilled over to other skilled workers, to public knowledge or to the stock of knowledge embodied in capital goods.[5] The second feature of technological knowledge is that, because it is a nonrival good, competing firms cannot or can only partially be excluded from using knowledge spill-overs.[6] The two above features of technological knowledge, i.e. *nonrivalry* and *incomplete*

5. Due to these spill-overs technological knowledge becomes less exclusive, and thus can just be called 'knowledge'.

6. Product licenses can offer protection to prevent the use of innovations by competing firms for a certain period of time (see e.g. Van Dijk, 1994).

appropriability are generally recognized to be relevant for self-sustaining growth in endogenous growth theory.

Endogenous growth theory tries to explain the economic growth of countries by assuming increasing returns to scale in the aggregate production function (see Grossman and Helpman, 1992; Van Ewijk, 1993).[7] In traditional neo-classical models the production function usually exhibits constant returns to scale, in other words degree one homogeneity. This implies that, if a firm multiplies the factor inputs, the output of the firm is multiplied by the same amount. The same holds for the aggregate production function. However, due to the existence of externalities between firms in endogenous growth models, other firms may profit from the increase of factor inputs of one single firm. These externalities are based on the two above mentioned features of knowledge, i.e. nonrivalry and incomplete appropriability. So externalities result in a more than proportional increase in aggregate output with factor inputs, that is, increasing returns to scale. An important aspect of endogenous growth theory is that it focuses on modelling externalities such as knowledge spill-overs from investments in research and development or human capital. The output of these investments, knowledge embodied in new products, production processes or workers, may become an input in the production function of all firms. In for example Romer (1986), firms invest in knowledge which can only partially be kept secret. Therefore both the state of knowledge in a firm and the aggregate level of knowledge (of a sector or the entire economy) are arguments in the production function. Lucas (1988) assumes that the general stock of knowledge accumulates due to external effects which arise from both investments in education and learning-by-doing of individual workers. Here knowledge acquired, whether by investments in education or by learning-by-doing (see Chapter 4), is called human capital. Again, externalities ensure that new knowledge can be used (partly or completely) by all firms.

The role of human capital in the generation of knowledge or knowledge spill-overs is explicitly modelled in the endogenous growth models of Romer (1990) and Lucas (1988). The former considers human capital as an important input factor for the generation of knowledge in the research sector. The latter considers spill-overs from individual investments in human capital to public knowledge. Moreover, according to Romer (1990), human capital is embodied knowledge, tied to a specific worker. This makes it different from technological knowledge embodied in materials in the sense that each worker can acquire only a limited amount of knowledge during his working life. Moreover, the knowledge is lost if the worker dies, whereas knowledge in materials can outlive individuals. Although Romer (1990) argues that knowledge embodied in materials is for this reason different from human capital, Lucas (1988) assumes that the knowledge embodied in workers can outlive these workers if it is passed on to younger generations. According to Lucas (1988) the stock of (technological) knowledge in a country is undisputably related to human beings, because (p. 19) "human capital accumulation is a *social* activity, involving *groups* of people in a way that has no counterpart in the accumulation of physical capital." The discussion of our

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7. Endogenous growth theory builds on the neo-classical theory of, for example, Solow (1957) and Arrow (1962), and is therefore also known as *new neo-classical growth theory*.

definitions of skills and technological knowledge showed that human capital includes the workers' embodied technological knowledge, which may spill over not only to younger generations, but also to other workers, public knowledge, production processes, blue prints, scientific laws, etc.

3.3 Generation of technological knowledge

Technological change refers to the generation of technological knowledge.[8] To understand the nature of technological change this section will first discuss technological change by pointing to the difference with technical change. Next it will be argued that technological knowledge can be generated firstly, from the research and development activities in a distinct research sector, and secondly, as an external effect or by-product of producing at the firm or sector level, which is referred to as learning.[9, 10]

Technical and technological change

Both the terms 'technological' and 'technical' change are used to indicate that progress has been made with regard to the production of goods. It is not easy to make a clear distinction between these two concepts, which are often used interchangeably. However, Freeman discusses the conceptual difference between technical and technological change as follows: "For the economist the rate of *technological* change is conceptually distinct from the rate of *technical* change. The latter is usually defined statistically as the 'residual' factor explaining that part of measured growth which cannot be attributed to increases in the inputs of labour and capital. Almost any significant slow-down in economic growth therefore implies a deceleration of the rate of *technical* change so defined. But the underlying rate of *technological* change may be unaffected, since this refers to changes in the body of *knowledge* relating to techniques of production." (citation from Patel and Soete, 1988, p. 123)

According to Verspagen (1992) neo-classical theory refers to the techniques used to indicate technical change and to the state of technological knowledge to indicate technological change. A technique is defined as a combination of production factors, such as labour, human capital and physical capital. A production function relates the (infinitely) large number of techniques to the resulting outputs. Given the specification of the production function (for example CES, Cobb-Douglas or Leontief), the general state of technological knowledge and the relative factor prices, the technique chosen

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8. As stated before, by referring to technological knowledge instead of just knowledge we intend to emphasize the relevance of the latest available knowledge, which is probably less disseminated than the previously available knowledge.

9. See Young (1993) for a model that emphasizes the interdependence between research activity in the laboratory and production experience on the factory floor.

10. In the next chapter it will be discussed how human capital is generated by learning-by-doing at the individual level.

is the one that maximizes profits (or minimizes costs).[11] This results in either a labour intensive, a physical capital intensive or a human capital intensive production technique. Changes in the general state of technological knowledge or the relative factor prices may lead to another choice of production technique, i.e. it may cause substitution of production factors. The possibilities for substitution are dependent on the form of the production function. In a Leontief production function the input ratios (for example the capital-labour ratio) are fixed, whereas in a Cobb-Douglas production function the elasticity of substitution equals one.

Moreover, Verspagen (1992) notes that in neo-classical theory the increase in the general state of technological knowledge (or technological progress) is assumed to increase the productivity of every technique without changing the total set of techniques available. As noted, this may induce the substitution of production factors. However, the productivity of all techniques may be altered to the same extent, in which case technological change is said to be Hicks neutral (i.e. capital intensity remains unchanged), or it may be altered in different proportions for the various techniques, in which case technological change may be either labour-saving or capital-saving.

However, as Freeman and Soete (1987) argue, the neo-classical way of representing technological change has some important drawbacks. Without going into details, we will note one important drawback. The neo-classical production function allows for factor substitution on the assumption of an infinite number of possible combinations of production factors to produce a given output. Besides, it emphasizes the relevance of the increase in the productivities of production factors and the substitution of labour for capital due to technological change. Therefore technological change is regarded only in terms of cost reductions and, as a result, neo-classical theory stresses the importance of process innovations and the price elasticities of demand. On the other hand, Freeman and Soete (1987) point to the importance of the income elasticities of demand in relation to new and improved products, which points to the use of technology in the broad sense. Instead of *input-saving* as with process innovations these so-called product innovations are *demand-creating* (see Soete, 1987). Product innovations may lead to new economic activities and to the rise of new industries. However, as this chapter analyses the role of human capital in the innovation process rather than the types of innovations that occur, we will not distinguish between process and product innovations when analysing the impact of innovations on growth.

Research and development

The first type of knowledge generation comes about by formal research conducted in a laboratory setting, in other words by research and development (R&D) activities. Research and development conducted in a particular sector may increase productivity

11. Gomulka (1990, p. 4) explains the choice of production technique by referring to production processes: "Production is often a very complex operation, but it can be broken down into many direct standard operations, some or all of which may take place simultaneously. These are called *production processes* or *activities*." The method of production that is chosen by combining some of the available production processes is called 'production technique'.

through cost reductions, i.e. process innovations, and market expansions, i.e. demand creating product innovations. It should be realized that research and development activities are part of a complex innovation process. The first stage of this process is the invention, i.e. ideas or insights of new technical opportunities. Parker (1978, p. 50) describes the innovation process and the resulting diffusion as follows: "The innovative process can be divided into four functions: invention, entrepreneurship, investment and development. The entrepreneurial function involves deciding to go forward with the effort, organising it and obtaining financial support. Investment is the act of risking funds for the venture. Development is the lengthy sequence of detail-orientated technical activities, including trial and error testing, through which the original concept is modified and perfected until it is ready for commercial utilisation. Innovation thus covers all the activities in bringing a new product or process to the market. It is the pre-imitation stage. The term 'diffusion' is reserved to describe what occurs later, and includes the spread of an innovation and its adoption by rivals."

According to Mohnen (1992) R&D is a commodity that represents a stock of accumulated knowledge. Like physical and human capital (see Chapter 2) this stock can be calculated from investment expenditures in R&D, and is subject to a certain rate of depreciation. This thesis does, however, not regard R&D as a stock of knowledge on its own. The output of research and development activities is technological knowledge, which may be used again as an input factor for research and development. It can be embodied in either workers or materials. The workers who are involved in research and development are called R&D workers. Their human capital consists of both skills acquired by investment in education and training, and embodied technological knowledge generated by R&D. The human capital of highly-specialized workers involved in research and development are the most important input factor of research and development activities.

Grossman and Helpman (1992) present an example of a simple endogenous growth model (based on Shell, 1967) in which economic growth is no longer exogenous but self-sustaining, though the government finances basic research from tax revenues. They assume that researchers from the research sector make their findings (i.e. their output) immediately available for all sectors in the economy so that these findings (externalities or knowledge spill-overs) are inputs for all sectors. As a result the level of productivity of an economy increases with the cumulative output of the research sector. Moreover, they assume that the productivity level of the research sector equals the productivity level of other sectors.[12] Self-sustaining growth is established because the output of the research sector, i.e. technological knowledge, can be used as an input factor for all the sectors of the economy, including the research sector. Grossman and Helpman (1992) underline the importance of human capital for the research sector by assuming "in accordance with reality, that specialized skills are employed relatively more intensively in the industrial research lab than elsewhere in the economy." Moreover, they state that, in research and development activities, skilled workers are hardly substitutable for unskilled workers.

12. The conclusions of the simple model of Grossman and Helpman (1992) do not change much if it is instead assumed that the productivity growth of the economic sectors is proportional to the productivity growth of the research sector.

Learning

The second type of knowledge generation is learning. The increase in the stock of knowledge due to learning is called technological change, since learning refers to improving the state of knowledge. This form of technological change is an accidental consequence of a firm's private investments in knowledge. Learning is not an investment, but a by-product of production or investments in capital goods. Therefore learning can be regarded as an external effect of producing or investing. Learning at the firm or sector level is discussed below.[13]

The effect of learning at the industry level is illustrated by the well known 'Horndal effect' (see also Arrow, 1962). The Horndal effect refers to the average productivity increase of almost 2% per annum for a period of 15 years in the Horndal iron works in Sweden. During that period the steel plant did not invest in new capital goods, and presumably did not significantly change its production techniques. Therefore it was concluded that the productivity increase can only be understood as the result of the large number of small improvements and modifications that were made, which might be called learning-by-doing or learning-by-experience. The empirical relationship associated with the Horndal effect is known as the 'learning curve'. It describes the relationship between the growth in productivity, although at a diminishing rate, and cumulated output (i.e. the total output from the beginning of production) at the sector or firm level. The progress rate is also connected with the learning curve. A progress rate of 80% means that a doubling of the production leads to a decrease in the average costs to 80% of their original level (for references see Malerba, 1992). Again, average costs decline at a diminishing rate with cumulated output. Also Bartel and Lichtenberg (1987) make use of a similar concept of learning when they state that experience with a production technique (proxied by the mean age of the capital stock) shifts the cost function of a firm downwards (or its output function upwards).

Learning can refer to general, i.e. relevant for all firms in the market, activities (see Arrow, 1962) and firm-specific activities (see Rosen, 1972). Arrow assumes that learning is unmarketable because it is via spill-overs available for all. Moreover, Arrow takes the cumulative production of capital goods (i.e. cumulative gross investment) instead of the cumulative output as an index of experience which was used to measure the Horndal effect. According to Arrow only new vintages of capital goods provide opportunities for learning, because once the investment has been made, productive efficiency can not be altered by subsequent learning. This implies that all new knowledge due to learning is completely embodied in new vintages of capital goods. Thus contrary to the above Horndal effect, learning in Arrow's model takes place only because of the production of capital goods. Improvement in the efficiency of new capital goods is considered as technological change, since the stock of knowledge embodied in materials increases. As noted, the knowledge with regard to this form of learning, i.e. the technological knowledge embodied in the new capital goods, is free

13. Also labour economists often refer to learning-by-doing, together with other forms of on-the-job training, to explain productivity increases at the individual level. Learning-by-doing at the individual level will be discussed in Chapter 4.

to all firms.

In contrast, Rosen (1972) emphasizes that knowledge from learning is fully vested in the firm. A firm's specific stock of knowledge may generate incremental innovations which consist of modifications and improvements to existing products or processes. Although the model of Rosen (1972) could easily include the specific human capital embodied in the employees of the firm it emphasizes the entrepreneurship and knowledge of owners or managers. The knowledge is an asset to the firm, but it may be limited to the working life of the owner or the manager. This implies that learning embodied in the managers or owners is included under individual, firm-internal knowledge. However, such knowledge may also be transferable when selling the firm (goodwill), independent on the owner or manager. In both cases the knowledge is specific to the firm, because it is directly related to the accumulated production costs of the firm.

However, learning-by-doing arising as a function of cumulative output, capital or time is just one way in which firms can learn. Learning within a firm, i.e. internal learning, is generated from several activities such as production, design, engineering, organisation, marketing and R&D (Malerba, 1992). Malerba (1992) remarks that "learning processes may be more than simple learning by doing and that the effects of learning may be more than just average cost reductions." He distinguishes learning-by-doing from learning-by-using, to refer respectively to learning related to the production activity or output and learning related to the use of inputs (see Rosen, 1972). The traditional learning curve takes only these two learning processes into account, but Malerba (1992) distinguishes another form of learning that occurs in the firm, namely learning by searching. This form of learning is related to formalised activities (for example R&D) intended to generate new knowledge. Moreover, Cohen and Levinthal (1989) refer to the 'two faces' of investments in research and development to clarify that the firm's stock of technological knowledge is not only directly increased by its own R&D, but also that the firm's own R&D makes it easier to utilize spill-overs from knowledge generated by external R&D. In fact Cohen and Levinthal refer to learning spill-overs of technological knowledge generated by the research departments of other firms. Other forms of learning distinguished by Malerba (1992) are external to the firm and are related to the knowledge needed to absorb new developments in science and technology, knowledge about competitors, suppliers, and users, and knowledge about the opportunities of cooperating with other firms. However, in this thesis we will not distinguish between all these different forms of learning.

3.4 Modelling human capital in R&D and diffusion

This section further analyses the role of human capital in research and development and technological diffusion. Technological diffusion refers to the use of technological knowledge in production. This knowledge has been generated before by investments in research and development or by learning. Diffusion of technological knowledge can take place in the same firm or sector or in other firms or in sectors than where technological knowledge has been generated.

Since human capital is an important input factor for investments in R&D, human capital contributes to productivity growth resulting from advances in technological knowledge. To illustrate how human capital can be modelled in research and development and diffusion, the model of Nelson and Phelps (1966) is used. They presume that the level of educational attainment of workers is an important variable for the rate of technological diffusion. What Nelson and Phelps (1966) actually mean by technological diffusion is the introduction of new production techniques. Technological change, i.e. the increase in technological knowledge makes it possible to choose a new, more efficient production technique by introducing process and product innovations. Nelson and Phelps (1966, p. 70) suggest that "production management is a function requiring adaptation to change and that the more educated a manager is, the quicker will he be to introduce new techniques of production." Diffusion of technological knowledge first takes place by knowledge spill-overs to educated managers and workers, who learn fast compared to less educated managers and workers.[14]

The following equation shows the firm production function with output $Y_i(t)$, capital $K_i(t)$, labour $L_i(t)$ at time t. Moreover, $A_i(t)$ represents the level of technological knowledge that is actually used in the production technique.[15] Diffusion of technological knowledge may change the choice of the production technique. In Section 3.3 this change is defined as technical change. Technical change is here assumed to be Harrod neutral (labour-augmenting), which implies that the same output can be produced with less labour for a given capital stock.

$$Y_i(t) = f(A_i(t)L_i(t), K_i(t)) \tag{3.1}$$

Equation (3.2) introduces the theoretically available level of technological knowledge $T(t)$, which advances at a constant exponential rate λ.

$$T(t) = T_0 e^{\lambda t} \quad ; \lambda > 0 \tag{3.2}$$

If technological diffusion is completely instantaneous, the level of technological knowledge $T(t)$ that is theoretically available for the firm equals the level of technological knowledge $A_i(t)$ used in the production technique. Equation (3.3) shows that the time lag l between the former and the latter depends on the average educational attainment H_i of the workers in a firm, with l a decreasing function of H_i. This is the basic equation for the first model of Nelson and Phelps (1966).

$$A_i(t) = T(t - l(H_i)) \quad ; \quad \frac{\partial l(H_i)}{\partial H_i} < 0 \tag{3.3}$$

The equations above imply that both the theoretical level of technology and the level of technology applied in the production process grow at the same rate λ. If the

14. This issue will be discussed extensively in Chapter 5.

15. The level of technological knowledge that is actually used in production indicates the stock of technological knowledge embodied in either labour or physical capital. Therefore this section makes no distinction between different types of labour or different capital vintages, which is an alternative way to indicate the embodiment of knowledge in labour and physical capital.

level of educational attainment of workers H is increased then the lag will be reduced, which leads to a temporarily larger growth of A. In other words, the growth of total factor productivity (i.e. Solow's residual) is influenced by the average level of educational attainment in the short run. However, in the long run total factor productivity grows at rate λ. This growth rate is exogenously given in the traditional neo-classical growth models. In more recent growth models the growth of the level of technology in practice, and thus the growth of total factor productivity, is often assumed to be directly dependent on the average level of education of workers (see e.g. Benhabib and Spiegel, 1994 and Leiponen, 1995).[16] By contrast, in equation (3.3.) the growth rate is only indirectly dependent on the average level of education of workers, namely through a faster rate of diffusion by the reduction of the time lag. While the direct effect of human capital on growth directly increases the long term rate of growth λ, the indirect effect of human capital on growth works through a reduction of the time lag $t-l(H_i)$. Both effects are incorporated in the next equation.

$$A_i(t) = T(\lambda(H_i), t-l(H_i)) \ ; \ \frac{\partial\lambda(H_i)}{\partial H_i} > 0 \ ; \ \frac{\partial l(H_i)}{\partial H_i} < 0 \tag{3.4}$$

Substitution of (3.2) and (3.4) in (3.1) yields

$$Y_i(t) = f(T_0 e^{(\lambda(H_i))(t-l(H_i))} L_i(t), K_i(t)) \tag{3.5}$$

If we abstract from the direct effect of human capital on the growth rate λ, like Nelson and Phelps (1966) do, and differentiate the production function to the average educational attainment of workers, we find equation (3.6). The equation shows that the marginal productivity of education is dependent on the rate at which the theoretical level of technological knowledge advances, i.e. λ.

$$\begin{aligned} \frac{\partial Y_i(t)}{\partial H_i} &= \frac{\partial Y_i(t)}{\partial(A_i(t)L_i(t))}\frac{\partial(A_i(t)L_i(t))}{\partial H_i} \\ &= -\frac{\partial Y_i(t)}{\partial(A_i(t)L_i(t))}L_i(t)T_0 e^{(t-l(H_i))}\lambda l'(H_i)) \\ &= -\lambda l'(H_i)\frac{\partial Y_i(t)}{\partial(A_i(t)L_i(t))}A_i(t)L_i(t) \end{aligned} \tag{3.6}$$

The following equation represents a second model of Nelson and Phelps (1966) which is more realistic than the first one, since in the first model the time lag is merely

16. Endogenous growth models further emphasize the endogenous nature of growth and technological progress, for example by letting agents decide on the allocation of human capital between research and development activities and the production of ordinary (e.g. low-tech) goods. However, this does not change the general statement that a higher level of educational attainment of workers in firms directly increases the level of technology in practice of these firms, and thus the growth of total factor productivity.

dependent on the level of educational attainment of workers.

$$\frac{\partial A(t)}{\partial t} = \varphi(H)[T(t) - A(t)] \quad ; \quad \varphi(0) = 0, \ \frac{\partial \varphi(H)}{\partial H} > 0 \tag{3.7}$$

Here the speed of technological diffusion depends on both the level of educational attainment and the gap between the theoretical level of technology and the used level of technological knowledge. Nelson and Phelps (1966) show that in this model the elasticity of the long-run equilibrium level of technology in practice with respect to human capital is increasing with the rate of technological progress λ.

$$\frac{\partial A^*(t)}{\partial H}\frac{H}{A^*(t)} = \frac{H\varphi'(H)}{\varphi(H)}\ \frac{\lambda}{\varphi(H)+\lambda} \tag{3.8}$$

where $A^*(t)$ represents the long-run equilibrium level of technology in practice. This indicates that marginal productivity of educational attainment is greater, the more technologically progressive the economy is. This conclusion follows from the assumption of Nelson and Phelps (1966) that education is an important source of technological diffusion. Moreover, in Benhabib and Spiegel (1994) the long term rate of technological progress λ is also determined by the level of education of workers. This alters the model of Nelson and Phelps as firms can become the technological leader (i.e. with the highest level of theoretical technological knowledge T) by creating the largest stock of human capital per worker.

3.5 Conclusions

This chapter has shown that human capital plays an important role in economic growth due to its relationship with technological change. Human capital consists of both a stock of skills used as a factor input in production (see Chapter 2) and a stock of embodied (technological) knowledge used for the innovation and diffusion of new products and production processes. However, technological knowledge is not only embodied in workers but also in materials like machines, books or blueprints. The change in the state of technological knowledge refers to technological change. On the contrary, technical change refers to the change in the use of factor inputs, given the level of technological knowledge.

Technological knowledge has two important features, namely nonrivalry and incomplete appropriability. These features are useful to understand why knowledge can spill-over from one firm to another firm. A particular firm can generate technological knowledge by research and development activities. The result of this knowledge generation, for example a blueprint, can be imitated by other firms. For these firms the blueprint is an externality by which they can achieve productivity growth. Apart from research and development activities, firms generate knowledge by different forms of learning. The resulting knowledge of learning within one firm, for example how to produce more efficiently with a new production technology, can be used by all other firms. Again, this knowledge is an externality for the latter.

Human capital plays an important role in the relationship between technological change and economic growth for two reasons. First, specialized highly-skilled workers are required to perform research and development activities. These highly-skilled R&D workers are hardly substitutable by less skilled workers. Research and development is a driving force behind economic growth since it increases the level of technological knowledge. By increasing both the input of R&D workers and their level of education economic growth can be stimulated directly. Second, better educated workers know better how to implement new production techniques efficiently. Therefore technological diffusion of both new products and production processes goes faster with a higher educated work force. Moreover, the larger the rate of technological change, the larger the pay-off from educated workers (including managers). An improvement of the average level of educational attainment of the work force indirectly stimulates economic growth by facilitating the use of knowledge that is generated by research and development or learning in other firms.

Chapter 4

Acquiring skills by initial schooling and continuing training

4.1 Introduction

As has been argued in Chapter 2, the skill structure of the work force represents the human capital accumulated by workers. When workers accept a new job, they can immediately use at least some skills they have acquired during their initial schooling period or during their working career. Some skills are generally applicable in different types of occupations, while other skills are only applicable in a small spectrum of occupations. However, most workers have to adapt to their new working situation, which implies that they also have to acquire new skills on-the-job. For most workers who start in a new job there is a difference between the skills they *acquired* and the skills that are *required* in their occupation. This chapter will show how the difference between acquired and required skills disappears in the long run due to participation in the continuing training that workers enjoy when they are employed. It will be argued that the extent to which workers can profit from continuing training is dependent on the type of initial schooling they completed before, i.e. primary, secondary or tertiary, and vocational or general.

The shortage of acquired skills of the worker relative to the required skills in the respective occupation is called the mismatch. This shortage of skills results in a lower productivity of the worker than the maximum productivity that can be achieved if the acquired and required skills match perfectly. The initial productivity loss of a worker in a new job depends on the mismatch between acquired and required skills. The larger the mismatch, the larger the initial productivity loss. One of the main points of this chapter is that the workers' investments in both initial schooling and continuing training largely contributes to the improvement of the match with the workers' job tenure. Therefore the productivity level of the human capital stock represented by the skill structure of the work force (see Chapter 2) is probably not seriously affected by the mismatch between acquired and required skills. Although we will argue that investments in human capital contribute to establish the long run perfect match, which in general preclude both serious skill shortages and productivity losses of workers, there may be two reasons why a perfect match is not achievable in the long run, i.e. underinvestment in training and skill obsolescence. Furthermore, it will be argued why not only underinvestments in skills but also overinvestments in skills may occur.

The remainder of this chapter is structured as follows. Section 4.2 and 4.3 will first discuss the contributions of investments in initial schooling and continuing training, respectively, to the long run perfect match. Furthermore, Section 4.3 will refer to the theoretical background with regard to sharing the costs and benefits of training. Section

4.4 uses this theoretical background to discuss the above mentioned reasons of underinvestment in training and skill obsolescence. Finally, Section 4.5 provides a summary of the main conclusions.

4.2 Initial schooling

By investing in initial schooling the average skill level of workers is improved before they enter the labour force. Initial schooling, also referred to as initial education,[1] stands for general or vocational education. Workers may have attained education at primary, secondary and tertiary levels. Employers are usually unable to influence the outcome of the educational system for initial education because, apart from apprenticeship training, the government is primarily responsible for the initial schooling of the labour force.[2] The government can increase the productivity of workers for example by improving the quality of the courses or stimulating the enrolment rates. The latter can for example be achieved by lowering tuition fees or by supplying scholarships. However, for an individual firm, both the average level and the distribution of initial schooling of the labour force is mainly given. A larger supply of skilled relative to unskilled workers reduces the relative wage of skilled workers. This makes it more profitable for employers to engage skilled instead of unskilled workers, thereby increasing the average productivity of workers (see Chapter 2).[3] The employer may even have an incentive to appoint workers that are overeducated relative to the job that these workers have to perform.

General and vocational education

The skills acquired by initial schooling are supposed to be useful for a relatively broad spectrum of jobs on the labour market. To analyse how initial schooling contributes to the long run perfect match between workers and occupations, it is useful to distinguish between general and vocational initial education. *General education* may increase communication skills and problem solving skills, and may increase skills to be better prepared for new situations. According to McMahon et al. (1992, p. 182) "general education is more broad and basic in nature, enhancing individuals' ability to learn on the job, to receive and benefit from further on-the-job training and therefore to adapt to future career changes and technical change." When workers are faced with changes (or uncertainties) in technologies and in labour demand or supply, skills acquired by

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1. Schooling and education are used interchangeably. However, Pencavel (1991) states that education and schooling are not synonymous, because education takes place not only in schools, but also out of schools, i.e. in families, communities and work places.

2. Of course, students choose for a particular type of education. Their choice may be dependent on the labour market situation with regard to unemployment, wage, career prospects, working environment, etc. This labour market situation can be partly influenced by employers.

3. The next chapter will distinguish between low skills, intermediate skills and high skills to discuss the effects of initial schooling and continuing training on productivity.

general initial schooling keep workers productive on the labour market. In case workers have to find another job that requires new skills, they can rely on their general initial schooling. It provides "a flexible foundation for future learning." (Bowman, 1993, p. 167) General initial schooling increases the flexibility of workers to be employed in different occupations and firms, working with different production techniques or technologies.

The concept of flexibility may be related to the concept of *trainability* (see also Chapter 2). According to Thurow (1975) workers with the highest level of education have the highest trainability, i.e. the lowest cost of training when they start working. Thurow (1975) supposes that better educated individuals get a higher position in the so-called labour queue and therefore are selected first by employers (i.e. labour queue model). In Thurow's model the maximum productivity level that can be achieved by the worker is determined by the job. Thurow (1975) regards educational qualifications merely as a selection device or signal for employers. Individuals on top of the labour queue are selected first by employers, because they have a higher trainability. This implies that they have lower cost of training before reaching the productivity maximum. The higher the worker's level of initial schooling, the lower the training costs.

More broadly interpreted, the tasks of a job and the circumstances associated with the job (e.g. complexity, uncertainties, change) determine the maximum productivity, whereas the level of general education of workers determines how fast or how easy (in training time or costs) workers can achieve the maximum productivity level. The higher the level of general education of workers, the sooner workers achieve the productivity maximum in a large spectrum of jobs (occupations). Moreover, if circumstances change, like the tasks of a job, the technology in use, the economic and political environment, etc., workers with a high level of general education are in particular suited to adapt to such changes, i.e. they are more flexible since they have a higher trainability.

On the other hand, also *vocational education* is important when individuals acquire skills during the initial schooling period. Workers can achieve specialization in skills by vocational initial schooling. The importance of specialization for the economy was already noticed by Adam Smith (1776, reprint 1981) in his "Wealth of Nations", in which he expressed the idea that the division of labour raises productivity.[4] Smith argues that specialization has a threefold impact on productivity. Firstly, it increases the dexterity of workers, which implies that both the rapidity and the quality of production are improved. Secondly, specialization is timesaving since workers do not (or less often) have to switch from one task to another. Thirdly, specialization induces labour-saving innovations, since the attention of workers is so much directed to a particular task that they are more likely to improve the production process, or find out improvements of machines. Although Smith refers to the specialization in tasks instead of specialization in skills to explain the productivity-enhancing effects of specialization, both kinds of specialization go hand in hand for the reason that a particular job, which

4. Much later also Schultz (1990) regarded the division of labour, or specialization, as a key to income and productivity increases.

represents a bundle of specific tasks, requires specialization of workers in vocational skills to perform the specific tasks. The vocational skills can be acquired by workers both during the initial schooling period and on-the-job. To prevent (part of) the initial productivity loss of workers in a new job workers have to acquire vocational skills by means of attending specific vocational classes during the initial schooling period.

Since vocational skills are relatively specific to particular occupations, it may be beneficial to offer students the opportunity to acquire vocational skills during their studies, if the demand for these skills is sufficiently widespread across the economy. The relevance of vocational skills for the economy is expressed by for example McMahon et al. (1992, p. 182): "occupation-specific skills are immediately useful at work and thus are generally associated with higher initial earnings and lower initial unemployment." Thus, individuals can directly increase their *productivity* by vocational specialization during the initial schooling period.

Rosen (1983) develops a model in which specialization is based on the increasing return on human capital accumulation. He points out that the incentives for specialization mainly arise from the increasing returns on the utilization of human capital, since the use of human capital is costless once the investment costs are made (Rosen, 1983, p. 44): "The return to investment in a particular skill is increasing in its subsequent rate of utilization because investment costs are independent of how acquired skills are employed. This element of fixed costs of investment makes it advantageous to specialize investment resources to a narrow band of skills and employ them as intensively as possible." Moreover, following Smith's argument that the division of labour is limited by the extent of the market, the opportunities for specialization in particular skills are larger if markets grow.

Only if there is a good match between job requirements and vocational skills, vocational initial schooling increases workers' productivity significantly (Bishop, 1989). According to the assignment theory (see Chapter 2) both the job requirements and the level and type of education are important for the productivity level of a worker, which probably applies to vocational education in particular. Bishop (1995) discusses the relevance of vocational skills (which he calls occupation-specific skills) relative to other skills and abilities, like the ability to learn new skills, the work habits, social and communication skills, leadership ability, reading, writing, mathematical and reasoning abilities. He shows that vocational skills on the whole have the largest positive impact relative to the other skills and abilities on the hiring decisions of employers and the job performance (measured by both productivity standards and wages) of workers.

However, if workers have acquired skills only by vocational initial schooling, they may have increased their productivity for a relatively small spectrum of jobs, at the risk that they are strongly dependent on the rapidly changing labour market perspectives of a small labour market segment (De Grip and Heijke, 1991). Labour market perspectives may be influenced by the business cycle or by technological change. As stated before, workers with a high level of general initial schooling are relatively well suited to adapt to changes like the tasks of a job or the technology in use.

Matching between acquired and required skills

Figure 4.1 indicates how both general (G) and vocational (V) initial schooling contributes to the improvement of the match between the acquired skills of the workers and the required skills of the occupation.[5] The figure shows the *tenure-productivity profiles* of workers with both a general and a vocational educational background.[6] The vertical axis represents workers' marginal productivity *MP* which is assumed to equal their real wage *w*, whereas the horizontal axis represents time *t* measured by the job tenure. The curves of the figure show that the marginal productivity of workers increases with their job tenure. When workers accept a new job, they have a lower productivity than the maximum productivity (MP_{max}) associated with the job.[7] The initial productivity loss equals $MP_{max} - G_0$ for workers who do not have a vocational educational background that corresponds with the tasks of their new job. If workers' vocational education matches with the job, the initial productivity loss is lowest, i.e. $MP_{max} - V_0$. In other words, vocational education contributes directly to workers' productivity, provided that the type of vocational education corresponds to the tasks of the job that are performed by the worker.

Both curve *V* and *G* in Figure 4.1 show that the longer workers are employed in the job, the smaller the mismatch measured by the difference between the maximum and the actual productivity. As a result the mismatch decreases with job tenure. This is due to continuing training of workers, whether formal or on-the-job (including learning-by-doing).[8] As stated above, general education makes workers more flexible with regard to the range of jobs in which they can be employed. The flexibility of workers is related to their trainability, which is increased by general education. When determining the rate of return on investments in continuing training by calculating the marginal benefits and costs (see Chapter 2), it is expected that general education of workers results in a larger rate of return on investment in continuing training. This implies that the level of general education attained by workers determines the rate of return on investment in continuing training at the beginning of the job, whereas the initial productivity loss does not change due to general education. Figure 4.1 illustrates this with curve G_H for workers with higher general education and curve G_L for workers with lower general education. Although both curves start at point G_0, higher educated workers have, in line with Thurow's labour queue model, a larger rate of return on investments in continuing training, which is revealed by the larger slope of curve G_H relative to curve G_L. This implies that the productivity maximum associated with the job will be achieved sooner by higher educated workers than by their lower educated colleagues (see also Van Eijs

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5. Of course these curves represent stylized patterns of the tenure-productivity relation of workers with general and vocational education. In practice there is a large variety of workers with different 'mixtures' of general and vocational initial schooling.

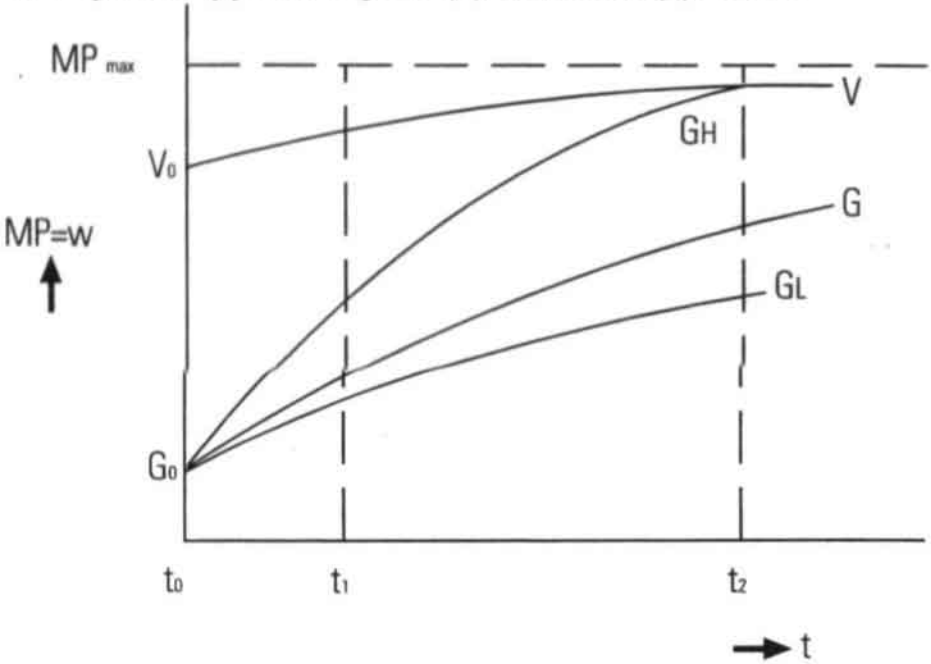
6. Figure 4.1 is inspired by Van Eijs and Heijke (1996), who combined the idea of maximum productivity associated with the job with the matching of required and acquired skills.

7. The idea that the jobs characteristics determine the maximum productivity level is taken from Thurow (1975).

8. The implications of continuing training for improving the match between acquired and required skills will be discussed in the next section.

and Heijke, 1996).[9] Workers who have largely participated in vocational educational courses (curve *V*) can also profit from investments in continuing training, since they probably have attended some general educational courses. As can be concluded from Figure 4.1, in the long run all types of workers will achieve the productivity maximum associated with the job. Therefore the mismatch between acquired and required skills decreases to zero in the long run.

Figure 4.1
Tenure-productivity profiles for general (*G*) and vocational (*V*) education



The concavity of the curves *G* and *V* can be explained as follows. Workers acquire skills by continuing training at the moment they start in their new job. At the beginning of the working career there is relatively much to learn with regard to the performance of the new tasks in the job. Workers can acquire some of the skills by instructions and demonstrations of colleagues. For other skills workers have to join formal training programmes. In particular skills acquired by general education reveal a large rate of return at the beginning of the working career, since general education makes workers more trainable (see above). The rate of return is indicated by the slope of the curve in Figure 4.1: the larger the slope, the larger the rate of return (Van Eijs and Heijke, 1996). Therefore the slopes of curves *G* and *V* represent the rate of return on investment

9. Workers with a very high level of general education relative to the job level may achieve the productivity level of the job almost immediately. In Figure 4.1 this implies that the initial slope of the tenure-productivity curve approaches infinity.

in continuing training. The sooner workers and their employers invest in the skills required for the new job, the larger the period the investments in the required skills can be made profitable. Therefore it is most efficient to invest in the acquisition of skills at the start of the job (e.g. before t_1). However, when job tenure increases, the law of diminishing returns (see Chapter 2) begins to work. Figure 4.1 illustrates this by the decreasing slopes of the curves in the course of time. After time t_2, it is still possible to refine the skills of the more experienced workers to achieve the productivity maximum of the job. Nevertheless, the marginal benefits do probably not outweigh the marginal costs to invest in the further refinement of skills, since both the period during which the investment is of benefit is shorter and the costs to acquire the specialized skills are higher than at the start of the job. Therefore experienced workers acquire the remaining specialized skills required to achieve the maximum productivity of the job mainly by learning-by-doing.

The above discussion shows that both general and vocational initial schooling are relevant for the productivity of workers and the match between their acquired and required skills. General initial schooling indirectly increases the productivity of workers due to the larger trainability of workers (related to their flexibility, see above), which improves the match when job tenure increases. Vocational initial schooling directly increases workers' productivity (by specialization, see above), provided that there is a good match between the workers' acquired skills and the required skills by the occupation. In the long run, however, the mismatch between the required skills of the job and the acquired skills of the worker will disappear as a result of continuing training.[10] Moreover, McMahon et al. (1992) and De Grip and Heijke (1991) point to the importance of an appropriate balance between the general and vocational skills that are acquired during the initial schooling period. This balance may in particular be important since general initial schooling and vocational initial schooling are complementary "both in learning and later in use of the more general and the more applied concepts and skills." (McMahon et al., 1992, p. 183)

Overeducation of workers

Thurow (1975) suggests that employers assume the existence of an inverse relationship between workers' initial schooling and the amount of continuing training workers require to achieve the maximum performance associated with the job. This implies that students, who know that employers assume the above inverse relationship, may compete for a job by investing in initial schooling before they offer themselves on the labour market (job competition). Consequently, this mechanism may cause overeducation of workers.

From a social point of view, overeducation of workers[11] may be less wasteful if it is a substitute for continuing training in firms. Substitutability of initial schooling and

10. This is confirmed by the empirical results in Van Eijs and Heijke (1996).

11. For a short introduction and some references on overeducation see Groot (1993). See also Van Eijs and Heijke (1996) for a theoretical discussion about over(and under)education and some typical rates of return for over(and under)education relative to the education required.

continuing training[12] would arise because a worker with a higher level of initial education needs less training or less learning-by-doing (i.e. experience) to accumulate the same amount of human capital. If initial schooling and continuing training are substitutable, firms have the option of recruiting overeducated workers, who would need little or no training, rather than training workers with the usual (required) level of education.

Sicherman (1991) indeed finds that overeducated workers require less training and experience. According to Sicherman (1991) this points to a trade-off between initial schooling and training or experience, which supports the hypothesis that different forms of human capital, such as initial schooling, training and experience, are substitutable. Also Hersch (1991) finds that training time is significantly negatively related to the overeducation of workers.[13]

We did not allow for overeducation in Figure 4.1, since it is supposed that workers always need some training. This implies that overeducated workers are always below the maximum productivity line when they start in a new job. Since the empirical studies mentioned above confirm that these workers need relatively less continuing training, the productivity of overeducated workers will rise very quickly from the beginning. After a relatively short period of time overeducated workers will reach the productivity maximum of the job.

4.3 Continuing training

Investment in continuing training is the second form of human capital that will be discussed in this chapter. In Section 4.2 the quality of labour supply on the external labour market was treated as an important exogenous variable when firms want to hire new workers. New workers recruited by firms nearly always have to learn additional skills they have not acquired during their initial education or previous jobs. Therefore we also have to consider various forms of human capital accumulation that can be directed by the firm on its internal labour market, such as formal training and on-the-job-training, including learning-by-doing. Moreover, the widely-used distinction between general and specific training is used to understand the nature of these training forms, the investments of workers and firms with regard to continuing training and the impact of training on productivity and wage growth.

Forms of continuing training

Often the workers' skills acquired by training are firm-specific, i.e. they can only be

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12. See the next section for the different forms of continuing training.

13. However, Hersch (1991) uses a different argument to explain the negative relationship between overeducation and training time. According to Hersch (1991) the overeducation of workers may indicate a greater innate ability and may lead to lower job satisfaction, resulting in a higher chance of turnover. This makes it unattractive for either the employer or the employee to invest in specific training (see Section 4.3 for the definition of specific training).

learned on-the-job within a particular firm.[14] Standard textbooks on labour economics, such as Ehrenberg and Smith (1994), distinguish between formal training, informal training and learning-by-doing, which all three form part of on-the-job training.

Formal training stands for training courses inside the firm, whereas informal training is instruction, demonstration, help, etc. in the workplace. Moreover, Lynch (1992) distinguishes between formal on-the-job training on the one hand and formal off-the-job training on the other hand. Formal off-the-job training are training courses which are organized outside the firm, e.g. by a training institution. Bowman (1987) discusses the somewhat confusing range of definitions of on-the-job training in the context of human capital theory.[15] He first mentions training in a narrow sense, which is organized instruction in the work place. Training in a broader sense encompasses all forms of job-related training, including formal instructional programmes, either within or outside the firm. Apprenticeships are a special form of training within the firm. They are often sponsored by the government, although this is dependent on the educational system of a country. This thesis will consider all these kinds of formal and informal training as continuing training, whether on-the-job or off-the-job, whether inside or outside the firm.

Also the third form of training mentioned above, learning-by-doing, can be regarded as part of on-the-job training and thus as part of continuing training.[16] The difference between acquiring skills that are learnt by sacrificing working time for training time (either formal or informal training), and acquiring skills that are learnt by repeatedly fulfilling tasks without any loss of productivity, i.e. learning-by-doing, seems to be important for firms to make training decisions. Time spent on working cannot be spent on training, i.e. they are substitutable, whereas working and simultaneously learning are complementary. Killingsworth (1982) calls the former way of generating skills 'investment in training', the latter 'learning-by-doing'. These are alternative forms of human capital accumulation. The difference is that training requires an investment decision by the employee and employer, whereas learning-by-doing occurs as an inevitable by-product of working, without any investment decision. Furthermore, training can occur either in a formal training programme or informally, on-the-job. Thus employees, in being supervised, in consulting colleagues or books, or in learning to understand how work processes are carried out, are engaged in some form of training.

However, the dividing line between acquiring skills through working in a job, i.e. learning-by-doing, on the one hand, and acquiring skills by informal training on the other is rather thin for two reasons. First, although we have drawn a clear conceptual distinction between investment in training and learning-by-doing, in practice it is not easy to distinguish between informal forms of investment in training on the one hand,

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14. This is emphasized by e.g. Chapman (1992).

15. In fact Bowman (1987) does not consider learning-by-doing.

16. However, note that the concept of learning-by-doing has been widely used in differing contexts by micro-economists, industrial economists and international trade theorists (see e.g. Malerba, 1992, and Cörvers, 1994).

and employees' learning-by-doing on the other hand. Both are usually regarded as on-the-job training. Informal forms of training often go hand-in-hand with being at work and producing something, i.e. learning-by-doing. The major difficulty in distinguishing informal investment in training from learning-by-doing is the increase in job-related skills with experience, tenure or age.

Second, apart from the difficulties of distinguishing informal forms of investment in training and learning-by-doing, even the conceptual difference between investment in training and learning-by-doing can be disputed. This conceptual difference is based on the principle that learning-by-doing is considered to be a by-product of the production of goods. However, this does not imply that learning-by-doing is costless (Rosen, 1972a). For example, Bowman (1974, p. 148) argues that "some jobs have large learning components in them, while other may entail little learning; when people choose between such alternatives they are choosing whether or not to invest in further training". Employers may deliberately create jobs with a large learning content, which implies that the required skills of these jobs are larger than the acquired skills of newly recruited workers. By continuing training these workers will in the long term acquire the skills that are required in their jobs. If workers are paid more or less their marginal productivities "the learning opportunity is implicitly sold to the worker, who buys it when he accepts lower wages." (Bowman, 1974, p. 148) Therefore learning-by-doing can be regarded as a human capital investment as well.

The experience or age of individuals is often used as a proxy for on-the-job training. Due to the lack of training data, Mincer (1974) takes the work experience of individuals as a proxy for investments in training during their work life. Later, when training data became available, he compares the direct method which estimates the relationship between training, the learning contents of jobs and wage profiles with the indirect method which estimates the relationship between work experience as an indirect proxy for on-the-job training and wage profiles (Mincer, 1989). He comes to the conclusion that the empirical results of the two methods do not differ very much and that about two thirds of the rise in wage profiles stems from investment in training. The residual is to a large extent a result of job searching. Another illustration of the use of work experience as a proxy of both investment in training and learning-by-doing at the individual level is given by Hashimoto and Raisian (1992). They take the number of years of tenure in the firm as a proxy for firm-specific capital, whereas years of work experience is a proxy for general market experience.

General and specific training

According to human capital theory, the decision of an employee or employer to invest in training is based on a cost-benefit analysis (see also Chapter 2). Training is an investment in workers which raises both current training costs and future benefits, in the form of increased marginal productivity of workers. Firms and workers may incur training costs such as the costs of the trainers in a formal training programme or in a less formal training situation (for example a demonstration), the costs of materials consumed during the training process and the opportunity costs of the workers' time devoted to training rather than to production activities (Ehrenberg and Smith, 1994).

The cost-benefit analysis of training is particularly relevant to understand how the match between the acquired skills of workers and the required skills in their jobs becomes perfect in the long run, and in which forms of training is invested. To analyse this problem Becker (1975) distinguishes between general and specific training.[17] Completely general training increases the marginal productivity of employees by the same extent in all firms. Workers acquire skills by general training which are of the same value for all firms, since the labour market with regard to these skills is perfectly competitive. Completely specific training only increases the marginal productivity of employees in the firm in which they are working, and has no effect on their marginal productivities in other firms. In other words, there is no perfectly competitive labour market for specific skills. Bowman (1987) explains the difference between general and specific training by pointing to the complete portability of general skills and the complete non-portability of specific skills. Skills acquired by workers during formal training courses organized by for example training institutions are expected to be portable to other firms, since these general skills are probably also required by workers of other firms. Skills acquired by workers during formal internal training courses or informally during working time probably are more specific to the production process of the firm.

In case of completely portable skills (i.e. general skills), the firm that provides general training to the employee must pay a wage that reflects the employee's marginal productivity. If not, the employee will quit, since other firms are willing to pay according to his marginal productivity. Therefore a firm in a perfectly competitive environment will not be willing to pay for the cost of training workers that acquire general skills (i.e. these skills are portable to other firms) during the training course. This implies that firms do not invest in general training, so the costs of general training must be paid by the employees during their training time. Employees pay not only for direct training outlays of general training, but also for the forgone earnings due to spending time on general training instead of working.

In contrast to the complete portability of skills acquired by general training of workers, skills acquired by specific training of workers are non-portable to other firms and only of value for the firm in which the worker is employed (Bowman, 1987). Now assume that the firm pays for all training costs of the specific training in the initial period and collect all returns in the next period. The employee will be paid according to his marginal productivity in the absence of training before and after training. His[18] wage will not differ from the wage that he could get elsewhere, i.e. the market wage, so there will be no incentive for the employee to stay with the firm. In other words, he could, for whatever reason, easily quit. If the employee quits, the firm loses the opportunity to earn a return on the investment and is left behind with a net loss. Thus if either the firm or the employee pays all the costs of specific training, each would have to fear that the other party might terminate the labour contract. A solution lies in sharing the costs and returns for training between the firm and the employee. If both parties share the training costs they have an incentive to preserve the contract in order

17. See also Stevens (1996) for a short overview of different interpretations of general and specific training.

18. The use of 'he' or 'his' stands for either a male or a female employee.

to earn the return on investment (Becker, 1975).

The above analysis of specific training has been formalised by Hashimoto (1981). However, he allows for uncertainty about the marginal productivity of the worker's specific human capital (i.e. specific skills) both in the firm and in an alternative employment situation. This uncertainty reflects errors in predicting market conditions. Given the density functions of expected values of the worker's real productivities inside and outside the firm, Hashimoto (1981) shows that the sharing ratio, i.e. the worker's share in the cost of investment, affects both the dismissal and quitting probabilities and the expected net gains of the employer and employee. With regard to sharing the return to investment he remarks that "quits and dismissals produce external effects by preventing the parties from capturing the full return to investment. The worker is fully aware that the larger the share he claims, the greater is the probability of dismissal. The employer is just as aware that the larger the share he claims, the greater is the probability of quit." Both parties take into account the quit and dismissal probabilities of the other party. The higher the probability of a dismissal, the lower the worker's share of the costs. The higher the probability of a quit, the lower the employer's share of the costs. Both parties maximize the sum of their net gains by choosing the sharing ratio and the amount of specific human capital invested. Hashimoto (1981) concludes, like Becker (1975), that the sharing ratio is equal to the ratio of the worker's expected return to the total expected return (i.e. to the sum of the worker's and employer's expected returns).

Hashimoto's analysis also confirms an important conclusion of Becker (1975) that specific training raises a worker's wage profile, which is above his marginal productivity in the investment period but is below his marginal productivity during the post-investment period. Only with general training, when the worker pays all the costs of training, does the wage reflect the marginal productivity in both the investment period and the post-investment period. This implies that a worker's wage profile during his life-time is expected to be steeper with general than with specific training. Moreover, the analysis shows that the productivity and wage growth due to training courses of workers who acquired specific skills are not necessarily equal to each other,[19] which is an important pitfall when measuring the benefits of training courses by the wage growth of workers instead of by the productivity growth of workers.

Figure 4.2 illustrates the above two findings (see also Bowman, 1974). The figure shows the tenure-productivity profile GT_{MP} of workers with a similar type of initial education (whether general or vocational). As in Figure 4.1 of Section 4.2 workers are faced with a productivity loss at the beginning of their job. The initial productivity loss when workers invest in continuing training may be even larger than without investing in continuing training due to the forgone earnings of not working. However, workers enjoy the benefits of training by means of a rise in marginal productivity (MP) when job tenure (t) increases. In the long run the productivity maximum associated with the job is reached due to the investments in continuing training. Again the tenure-productivity curves are concave for reasons mentioned in Section 4.2. However,

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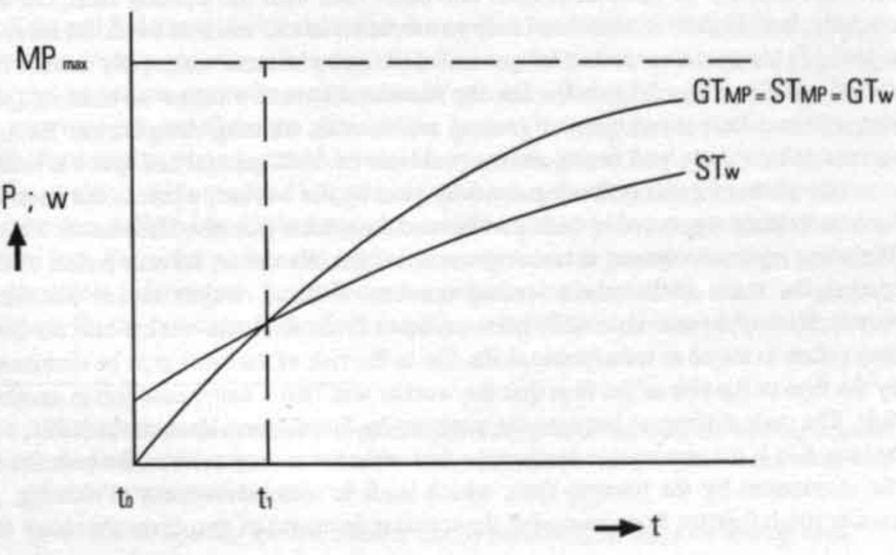
19. See e.g. Cörvers (1994) for an overview of empirical research with respect to the sharing, productivity growth and wage growth as a result of training.

contrary to the tenure-productivity profiles drawn in Figure 4.1, workers can invest in either general training or specific training. It does not make a difference for the productivity increase over the time period in question (e.g. the working career) whether workers or firms invest in general or in specific training, since the skills acquired by workers for a particular job are assumed to be similar in both forms of training. As is argued above, the specifity of training is determined by the portability of the skills to other firms and the market conditions, i.e. the dismissal and quitting probabilities. Therefore the tenure-productivity profile of workers who invest in general training (GT_{MP}) is similar for workers who invest in specific training (ST_{MP}), i.e. $GT_{MP} = ST_{MP}$. The theoretical background given above shows that workers who invest in general training pay for the investment by themselves, and also profit from the resulting wage increase without sharing the costs and benefits of the investment in training with their employer. Therefore the marginal productivity of workers who invest in general training equals the real wage during their working career, i.e. $GT_{MP} = GT_w$. On the contrary, the marginal productivity of workers who invest in specific training is not equal to their real wage as a result of sharing the costs and benefits of the training investment with their employer. Therefore the wage is lower than marginal productivity at the beginning of the working career (from t_0 to t_1), which implies that the employer shares in the investment costs of training. After some time (after t_1), the real wage becomes lower than the marginal productivity, which implies that the employer shares in the benefits of the training investment. As a result the tenure-wage profile of workers who invest in general training GT_w is steeper than the tenure-wage profile who invest in specific training ST_w . In practice most training courses or informal training activities will contain both general and specific components. Due to workers and employers sharing the costs and benefits of specific training the tenure-wage profile will almost never be identical to the tenure-productivity profile.

Figure 4.2
Tenure-productivity profiles for general (*GT*) and specific (*ST*) training



4.4 The imperfect match

This section gives two reasons why the perfect match between the workers' acquired skills and the required skills of the job may not be established after some time. Whereas Sections 4.2 and 4.3 assume that the perfect match will be established by the continuing training of workers after some years of working experience, this may not always hold true due to underinvestment in training and skill obsolescence of workers.

Underinvestment in training

The theoretical analysis in Section 4.3 revealed that firms are not willing to pay for general training. It follows that workers have to pay for it, e.g. by paying the direct training costs or by accepting a wage loss. According to Becker (1975) there is no externality problem (or market failure) with regard to skills acquired by general training, since workers pay for the costs of acquiring these skills. However, low liquidity and imperfect capital markets make it very difficult for the employee to borrow for investments in general training. Therefore the failure of the capital markets to allow individuals sufficient credit may lead to underinvestment in general training (see e.g. Chapman, 1992). Another explanation for underinvestment in general training is offered by Ritzen (1991). According to him the underinvestment is caused by the high risk associated with the returns to general training, which is empirically confirmed by some studies he mentions. Ritzen remarks that the high level of uncertainty as to future returns when investing in training influences the training decisions of workers more than those of employers. This is caused by both the higher risk aversion of workers and their more limited means of pooling (diversifying) the risks, as compared to firms.

Stevens (1994, 1996) introduces the concept of transferable training to show that underinvestment in training can also occur in imperfectly competitive markets for skills. She defines transferable training as all kinds of training (except purely general training) that are of value to at least one other firm than the training firm. On the contrary, Becker (1975) considered only two extreme labour markets for skills, namely a perfectly competitive market for general skills and a bilateral monopoly market for specific skills. According to Becker the various alternative forms of training (see above) are different mixtures of general and specific training components. Becker seemed to have dissolved the externality problems for both general and specific skills, since the costs of general training are fully paid by the worker, whereas the costs of specific training are shared by both the firm and the worker (see also Hashimoto, 1981). Therefore underinvestment in training can not occur. However, Stevens points to the market for skills with only a limited number of firms, which causes poaching externalities of transferable skills between these firms. Both the worker and the firm may refuse to invest in transferable skills due to the risk of the worker to be dismissed by the firm or the risk of the firm that the worker will find a better paid job in another firm. The main difference between the analyses by Stevens and Hashimoto (1981, see Section 4.3) is the assumption by Stevens that other firms may share in the benefits of the investment by the training firm, which leads to underinvestment in training. A similar result follows from analysing the training decisions of two firms that have the choice to train or not to train their workers. A well-defined pay-off matrix of training illustrates that the firms find themselves in a prisoner's dilemma. This results in a Nash equilibrium with both firms not training their workers, which is Pareto inefficient (see e.g. De Grip, 1987 and Chapman, 1992).

However, Ritzen (1991) notes that there is ample empirical research to show that employers do share in the costs of general training, for example Bishop (1991) and Hill (1991). If employers do indeed pay an important share of the costs of general training, then the empirical research contradicts the results of Becker's theoretical analysis. At the same time the argument of underinvestment in general training is weaker, because employers seem also to invest in general training. Ritzen argues that the willingness of employers to invest in general training may be related to the transaction costs of changing jobs. The higher the transaction costs for the worker if he quits, the more the firm is willing to pay for general training. Ritzen (1991, p.189) takes another definition of general and specific training, using the concept of transaction costs: "the category of specific training can be defined to include all those types of training for which the expected benefits of moving to another firm are not sufficient to offset the transaction costs of a move." This definition makes it possible to understand that circumstances other than the nature of training itself can be important. For example, training in a firm that is situated in a thinly populated region with low economic activity will be more specific than the same company training in a region in which similar firms are established. Furthermore, training in large firms tends to be more specific than the same training in smaller firms, because internal labour markets are probably better developed within large than within small firms (see also Chapman, 1992).

The so-called complementarity hypothesis is another alternative which Ritzen (1991) mentions to explain investments in general training by firms (see also Feuer et al., 1991). This hypothesis implies that it may be profitable for firms to invest in general training because it enhances the efficiency of specific training.[20] A worker will not switch to another firm as long as his share of the return in general and specific training is larger than the full return on his general training[21] if he switches to another firm.

Katz and Ziderman (1990) show that the predictions of Becker's model are reversed if informational asymmetries are assumed. Due to a lack of information the employer may not be certain about the real amount of general training the applicant enjoyed in his previous job and about the value of the general training for his firm (see Bishop, 1991, for a similar argument). As a result the recruiting firm may place a lower value on the worker's skills acquired by general training than the firm that trained the worker. The worker will be less likely to quit and will be paid a lower wage in the firm that trained him. Since the worker can not fully benefit from his general training in the case of imperfect information, he will not be prepared to bear all the costs of general training. On the other hand, the firm may find it feasible to pay for part, or all, of the

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20. Note that the complementarity-hypothesis between general and specific training is based on the similar principle as the complementarity-hypothesis between general and vocational education mentioned in Section 4.2.

21. Given that completely specific training has, by definition, no value for another firm.

costs of the worker's general training, since informational asymmetries make general training effectively specific. According to Bishop (1991) this argumentation also leads to the conclusion that the lower the informational asymmetries, the higher the wage growth of workers. Informational asymmetries are lower for formal training than for informal training. Bishop (1991) shows in an empirical analysis that formal training has significantly larger effects on wage growth than informal training, although he cannot establish a similar result with regard to general training as compared to specific training.

The above analysis shows that the larger the general training components in a particular form of training, the larger the probability that underinvestment in training occurs. Solving the informational asymmetries on the training market, i.e. improving the transparency of the skills acquired by continuing training, may also increase underinvestment in training. Due to serious underinvestment in training it can take much longer before workers achieve the productivity maximum associated with the job. In other words, the match between the acquired and required skills may not become perfect for the experienced workers on the job if acquiring skills by learning-by-doing takes very long.

Skill obsolescence

Workers do not only accumulate human capital, but are also subject to the obsolescence of human capital. The change of the production function, as a result of the diffusion of new technologies, leads to a change in the demand for human capital because of capital skill and technology skill complementarities (see also Chapter 2 and 3). The flattening out or diminishing of the age-earnings profile some years before workers' retirement, which is often accounted for by adding a squared age, experience or tenure variable to the earnings function of workers (see for example Mincer, 1974 and Hashimoto and Raisian, 1992), in fact provides an indication that, sooner or later, older workers become less productive.[22] Both the physical and economic depreciation of workers may cause this decline (Van Dalen, 1993, see also De Grip et al., 1998), which may result in a mismatch between the acquired skills of workers and the required skills on the job. Skill obsolescence may lead to the early retirement or disablement of older workers and even to the economic depreciation of the human capital of all workers, as will be argued below.[23]

Van Dalen (1993) enumerates some reasons for the physical depreciation of workers. The decrease in the productivity of older workers is determined by work pressure, health, age and gender. The last two factors are only important when large

22. An empirical analysis by Gelderblom and De Koning (1992) presents the results of a large-scale survey among over 1600 Dutch firms and institutions. The analysis shows that, on average, both the productivity and wages of workers reach their peak between the ages of forty and fifty. In line with the age-earnings profile mentioned above, productivity and wages tend to decline after this age, which is usually seen as an indication for obsolescence.

23. See also De Grip et al. (1997), in which different forms of skill obsolescence and their remedies are distinguished.

physical efforts are required, as physical strength declines with age and the decline of physical strength with age may be different between male and female workers. With regard to the first two factors, older workers seems to be more sensitive to work pressure (time pressure and working at different tasks at the same time), have a higher chance of occupational disablement and have higher illness rates (see also Gelderblom and De Koning, 1992, 1992a). Higher illness rates were found in particular for workers involved in jobs in which physical efforts are required.

Economic depreciation may also be a cause of obsolescence. However, in contrast to physical depreciation, it is not obvious here that age plays an important role. As Van Dalen (1993) stresses, the decline in productivity in the case of economic depreciation is not directly linked to age, but to the obsolescence of human capital. Like physical capital, human capital depreciates due to technical change, that is, the available human capital of workers is unsuited or less suited to new production techniques. Similarly, De Grip (1987) argues that changes in the demand for labour, for whatever reason (thus including technical change, but also a change of consumer preferences), may result into a smaller *ex post* rate of return for human capital investments than expected *ex ante*. When this happens during the initial schooling (or training) of individuals, this form of obsolescence is called 'in process' obsolescence of schooling (De Grip, 1987). Moreover, since a change in production techniques alters the firm's demand for specific rather than general skills, firm-specific skills have a higher probability of economic depreciation. Another important cause of economic depreciation is the non-use of knowledge and skills, for example during unemployment.

It follows that not only older workers may suffer from skill obsolescence due to economic depreciation. But most empirical research concentrates on skill obsolescence among workers of fifty years or older. Empirical results indicate that older workers' real wages relative to their productivity are too high (see for example Gelderblom and De Koning, 1992; Kotlikoff and Gokhale, 1992). These relatively high wages of older workers cannot be explained by human capital theory, as this theory suggests that due to the sharing of the costs of specific and even general training (see Section 4.3), the real wage is higher than the marginal productivity at the beginning of someone's working career, and lower than marginal productivity towards the end of someone's working career. However, Gelderblom and De Koning (1992) refer to what they term 'contract theory' to explain the relative high wage of older workers.[24] According to Gelderblom and De Koning (1992) these theories indicate that employers postpone wage increases for workers until they are approaching the end of their working careers. By postponing wage increases of new workers, employers want to reduce the costs of uncertainty as to the productivity of new workers. Employers also want to diminish the turnover of workers in this way and to give them incentives to achieve maximal performance till the end of the contract. However, the consequence may be that when older workers become less productive while still enjoying relatively high wages, employers want to get rid of them.

Employers can pursue several policies to prevent the negative consequences of the

24. By contract theory they mean various theories such as the implicit contract theory and the theory of efficient wages (for references see Gelderblom and De Koning, 1992, p. 27).

productivity loss and the mismatch between acquired and required skills as a result of skill obsolescence (see Van Dalen, 1993, and Gelderblom and De Koning, 1992). A first option is that employers offer real wages to older workers which better reflect their marginal productivities (i.e. lower wages). This option is mentioned by Gelderblom and De Koning (1992a) and Van Dalen (1993), who also state that firms should profit more from some advantageous characteristics of older workers such as superior problem solving, negotiating and public relations skills, consistent performance, lower accident rates, etc. These skills may more than compensate for the decline in productivity due to other characteristics. It is also possible to let older workers stay with the firm by offering them another job which better matches to their characteristics. Moreover, Hebbink (1992) shows that older workers are complementary with young workers, which suggests that there may be an optimal mix of older and young workers in a firm. So firms can profit from older workers by applying a human resource policy better suited to older workers, for example offering them other jobs, possibly in connection with lower wages. A second option is to replace older workers by younger workers or physical capital. Some support for the viability of this option may be found in the empirical study of Hebbink (1992). He shows that older workers are substitutable by physical capital and medium-aged workers in the Netherlands.

Furthermore, Gelderblom and De Koning (1992, 1993) remark that older workers do not have a smaller learning capacity than younger workers, so long as the didactics of the training method are suited to older workers. Gelderblom and De Koning note that the obsolescence of older workers as indicated by their falling productivity is reinforced because they participate less in training courses than younger workers.[25] Thus, greater participation of older workers in training courses is recommended as another option if employers want to increase productivity. However, retraining for another job is less attractive for older workers, because they have accumulated a larger stock of human capital during their working career, some of which will be unusable in another job, and unused knowledge and skills can be lost (De Grip, 1987). Human capital theory explains that older workers participate less in training, since older workers have higher opportunity costs when participating in training (because they earn higher wages) and have a shorter period during which they can benefit from the returns of their investments (see also Mincer, 1974). Both circumstances mean that it is not attractive for either the worker or the employer to invest in the human capital of older workers. According to Van Dalen (1993) the relatively short post-investment period of older workers can be lengthened if employers and employees agree on postponing retirement.

In this context it is interesting that Bartel and Sicherman (1990) find that older workers retire later in industries with higher rates of technical change and on-the-job training. They explain this by the higher depreciation rates of human capital in industries with high rates of technical change, so that workers have flatter earnings profiles in these industries. As a result older workers have to retire later to capture the returns on investment in human capital. However, if there is an unexpected increase in the rate of technical change, older workers will be likely to retire earlier. In this case

25. The hypothesis that older workers participate less in training courses is confirmed by e.g. an empirical study of De Grip et al. (1998).

it is not attractive for older workers to invest in the required on-the-job training, because they are faced with unexpectedly high depreciation rates while their post-investment period is relatively short.

The above analysis shows that the productivity loss due to skill obsolescence can cause a mismatch between the acquired skills of workers and the required skills of their jobs. Older workers may have to change the tasks of their job, must retrain or must accept a job with a lower productivity and wage. If workers (at any age level) are faced with techn(olog)ical change and the resulting economic depreciation of their skills, they have to participate in training courses to adapt to the new skill requirements.

4.5 Conclusions

The aim of this chapter was to present a theoretical background of how different forms of initial schooling and continuing training improve the match between the acquired skills of the worker and the skills required by the workers' jobs. Vocational initial schooling directly increases the productivity of workers, provided that there is a good match between the acquired and required skills at the start of their jobs. The higher the level of general initial schooling of workers, the sooner workers achieve the productivity maximum in a large spectrum of jobs. Moreover, if circumstances change, like the tasks of a job, the technology in use, the economic and political environment, etc., workers with a high level of general education in particular are likely to adapt to such changes. As a result the trainability of workers increases due to general initial schooling. Therefore general initial schooling may raise the productivity of workers indirectly, by enlarging the rate of return on investments in continuing training. Different forms of continuing training can be distinguished, formal versus informal, on-the-job, including learning-by-doing, versus off-the-job, general versus specific. In particular distinguishing between general and specific training is useful since it is a starting point for understanding why underinvestments in training may occur. Underinvestment in training may, together with skill obsolescence, be accountable for an imperfect match between the workers' acquired skills and the skills required by the job. On the other hand, workers may compete for a job by investing in initial schooling before they offer themselves on the labour market. This may lead to overinvestment in initial schooling, although the overeducation of workers is less wasteful if it is a substitute for continuing training in firms.

In this chapter it has been argued that investments in initial schooling and continuing training, the main two forms of human capital distinguished, increase productivity. Moreover, the chapter shows that investing in various forms of initial schooling and continuing training by both employers and employees results in a better match between the acquired skills of workers and the skills required by the job. In the long run the mismatch between acquired and required skills even disappears. Experienced workers may even have reached the productivity maximum associated with the job. In other words, their acquired skills are almost similar to the required skills by the job, apart from the risk of underinvestment in training and skill obsolescence. The analysis in this chapter shows that the larger the general training components in a particular form of training, the larger the probability that underinvestment in training occurs. Moreover, solving the informational asymmetries on the training market, i.e. improving the transparency of the market for skills acquired by continuing training, may also increase underinvestment in training. Furthermore, skill obsolescence can cause a mismatch between the acquired skills of workers and the required skills of their jobs, which may result in a productivity loss. For example, if workers (at any age level) are faced with techn(olog)ical change and the resulting economic depreciation of their skills, they have to participate in training courses to adapt to the new skill requirements. Although the analysis of Chapter 2 shows that there are good reasons to assume that the skill structure of the work force represents the human capital stock of the work force, the mismatch between acquired and required skills must be accounted for. Underinvestment in skills may occur as a result of underinvestment in training and skill obsolescence, whereas overinvestment in skills may occur as a result of matching relatively highly-educated workers to low-productivity jobs.[26]

26. This conclusion is consistent with the findings in Van Eijs and Heijke (1996), who show that the rates of return for under- and overeducated workers are lower than the rates of return of workers with the required level of education.

Chapter 5

Skills and productivity: a theoretical framework

5.1 Introduction

This chapter offers a framework for understanding *why* the skill level of workers matters for the level and growth of productivity.[1] In the previous chapter we have discussed how workers can achieve a particular skill level, namely by the various forms of initial schooling and continuing training, whereas in this chapter we focus on the productivity effects of the skill level of workers. A closer look at the role of human capital in the production process will be presented to understand the effects of skills on productivity. From research inspired by human capital theory, in particular Welch (1970), it follows that human capital has two important effects on the productivity level. These effects are called the *worker* effect and the *allocative* effect. The distinction between these two effects will be used as a tool to analyse the productive value of human capital in production. Although Welch (1970) discusses these effects with regard to the productive value of initial schooling, we consider the worker and allocative effect on productivity as a result of the workers' skill level achieved by both initial schooling and continuing training. It will be argued that these two effects offer an explanation for both the effective labour input hypothesis and the capital-skill complementarity hypothesis. Moreover, two other effects can be distinguished, namely the *research* effect and the *diffusion* effect. These latter two effects also provide a framework to understand the hypothesis on the complementarity between technological change and human capital. As in this thesis the skill structure of the work force is represented by differentiating between workers' low, intermediate and high skills, this chapter will also discuss the effects of these skills on productivity.

Furthermore, some empirical studies will be considered that point to the impact of the above mentioned effects on productivity. First, various case studies have been carried out on the relevance of education and training for productivity by the National Institute of Economic and Social Research[2] during more than a decade. In these case studies manufacturing plants of similar sectors (e.g. engineering, wood, clothing and food) in Great Britain, Germany and some other countries are analysed with respect to a wide spectrum of dimensions, including the production process, the quality of the products, productivity differences and the skill and organizational structure. Although these studies do not refer to the theoretical framework mentioned above, the results of

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1. This framework partly extends the framework that is discussed in Cörvers (1994), Cörvers et al. (1995) and Cörvers (1997).

2. See the reprints of these case studies bundled in a publication of the National Institute of Economic and Social Research (1990).

these studies underpin the relevance of the productivity effects in the theoretical framework. This chapter discusses the main findings in these case studies with respect to the productivity effects of skills. Second, this chapter regards some econometric studies that point to the relevance of the four productivity effects of skills. Also these studies do not refer to the above mentioned theoretical framework. Moreover, the econometric studies discussed usually measure one of the above mentioned productivity effects.

The chapter is organized as follows. Section 5.2 discusses the four effects of skills on productivity in a theoretical framework. Section 5.3 tries to underpin each of these effects by empirical evidence. Section 5.4 concludes the chapter.

5.2 Four effects of skills on productivity

Four different effects of human capital on productivity can be found in economic literature: the worker effect, the allocative effect, the research effect and the diffusion effect. These four effects are based on the studies of Nelson and Phelps (1966), Welch (1970), Ram (1980) and Pencavel (1991), inter alia. These effects are, however, often treated separately in both theoretical and empirical studies. In this section we will argue that the first and second of these effects underpin the relevance of human capital for the *productivity level*, whereas the latter two effects underpin the relevance of human capital for *productivity growth*. Furthermore, the impact of intermediate and high skills with regard to these productivity effects are considered.

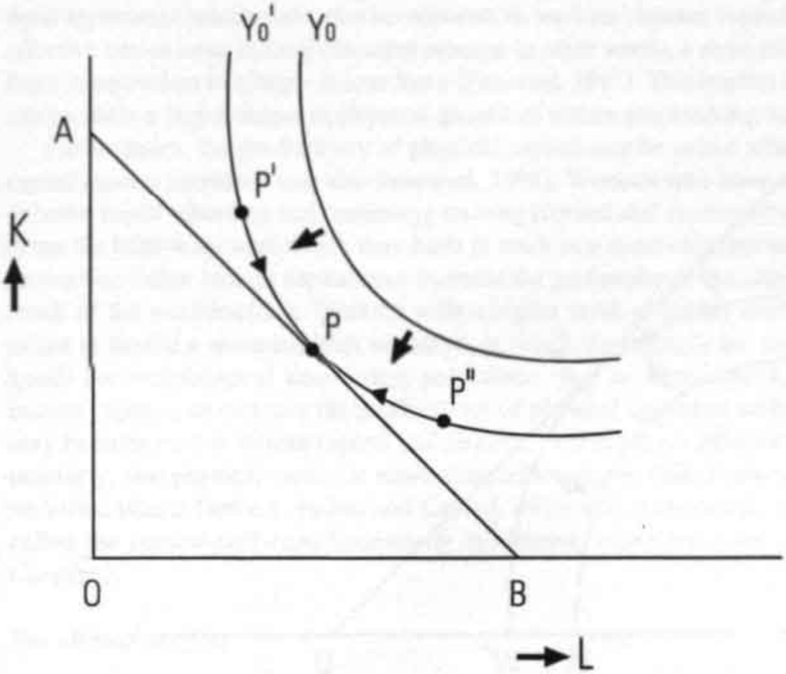
The worker effect

The worker effect (or 'own productivity' effect) has been explained by Welch (1970). He assumes that firms produce only one good with the production factor education, and that other resources are given. The worker effect refers to the positive marginal productivity of education with respect to that particular good. Workers with a higher level of education are assumed to be more efficient in working with the resources at hand, i.e. these workers produce more physical output. In other words, education increases the effective labour input from the hours worked. Therefore a better educated labour force shifts the production possibility curve outwards. According to Welch (1970, p. 43) the worker effect is presumably "related to the complexity of the physical production process."[3] The more complex a production technique is, the more 'room' is left for the worker effect to improve the (technical) efficiency of production. Human capital investments in workers increase their productivity level in physical units. If low-skilled workers are ignorantly wasting resources, the loss of production is due to a lack of human capital, i.e. the skills they could have had. This loss of production is related to the positive marginal productivity of human capital. The worker effect is the

3. Since it is not clear how Welch (1970) defines the 'production process', it is assumed that Welch means 'production technique' (see Chapter 3). Moreover, the complexity of a production technique can be interpreted broadly. This complexity is dependent on both internal and external factors, like the organization structure, the product quality, the behaviour of competitors, suppliers and customers, the political environment, etc.

(physical) marginal product of human capital, and equals the increase in (physical) output of goods per unit increase of human capital, holding other factor inputs constant. The human capital input embodied in the work force may be increased due to a raise in both the quality of skilled workers and the relative proportion of skilled to unskilled workers (see Chapter 2).

Figure 5.1
Effects on the isoquant of a single good



The worker effect can be illustrated by considering the shift of the isoquant of an economy, a sector or a firm. Figure 5.1 shows the isoquant Y_0, which represents the technically most efficient input combinations of labour (L)[4] and physical capital (K) for a given level of output (Y_0). Given the input levels of both labour and physical capital, the higher to the right an isoquant, the higher the level of output it depicts (see e.g. Koutsoyiannis, 1985). Moreover, given the output level (Y_0 in Figure 5.1), the higher to the left an isoquant, the lower the input levels of labour and physical capital. The slope of an isoquant indicates the marginal rate of substitution between physical capital and labour. It follows that labour and physical capital are substitutable within a certain range. The worker effect of a better educated labour force results in a decrease of the required inputs of labour and physical capital to produce a given level of output Y_0 due

4. Labour is measured by the number of persons without correcting for the amount of human capital they embody.

to working more efficiently with the resources at hand.[5] Figure 5.1 illustrates this by the shift of the convex isoquant to origin, i.e. from Y_0 to Y'_0. In other words, the efficiency of the cost-minimizing set of production techniques represented by the isoquant increases. The impact of the worker effect on the isoquants in Figure 5.1 has close resemblance to the impact of technological progress on the isoquants. In both cases the isoquant for a given output level shifts to the origin.[6]

Figure 5.2
Effects on the production possibility frontier of the goods

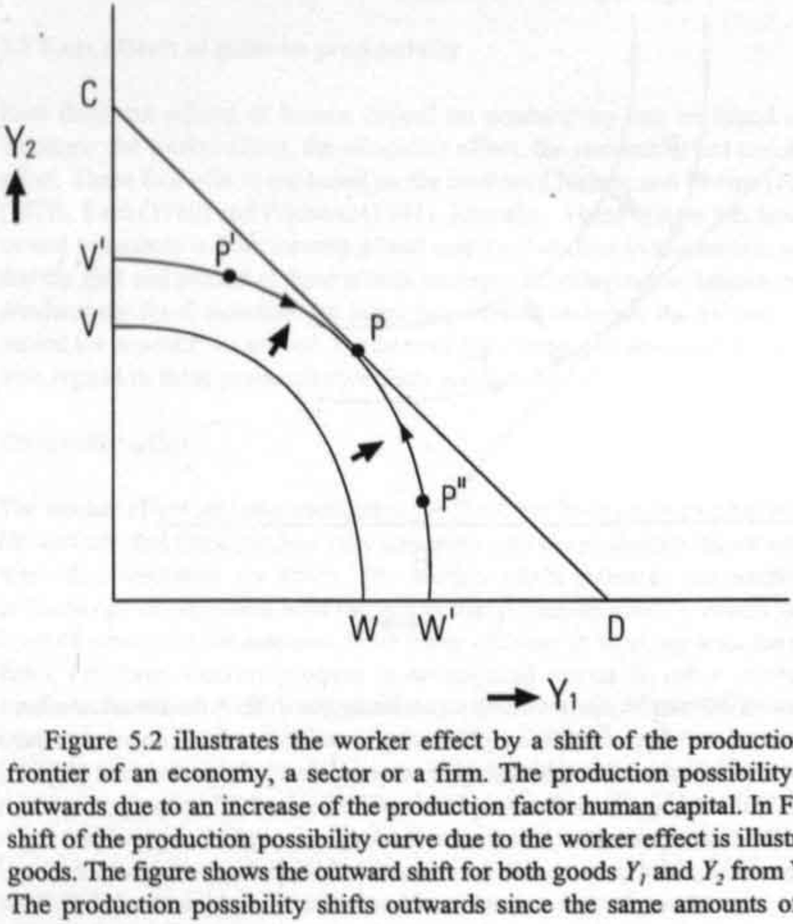


Figure 5.2 illustrates the worker effect by a shift of the production possibility frontier of an economy, a sector or a firm. The production possibility curve shifts outwards due to an increase of the production factor human capital. In Figure 5.2 the shift of the production possibility curve due to the worker effect is illustrated for two goods. The figure shows the outward shift for both goods Y_1 and Y_2 from VW to V'W'. The production possibility shifts outwards since the same amounts of labour and

5. As will be argued below, the productivity of both input factors labour and physical capital may increase due to the worker effect. Therefore the inward shift of the isoquant in Figure 5.1 is not only downwards, but also leftwards.

6. The distinction between capital-deepening, labour-deepening and neutral technological progress (see e.g. Koutsoyiannis, 1989) may also hold for the impact of the worker effect on the use of inputs. However, the worker effect is probably most similar to labour-deepening technological progress, since the marginal (physical) product of labour is increased due to the worker effect.

physical capital are used more efficiently as a result of an increase in the input of human capital.[7] The points on the isoquant or production possibility curve are considered to be technically efficient. Technical efficiency increases due to the raise of the average skill level of the work force, which implies that the locus of production is on the isoquant Y_0' instead of Y_0 (Figure 5.1) or on the production possibility curve V'W' instead of VW (Figure 5.2).

The shift of the isoquant in Figure 5.1 illustrates that human capital may increase the marginal productivity of both the input factor labour and the input factor physical capital (see also Schultz, 1990). The former increase is known as the *effective labour input hypothesis*, which states that investments in workers' human capital enlarges the effective labour input in the production process. In other words, a more educated labour force is equivalent to a larger labour force (Pencavel, 1991). This implies that a worker can produce a larger output in physical quantities within one working hour.

Furthermore, the productivity of physical capital may be raised when the human capital input is increased (see also Pencavel, 1991). Workers who have enjoyed more or better initial schooling and continuing training (formal and on-the-job) may be able to use the hard-ware with which they have to work in a more efficient way. Thus, the production factor human capital may increase the performance of a capital good as a result of the worker effect. Workers with a higher level of human capital are better suited to handle a more complex situation, in which for example the input of capital goods (or technological knowledge, see below) may be important. It follows that human capital can increase the productivity of physical capital as well. Therefore it may be inferred that human capital and physical capital are complementary, or more precisely, that physical capital is more complementary to skilled labour than it is to unskilled labour (see e.g. Fallon and Layard, 1975, and Hamermesh, 1993). This is called the *capital-skill complementarity hypothesis*, which has been referred to in Chapter 2.

The allocative effect

The allocative effect points to the greater (allocative) efficiency of better educated workers in allocating all input factors to the production process (including education itself[8]) between the alternative uses. Welch (1970) gives two examples of the allocative effect. If there is one fixed input factor to produce two goods (or varieties), education may improve the total revenues of firms by means of a better allocation of the input factor between the alternative outputs. Although the production process is technically efficient because the firm produces on the production possibility curve (expressed in physical units), workers have more knowledge of how to maximize the marginal value product (expressed in monetary units) of the input factor. Total revenues are maximized

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7. Thus the productivity of both labour and physical capital is increased as a result of the worker effect. See below on the complementarity between physical capital and skills.

8. Better educated managers may also take better decisions in personnel management. Therefore the matching between acquired skills of workers and the skills required by the job (see Chapter 4) may improve due to better allocative decisions of managers.

if the marginal value product of the input factor is equalized for all goods. Another allocative effect is present if, in addition to education as an input factor, two (or more) other inputs are included in the production function. If just one good is produced with two inputs, education may also help to select the efficient quantities of inputs. In equilibrium the marginal value product of the inputs should equal the price of the inputs. In fact, education seems to provide the skills to make better decisions based upon the available information (see below). As a result of the allocative effect, investments in human capital of workers are expected to lead to a higher productivity level in monetary units.[9]

The allocative effect explains why human capital is important for, on the one hand, the optimal bundle of different inputs required for the production of one unit of output and, on the other hand, the optimal allocation of inputs over different output factors. The difference between the worker effect and the allocative effect is that the former focusses on the productivity increase (in physical quantities) of the other production factors (e.g. labour and physical capital) when investing in human capital, whereas the latter means that, due to the production factor human capital, all other production factors (including purchased inputs) are allocated more efficiently between competing uses (outputs) in the production process. The allocative effect may concern the amount of physical quantities produced, like the worker effect, but the allocative effect supposes that human capital improves the choice of both the amounts of the different factor inputs and the amounts of the different goods produced. Furthermore, the choice of inputs and outputs is directly related to the production technique, that is the choice of the production processes (as defined above). Gomulka (1990, p. 5) in fact relates this choice to the allocative effect by stating: "When several processes are involved, we may need someone in the firm to know that they are in fact available and to be able to make the best selection from among them. We include this higher level of organizational and management knowledge in our concept of technology in the broader sense, or simply technology."

Figures 5.1 and 5.2 clarify the two aspects of the allocative effect with regard to the choices of inputs and outputs respectively. In Figure 5.1 the Y_0' isoquant represents the amount of labour and physical capital required to produce one particular good. The line AB represents the budget contraint of the production factors labour and physical capital. The isoquant touches the budget constraint in P, which implies that the marginal rate of substitution of labour and physical capital equals the ratio of factor prices. Therefore P represents the Pareto-efficient point of production, whereas P' and P" represent the Pareto-inefficient points of production. Furthermore, the line CD in Figure 5.2 represents the isorevenue line of a firm or an industry producing two products, Y_1 and Y_2, and selling them at constant prices. Figure 5.2 shows that the isorevenue line touches the production possibility curve V'W' in P. Again, P represents the Pareto-efficient point in which the marginal rate of product transformation of Y_1 and Y_2 equals the ratio of the product prices. Therefore P' and P" are not Pareto-efficient.

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9. Not only managers but also production workers can benefit from the allocative effect of skills, since both types of workers may have to take decisions, although at a different level, with regard to for example the priorities of tasks to be done.

In general it can be said that Pareto-efficiency requires both technical efficiency and allocative efficiency (or price efficiency, see Fallon, 1987).[10] Allocative efficiency implies that the budget line (Figure 5.1) and the isorevenue line (Figure 5.2) touch the isoquant and the production possibility curve in P respectively. It follows that P' and P" only satisfy the condition of technical efficiency, whereas P satisfies both conditions of technical and allocative efficiency, and therefore also Pareto-efficiency. As stated before, the worker effect increases technical efficiency, which can be shown by a shift of the production isoquant to the origin or a shift of the production possibility curve away from the origin.

On the other hand, the allocative effect of human capital increases allocative efficiency, which can be shown by a move along the isoquant or production possibility curve towards P. The allocative effect refers to the effect of human capital on the choices of the bundles of factor inputs (Figure 5.1) and goods (Figure 5.2). Both in Figure 5.1 and 5.2 human capital is supposed to bring on a move from the technically efficient but allocative inefficient points of production P' and P" towards the Pareto-efficient point P. This move may be related to the skills to gather, decode and interpret information on prices of inputs and outputs. The relationship between human capital, information and allocative efficiency is stressed by Ram (1980, p. 366): "Education generally has the effect of lowering the (marginal) costs of acquiring production-related information, and of raising the (marginal) benefits of such information. Such lowering of marginal costs may occur for a variety of reasons, including the improved communication skills of more educated persons, and the possible superiority of their 'contacts'. The rise of marginal benefits could similarly be rationalized through the consideration that higher schooling probably sharpens the judgemental faculties of persons and increases their capability to process and apply the received information."

It follows that the allocative effect of human capital is strongly related to the role of information, and therefore the value of human capital is related to the value of information. Human capital is needed to collect information or handle available information. If allocative decisions have to be made it is important that workers can perceive the problem (or change), collect and analyse useful information, draw valid conclusions from the available information, and act quickly and adequately (see Huffman, 1977). Human capital is supposed to increase this so called allocative ability. Huffman (1977) states that both initial schooling and experience play a role in increasing the allocative ability of workers. Therefore the allocative effect is, in relatively unchanging circumstances, an important effect of human capital on productivity for the various forms of initial schooling and continuing training distinguished in Chapter 4.

Thus, the allocative effect holds for initial schooling, formal training and on-the-job training equally well in relatively unchanging circumstances. This is illustrated by quoting Welch (1970, p. 47), who comments Schultz's analysis of the value of human capital: "... in economies in which agricultural production is accomplished almost solely by the use of 'traditional' factors, there is reason to believe that factors are more efficiently allocated than in 'modern' agricultural economies. Schultz's interpretation

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10. See Sharpe (1995) for a related discussion on technical and allocative efficiency.

is that traditional agriculture is close to an economic equilibrium in adjusting to relatively stationary techniques. Because of this, judgments about factors are based upon extensive observation; the stationary technology guarantees ample time to explore the potential of factors being used." This implies that skills (here allocative abilities) acquired by initial schooling can also be acquired by on-the-job training, including learning-by-doing. However, it may take longer for low-skilled workers to acquire the same allocative ability by training (formal or on-the-job) as highly-skilled workers have acquired by initial schooling. In fact this conclusion comes close to the theoretical background of Chapter 4 in which the perfect match between acquired skills of workers with different skill levels on the one hand and the required skills in the job on the other hand is finally achieved by investments in continuing training.

Research effect

The research effect refers to the role of higher education as an important input factor in research and development (R&D) activities. R&D, in turn, is a key factor for technological progress and productivity growth. Since R&D activities are very complex,[11] relatively large human capital investments in workers are a prerequisite to increase technological knowledge and achieve productivity growth (see also Englander and Gurney, 1994). As stated in Chapter 3, human capital is an important input factor for research and development in many endogenous growth models (e.g. Romer 1990, and Grossman and Helpman, 1992). Research and development activities lead to an increase in the stock of technological knowledge, which is favourable for economic growth. If firms want to invest in research and development (R&D), they have to recruit skilled workers (i.e. acquire human capital) and often have to offer these workers specialized training programs to prepare them for the complex tasks they have to perform in research and development. Relatively large investments in human capital are required to make research and development activities profitable. Therefore the share of skilled workers is expected to be relatively high for firms or sectors that invest relatively much in research and development.

The research effect implies that technological progress is not exogenously given, but is driven by investments in human capital. As argued in Chapter 3, technological progress is driven by specialized skills of workers who are employed in research and development activities. This implies that their human capital contributes directly to technological progress. The skill level of workers is supposed to be an important determinant in the success or failure of inventing new products or production processes (see also Chapter 3). Successful product or process innovations stimulate productivity growth, due to which it may be expected that the skill level of workers is also an important determinant for productivity growth. In Figure 5.1 a process innovation is illustrated by a shift of the isoquant closer to the origin, which implies that the costs of producing a given output decrease. In other words, technological progress and growth are skill-driven, whereas many empirical studies assume that technological progress

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11. Note that the research effect is similar to the worker effect in that both are related to the complexity of the production process.

and productivity growth are skill-biased (see Section 5.3). Whatever the causal relationship between technological progress and human capital, they seem to be complementary. This is called the *technology-skill complementarity hypothesis*.

Diffusion effect

The diffusion effect stresses that better educated workers are more able to adapt to technological change and will introduce new production techniques more quickly. A higher level of education increases the ability to discriminate between more and less profitable innovations and reduces the uncertainty about investment decisions with regard to new processes and products. Nelson and Phelps (1966) stress the role of receiving, decoding and understanding information in performing a job.[12] Therefore education increases the probability of successful and early adoption of innovations. Investments in human capital of workers would be expected to lead to both more rapid and more successful adoption of innovations and therefore higher productivity growth (see also Foster and Rosenzweig, 1996).

In particular in dynamic circumstances in which for example production technologies change, consumer preferences alter, or markets grow fast, the value of information and thus human capital (see Huffman, 1977 and Ram, 1980) may be large. Especially then it may be necessary that workers act adequately and quickly. Workers who have insufficient skills may need too much time to adapt to the changing circumstances, for example in case of technological change. Welch (1970, p. 47) stresses the role of initial schooling in reacting quickly on technological changes in agriculture: "...in a technically dynamic agriculture, a factor may be obsolete before its productivity can be fully explored! Herein, I think, lies the explanation of education's productivity. If educated persons are more adept at critically evaluating new and reportedly improved input varieties, if they can distinguish more quickly between the systematic and random elements of productivity responses, then in a dynamical context educated persons will be more productive."

From this it can be explained that Welch (1970) considers the Nelson and Phelps (1966) hypothesis that education increases the innovative ability of workers as a special, nevertheless important, consequence of the allocative effect of human capital. Schultz (1975) argues that more educated workers have larger allocative abilities to adapt to disequilibria of many kinds, although often caused by technological change. In Figures 5.1 and 5.2 technological change may shift the isoquant, the production possibility curve, the budget line and the isorevenue line, whether or not simultaneously. Workers (including managers) have to find the new Pareto-efficient location, for which they need allocative abilities. However, the productive value of workers who have acquired only low skills may be merely dependent on the static environment that is associated with the current production process. On the contrary, the diffusion effect of higher skilled workers is particularly relevant in (technologically) dynamic environments due to the complementarity between workers' higher skills on the one

12. In fact the diffusion effect can be regarded as a special case of the allocation effect (see below).

hand and the opportunities that are offered by the changing circumstances on the other hand. The diffusion effect is, apart from the research effect in complex production techniques in research and development activities, another reason for technology-skill complementarity.

Effects of low, intermediate and high skills on productivity[13]

By investing in human capital intermediate and high skills can be acquired. Ryan (1991, p. 2) defines intermediate skills as "those above routine skills but below professional ones". For statistical analyses such a definition is probably satisfying. However, definitions of skills say little about what is really learned when acquiring particular skills and about how the acquired skills affect workers' productivity. A taxonomy of cognitive skills, for example the taxonomy of Bloom which is used in Arents et al. (1996), may be a starting point for understanding the effects of different types of skills on productivity. This taxonomy contains a ranking of cognitive skills. Higher ranked skills can only be acquired after lower ranked skills have been obtained. Based on such a taxonomy we can differentiate between low, intermediate and high skills.

Furthermore, these three skill levels partly resemble the differentation between routinized skills, applied skills and conceptual skills by Ashton et al. (1991). Nevertheless, low, intermediate and high skills are heterogeneous in content and the boundaries between them are imprecise. Low skills consist of the remembering of previously learned material and the practised ability to achieve concrete results. By knowing methods and procedures, workers can perform the elementary tasks required in the production process in the same way, time and time again. Therefore low skills are often characterized as being routinized. As a consequence, low skills are often not transferable to other contexts, i.e. they can be characterized as context-specific. The higher the level of skills, the less context-specific they are. Low skills are particularly useful in large batch and mass production industries. Unskilled workers that are employed in low-skill jobs can reach the required skill level and the related productivity maximum of the job by learning-by-doing after some period of time.[14] Therefore unskilled workers become low-skilled workers when they get more experience.

Intermediate skills reflect the ability to understand the meaning of the learned material and enable workers to apply the learned material in variable contexts (see Arents et al., 1996). Contrary to low skills, intermediate skills evolve with the increase in technological knowledge and are applicable in a wide range of differing production techniques. Intermediate skills may be particularly useful in more complex and non-standardized production processes. Also high skills build on the features of intermediate skills, but over and above enable workers to analyse, synthesize and evaluate the material learned. High skills are also known as problem-solving skills, due to which workers are able to break down knowledge into parts, to marshall parts to form new

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13. Part of this subsection has been published before in Cörvers (1998).

14. Also other forms of continuing training can be offered to unskilled workers (see Chapter 4).

patterns and structures, and to evaluate the learned material. High skills can be used to think through problems and to resolve problems that come up in new situations, for example when new technologies are introduced (the diffusion effect, see e.g. Bartel and Lichtenberg, 1987). Therefore high skills are expected to be found in industries in which research and development activities play an important role.

Intermediate and high skills are supposed to be acquired by investments in both initial schooling and continuing training. As is explained in Chapter 4, due to general education workers become more flexible in different situations (including the 'confrontation' with changing technologies). The higher the level of general education, the lower the training costs of achieving the production maximum associated with the job. On the contrary, low (or routine) skills are mainly acquired by learning-by-doing. In other words, the stock of low, intermediate and high skills of workers represents their accumulated stock of past investments in initial schooling and continuing training.

An increase of the employment share of intermediate or highly-skilled workers in the work force of a firm or a sector, relative to the employment share of low-skilled workers, may raise the productivity level in physical units, which refers to the worker effect. Similarly, a higher productivity level in monetary units may be expected as a result of the allocative effect. Higher proportions of intermediate and highly-skilled workers, relative to low-skilled workers, would be expected to lead to a more rapid and successful adoption of innovations and higher productivity growth due to the diffusion effect. Since R&D activities are very complex, relatively large investments in intermediate and high skills are a prerequisite to increase technological knowledge and achieve productivity growth. Therefore the research effect of intermediate and high skills seems to be crucial for productivity growth.

5.3 Empirical research on productivity effects

It may be difficult to find empirical evidence on the four effects of skills on productivity mentioned before, since most empirical studies do not distinguish these effects as such. Moreover, although the worker effect on productivity, which is measured in physical units, should be distinguished from the allocative effect, which is measured in monetary units (see above), the data used in many empirical studies do mostly not allow this. Apart from measurement problems, productivity increases by investing in human capital may be reflected by productivity increases of other production factors than labour as well. This can be explained by the capital-skill and the technology-skill hypotheses referred to in the preceding section. Below the results of both case studies and econometric studies are reported. The results illustrate the relevance of the four productivity effects of skills, although the complete theoretical framework of the former section is usually not used explicitly in these studies.

Case studies

The English National Institute of Economic and Social Research (NIESR) has carried out a research programme in which the skill levels of the workforce across similar sectors of different countries are examined. Moreover, NIESR seeks to identify the mechanisms of how inter-country differences in average skill levels contribute to relative levels of labour productivity. To this end NIESR has developed a *plant-matching research method*. This method enables the analysis of the relative contribution of human and physical capital to productivity by site visits to samples of matched plants across countries. Daly et al. (1985) and Mason et al. (1992) report the results for the engineering manufacturing sector, namely the metal-working trades in springs, drills and vehicle components, in Britain, Germany and the Netherlands; Steedman and Wagner (1987) for the wood furniture manufacturing sector, namely fitted kitchens, in Britain and Germany; Steedman and Wagner (1989) for the clothing manufacturing sector, namely women's skirts, jackets, suits, in Britain and Germany; Mason et al. (1996) for the food manufacturing sector, namely biscuits, in Britain, Germany, the Netherlands and France. Most plants in these comparative studies had about 50 to 300 employees. Prais (1995) reports that this method has resulted in a total of over 160 visits to establishments[15] in the course of 1983 to 1991, and summarizes the most important results of the case studies listed above.[16] The empirical results reveal remarkable differences between Britain and the continental countries in firstly productivity, secondly the use of machinery and thirdly the average skill level of the work force. These differences will be discussed below.

Productivity rates in engineering plants are estimated to be 30 to 60% lower in Britain than in Germany and the Netherlands. Moreover, for wood furniture plants output per employee is more than twice in Britain than in Germany. Also the production in clothing of comparable types of garments is roughly twice as high in Germany as in Britain. For these three manufacturing sectors the differences can be partly explained by lower manning levels on the machine lines and lower rates of direct to indirect labour in the continental countries relative to Britain. Over and above, whereas British manufacturing sectors often produce highly standardised products at a large scale, German manufacturing sectors generally produce goods that are technically more advanced and of higher quality in a production process with smaller batches and in greater variety (shorter production runs). The relevance of quality differences is in particular illustrated by the study of Mason et al. (1996) in the biscuit

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15. Apart from the manufacturing plants also hotel establishments were visited and examined, firstly, whether international differences in productivity are equally important in a services sector as in manufacturing sectors and, secondly, whether and how the skill level of the workforce contributes to the international differences in productivity (see Prais et al., 1989). Below we will make no reference to the hotel sector, since the empirical analysis of Chapters 6 and 7 of the thesis does not incorporate services sectors. The conclusions reached by Prais et al. (1989) for the hotel sector do, however, not significantly differ from those of the manufacturing sectors.

16. During the visits semi-structured interviews were held with production managers, personnel managers and shopfloor supervisors. Also the production process and the work organisation on the shopfloor were directly observed during the visits. Moreover, interviews were held with representatives of machinery suppliers to cast light on the selection of modern machinery, the adaptation of machinery to specific product and process requirements and the maintenance of machinery. Interviews with representatives of teaching colleges were held to provide information on the initial level of educational attainment of craftsmen and technicians and the standards of their final qualifications as a result of training courses.

industry. In terms of tonnage biscuits per employee-hour, production in Germany is 20% lower than in Britain, whereas it is 15% higher in the Netherlands and 5% higher in France. However, to correct for the different quality grades of biscuits across countries price differences between countries are included in the calculation of so-called quality-adjusted productivity rates. Relative to Britain these quality-adjusted productivity rates are 25% higher in France, 35% higher in the Netherlands and 45% higher in Germany for the biscuit industry.

Possible sources of the productivity differences mentioned above may be found in differences in the use of machinery and workforce skills. Prais (1995) emphasizes that the use of machinery on the one hand and workforce skills on the other hand are related, as will be shown below. The comparisons of matched samples of plants across countries reveals that severe malfunctioning or reparation of one or more production lines seems to be a problem only in British manufacturing plants. Furthermore, the use of less technological advanced machineries in British compared to continental manufacturing sectors is related to the greater risk of breakdown of machinery in Britain. British foremen seem to prefer the use of less complex and older technologies, in which there are no automatic linking devices between successive machines in the production process, since a breakdown of one of the machines may stop the whole production line. The use of modern CNC (i.e. computer numerically controlled) technology in German manufacturing plants enables the production of a mix of smaller batches of varieties that can be produced in a relatively short production time at less extra cost than with the older technologies. Furthermore, these varieties can be manufactured to customers' order. By contrast, British plants generally manufacture standardised products for stock.

Skill differences between Britain and other countries are found to be of no relevance for workers engaged in simple routine manufacturing tasks (e.g. loading components, packaging), which is hardly surprising. Workers are usually not required to have vocational skills for these tasks, and usually have none. However, in the Netherlands new workers are expected to have some vocational skills at the secondary level when automation increases. Such a preference is not voiced in Britain. Furthermore, the more complex the jobs to be performed, the larger the skill differences between the employment shares of (intermediate and highly-)skilled workers in Britain and the continental countries. In the Dutch engineering plants of the sample, 80% of the turners and millers have acquired intermediate skills (i.e. craft qualifications), whereas this is only 40% in the matching British engineering plants. In the kitchen cabinet plants of woodworking, 90% of the shop floor production workers in the German plants have acquired intermediate skills, whereas this is merely 10% in the British plants. In the German clothing plants 80% of the sewing machinists have followed a systematic trainee ship at work combined with part-time college courses lasting at least two years, whereas no sewing machinist acquired skills at a similar level in the British matched sample. With regard to the skill level of workers in maintenance and technician teams, British workers mostly acquire skills by time-serving apprenticeships, sometimes combined with participation in related training courses. However, only the foreman of the team has usually acquired the formal qualifications. On the contrary, in German and Dutch engineering plants the employees of maintenance and technical support teams have at least acquired the formal craft-level qualifications (i.e. intermediate skills). Many of them even have acquired qualifications at the higher educational level. In the

British technical support staff, concerned with production planning, quality control and R&D, 45% of the employees have attained high skills, i.e. technician or higher qualifications, in contrast to 80% in the Dutch plants. Similar differences between Britain and Germany are reported for the production foremen and supervisors. The differences with regard to the foremen and supervisors are less marked between Britain on the one hand and France and the Netherlands on the other hand.

In all case studies mentioned above the productivity differences and the use of machinery are directly linked to the differences in workers' skill levels between Britain and the continental countries. In engineering plants in Germany, the Netherlands and France workers have, in combination with the use of more advanced and sophisticated technologies, a greater general ability to meet customers' specialised needs. Compared to British plants, the higher average skill level of workers in German plants has led to a relatively higher quality of German kitchens and clothing. The lower productivity of British clothing firms can be illustrated by the observation in British plants of a worker engaged in checking on faulty stitching at the end of most lines of sewing machinists, which is not observed in German plants. Moreover, when a new style is put into production, German machinists are able to achieve full operating speed in about 2 or 3 days by reading technical sketches with only consulting their supervisors occasionally on difficult points, whereas British machinists require several weeks to achieve full operating speed. British machinists can hardly read technical sketches and need to consult their supervisors frequently. Therefore it is rational that, firstly, British plants prefer relatively long production runs, and, secondly, more than half as many checkers and supervisors per machinist are required in British than in German clothing plants. Furthermore, it is comprehensible that supervisors and managers have less time to bother about preventive maintenance plans, production controlling, delivery plans and other organisational and strategic tasks.

The above results from the case studies fit very well into the theoretical framework exposed in Section 5.2. Workers with better skills due to a higher level of initial schooling are more productive in the sense that they make less mistakes and can handle complex machineries in a more efficient way. This clearly points to the worker effect of skills. The relevance of preventive maintenance in the production process is better understood by higher skilled managers, which points to the allocation effect of skills. Also production planning appears to be improved due the allocation effect of higher skills. Moreover, better skilled workers are more able to adapt to both small and large changes in the production process. Small changes include the production of a new style, whereas large changes include the use of new and technologically more advanced machineries. This points to the diffusion effect of skills. The worker, allocative and diffusion effect of skills do not only result in a more efficient production process with a higher physical output, but also allows the production of high-quality goods with a higher value added than goods of a moderate product quality, even if the products concerned are produced in the low-skill (see Chapter 6) or low-tech (see Chapter 7) manufacturing sectors. Furthermore, the relationship between these effects and the capital-skill and technology-skill complementarities are clearly illustrated in the case studies discussed above: due to the productivity effects of skills higher skilled workers know better how to handle complex machineries and can adapt more easily to more advanced production technologies.

However, the case studies considered above do only cover goods produced with a relatively low skill and technology-intensity. It is not evident how large the productivity effect of skills is in more technologically advanced manufacturing sectors, like chemicals or electrical machinery.[17] These manufacturing sectors usually have large expenditures in research and development. Including these sectors could cast more light on the research and diffusion effects of skills. Another limitation of the case studies above is their focus on the relative position of Britain against Germany in particular and the Netherlands and France to a lesser extent. Such a comparative analysis with British manufacturing sectors as points of reference is, however, too restricted to draw general conclusions on the relative magnitude of productivity effects in manufacturing sectors across other industrialized countries.

Econometric studies

Previous econometric studies on the four productivity effects focussed on the agricultural sector in the United States (see also Cörvers, 1994, and Cörvers et al., 1995). Huffman (1977) does not find a positive effect of farmers' education on corn yields in agricultural firms. It implies that he does not find evidence for a productivity increase due to the worker effect. However, his empirical study reveals that education increases the use of nitrogen as a new input factor, which points to a diffusion effect of human capital. On the other hand, Fane (1975) finds evidence for the allocative effect in managerial decisions on the purchasing of factor inputs and the choice of products to produce. He concludes that farmers with above average levels of education operate closer to the point of cost minimization. This points to a higher degree of allocative efficiency due to education. Lockheed (1987) gives an overview of a number of studies to test the hypothesis that higher levels of formal education increase farmers' efficiency. These studies used datasets on agricultural sectors in developing countries. By computing a weighted average of productivity increases found in various studies, he concluded that farm productivity increased by 7.4% where a farmer has four years of elementary education as opposed to none. However, it is not clear to what extent this increase is due to the worker effect or the allocative effect. Moreover, the productivity increase in the studies listed by Lockheed (1987) is only large if farms are confronted with technological change (i.e. diffusion effect).

Schultz (1975), in a review of empirical research on the impact of education on innovative ability, discusses some studies which reveal that better educated immigrants who used to be farmers, are more successful in farming than their less educated colleagues. Schultz finds relatively large returns to investments in initial schooling where there is a disequilibrium, for example due to changing technology (returns on investment being measured, e.g., by crop yields in agricultural sectors). This points to the relevance of the diffusion effect. Later empirical research on the relationship

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17. See, however, the empirical study by Mason and Wagner (1994). They use the same research method described before for the chemical and engineering industry in Britain and Germany. In particular intermediate-skilled German workers in engineering are, relative to British workers in similar jobs, more able to handle the continuing flow of incremental process innovations and the initial production problems when new products are introduced.

between human capital and technological diffusion confirms this conclusion (Huffman, 1977; Ram, 1980; Wozniak, 1984, 1987; Bartel and Lichtenberg, 1987; Mincer 1989a; Groot and De Grip, 1991; Foster and Rosenzweig, 1996). Therefore it is expected that the demand for better educated workers, indicated by the share of different educational categories in total labour demand, and the productive value of human capital, indicated by some productivity measure or the real wage, is larger if technology changes.

To analyse the effects of changes in technology on the demand for human capital, Mincer (1989b) notices that an increased supply of educated labour, which has been apparent in most countries during recent decades (see for example Barro and Lee, 1993), reduces its marginal product and therefore the educational wage differential, assuming that no other changes occur. Section 2.5 analyses the consequences of an increase in the supply of educated labour, for example of engineers. It concludes that due to a shift of the labour supply curve to the right, employment tends to increase, whereas both the marginal productivity and the real wage tend to diminish.[18] However Mincer (1989b) poses the question of why the massive increases in the supplies of educated workers did not lead to a significant downward long-term trend in the profitability of educated workers. He points to the production side of the economy to answer this question.[19] Given the capital-skill complementarity, one of the (widely accepted) explanations for the increased demand for educated workers is the growth of physical capital and the increased capital intensity in the industrial countries during the last decades.[20] Moreover, Mincer (1989b) explains the larger demand for educated workers as a result of technological change. This is confirmed by empirical studies, for example those by Welch (1970) and Bartel and Lichtenberg (1987). These studies find that relatively more educated workers are employed in industries with newer capital vintages or higher R&D expenditures. The real wages of more educated workers are also higher in those industries. Most empirical studies on this topic use a cross-sectional approach, whereas Mincer (1989b) confirms the skill bias of new technologies in a time series approach.

Further empirical research on this topic by Berman et al. (1994) shows that labour-saving technological change accounted for an important share of the shift in employment from production workers to non-production workers in US manufacturing between 1979 and 1989.[21] Less than one third of this shift is accounted for by a buildup of the defence industry and increased international trade (inter-industry shift). These factors result in a decrease in product demand from those industries with high shares of production workers. However, Berman et al. (1994) find that most of the shifts in employment occurred within four-digit manufacturing industries. These intra-industry

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18. Of course, this in part depends on the slopes of the demand and the supply curve.

19. This explanation is already given by Tinbergen (1975), who mentions the race between technological development and education to indicate whether or not the relative income of highly educated people, at a country level, increases over time.

20. A change in the input ratio indicates that another production technique is used. This may refer to either factor substitution (given the state of technological knowledge) or labour-saving technological change. See also Chapter 3.

21. See also Machin et al. (1996) for a similar empirical study with comparable results.

shifts were largely unrelated to defence procurements or imports. In Berman et al. (1994) the distinction between production and non-production workers is the only measure of skill. In accordance with the hypothesis that technological progress is skill biased, Berman et al. (1994) find that skill upgrading is positively related to investments in computers and computer-related technology as well as to R&D expenditures.

With regard to the impact of human capital on productivity growth there is little direct evidence in favour of the research effect (see e.g. McMahon, 1984; Benhabib and Spiegel, 1994; Leiponen, 1995). Pritchett (1996) even regards the evidence in growth studies with respect to the impact of the human capital level on total factor productivity growth across countries as not convincing. Nevertheless, human capital seems to be an important input factor in complex production processes such as research and development (Pencavel, 1991; see also Englander and Gurney, 1994; Berendsen et al., 1995). Moreover, there is abundant evidence that R&D efforts increase productivity growth (e.g. Mohnen, 1992; Verspagen, 1995). A survey of econometric studies by Mairesse and Sassenou (1991) shows the importance of R&D for productivity growth at the firm level. According to Patel and Soete (1988) the advantage of using R&D expenditures as a proxy for the input of technological knowledge is that R&D expenditures are an input proxy like conventional inputs such as labour and capital. However, both Patel and Soete (1988) and Mairesse and Sassenou (1991) point to some difficulties with regard to the empirical research on the relation between R&D and productivity growth. It is not only difficult to measure productivity, but also to decide whether particular investments belong to R&D. Moreover, a proxy such as R&D expenditures corresponds only to an investment flow, whereas a stock flow of previous and present R&D expenditures would be preferable. Nevertheless, this raises the difficulty that information is needed about the time lags between R&D expenditures and their effect on productivity. These time lags relate to the complexity of the innovation process described above, in particular the length of the period of the R&D project, and the uncertainty and delay in the revenues of the project. Moreover, the rate of depreciation of R&D capital has to be estimated in order to construct a R&D stock measure. Finally and very crucially, it is difficult to distinguish and measure the effects of a firm's R&D investments on its output, on the one hand, and productivity growth due to learning spillovers of investments in R&D by other firms on the other hand (see also Chapter 3). Spillovers occur not only between firms or sectors, but also between public and private research. The relevance of research at universities for corporate R&D expenditures and corporate patents has been shown by an empirical study of Jaffe (1989). Here we have to realize that expenditures on research in universities may coincide with public expenditures on higher education. This once more illustrates the relevance of human capital for R&D activities.

As has been argued in Chapter 4, continuing training builds up part of workers' human capital. An example of the effect of continuing training on productivity is given by Bartel (1991). Bartel's empirical study reveals that employee training programmes increase the growth in labour productivity of businesses[22] in the manufacturing sector

22. A business corresponds here to either a firm or a division of a firm.

of the United States significantly. Businesses that were below their expected productivity levels (relative to other businesses) in 1983 implemented training programmes which resulted in significantly higher rates of labour productivity growth between 1983 and 1986. Using a Cobb-Douglas production function Bartel (1991) finds an independent and significant impact of training on the productivity level. The training variable was measured by a dummy, indicating whether or not the business had a formal employee training programme. The rate of productivity growth between 1983 and 1986 was found to be at least 17% higher for businesses that implemented employee training programmes. Bartel (1991) concludes that "the implementation of formal employee training programs can enable businesses that are operating at below-expected level of labor productivity to eliminate this gap." Bartel thus finds the (labour) productivity level of workers can be raised by continuing training, which increases the effective labour input of workers. In terms of our theoretical framework this points to the worker and allocative effect of continuing training.

By contrast, the diffusion effect for continuing training (both formal and on-the-job) is not so evident. The human capital accumulated by continuing training can be indicated by the years of work experience (see Chapter 4). Wozniak (1984, 1987) shows that experience of farmers does not lead to faster adoption of new technologies. Wozniak (1987, p. 108) explains this by stating that "This may result from experience depreciating faster in a rapidly changing technological environment than in a static one."[23] Bartel and Lichtenberg (1987) even find that 'experience' on a technology declines the relative demand for highly educated workers, which may imply that skills acquired by initial schooling and continuing training have different productive values in stationary and dynamic environments. From their analysis it follows that the relative demand for highly educated workers may be large when technology changes rapidly, whereas the relative demand for experienced workers is large when technology changes slowly. With regard to the demand for training, Groot and De Grip (1991) find in a study on the banking sector that firms can respond to technological change by using both training policies and recruitment policies to upgrade the skills of employees. Furthermore, an empirical study by Bartel (1991a) confirms that both higher ratios of R&D expenditures to sales and of capital expenditures to the number of employees increase the probability of the presence of a formal training programme in a firm.

It can be concluded that the empirical evidence in econometric studies on the worker effect and the allocative effect is not yet convincing, whereas the diffusion effect seems to be relevant where there is technological change. Not much empirical research has been done regarding the research effect of human capital in research and development activities, whereas there is a direct link between investments in R&D and productivity growth. Moreover, the evidence presented usually does not differentiate between the four effects of human capital, and does not show the effects on sectoral labour productivity of intermediate skills and high skills separately.

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23. On the other hand, he finds evidence for the hypothesis that information plays an important role in the adoption of new technologies, since larger firms are adopting faster than smaller firms. This may be a result of scale economies in the use of information.

5.4 Conclusions

This chapter has presented a theoretical framework to understand the effects of human capital on productivity. The human capital stock of a firm, a sector or a country is represented by the low, intermediate and high skills of the workers employed. These skills are supposed to be acquired through investments in both initial schooling and continuing training (see Chapter 4). Four productivity effects of human capital have been distinguished: worker, allocative, diffusion and research. An increase of the employment share of intermediate or highly-skilled workers in the work force of a firm or a sector, relative to employment share of low-skilled workers, may increase the productivity level in physical units, which refers to the worker effect. Similarly, a higher productivity level in monetary units may be expected as a result of the allocative effect. Higher proportions of intermediate and highly-skilled workers, relative to low-skilled workers, would be expected to lead to more rapid and successful introduction of innovations and higher productivity growth due to the diffusion effect. Since R&D activities are very complex, relatively large investments in intermediate and high skills are a prerequisite to increase technological knowledge and achieve productivity growth. Therefore the research effect of intermediate and high skills seems to be very important for productivity growth.

The worker and allocative effect refer to the relevance of human capital in a static environment, i.e. without technological change. They are therefore called *static effects*. The research and diffusion effect refer to the relevance of human capital in a dynamic environment, i.e. when production technology changes. They are therefore called *dynamic effects*. Furthermore, it has been argued that the static effects underpin the relevance of human capital for the *productivity level*, whereas the dynamic effects underpin the relevance of human capital for *productivity growth*.

The empirical results from both the case studies and the econometric studies discussed in this chapter fit very well into the above theoretical framework. However, most empirical studies do not distinguish between the productivity effects of human capital as such and do not show the effects on sectoral labour productivity of intermediate skills and high skills separately. Case studies that consider the contribution of human capital to productivity differences across similar sectors in different countries do only cover goods produced with a relatively low skill and technology-intensity. Moreover, these studies focus on the relative position of Britain against some other countries. Such a comparative analysis with British low-skill and low-tech manufacturing sectors as points of reference is, however, too restricted to draw general conclusions about the relative magnitude of productivity effects. Furthermore, econometric studies on the worker effect and the allocative effect are not yet convincing. These econometric studies show that the diffusion effect seems to be relevant where there is technological change. The empirical evidence on the direct impact of human capital on productivity growth is in general not yet convincing for the reasons mentioned above. There is, however, convincing empirical evidence that research and development activities, in which human capital is an important input factor, contribute to productivity growth.

Chapter 6

Sector-specific human capital inputs, labour productivity and the impact on trade performance[1]

6.1 Introduction

According to the Ricardian theory of international trade the relative labour productivity level between countries is an important determinant of their trade flows. The relevance of productivity for international competitiveness and trade has been explained in Chapter 1. It has been argued that productivity can be considered as the principle indicator for international competitiveness. In this chapter we will conduct the empirical analysis along the lower line of research of the general framework of Figure 1.1. From this lower line of research it follows that differences in productivity between similar sectors across countries determine the sectoral trade performance. This chapter starts with an empirical analysis on the relevance of the sectoral labour productivity level for the trade performance of sectors.

However, by merely pointing to the relationship between labour productivity and trade performance the Ricardian theory does not provide an explanation for the sources of international competitiveness. One of the sources for different labour productivities between sectors of industry is human capital. The main focus of this chapter is on the question whether the factor input of human capital at sector level matters for the average productivity level of manufacturing sectors. In other words, this chapter will analyse the consequences for labour productivity of sector-specific differences in the use of skills. In Chapter 1 it has been argued that this way of analysing focuses on the sectoral employment of workers with different skill levels, whereas in the next chapter the national endowments of workers with different skill levels is taken as the starting point of the explanation of trade flows.

Based upon the human capital theory Chapter 5 referred to four different effects of human capital on labour productivity: the 'worker effect', the 'allocative effect', the 'diffusion effect' and the 'research effect'. The former two static effects underpin the relevance of human capital for the *productivity level*, whereas the latter two dynamic effects underpin the relevance of human capital for *productivity growth*. From the previous chapters it follows that the human capital stock of the work force in a sector can be represented by the employment shares of low, intermediate and highly-skilled workers. Both the sectoral production function and the effective labour input function are assumed to have a Cobb-Douglas form, which is sufficient for measuring the productivity effects of human capital (see Chapter 2). It will be shown that, under the

1. Parts of this chapter have been published before in Cörvers (1997) and Cörvers (1998).

assumptions given, two necessary conditions for profit maximization are that the elasticities of output with respect to intermediate and highly-skilled labour are both larger than zero. It will also be shown that these conditions hold if the employment shares of intermediate and highly-skilled labour are smaller than the respective combined worker and allocative effect of these categories of labour. If the employment shares of intermediate and highly-skilled labour are larger than the combined worker and allocative effect, this may point to an overinvestment of human capital. However, as mentioned before human capital may also have a diffusion and research effect on sectoral productivity growth. From this dynamic point of view, which takes account of technological change (see Chapter 3), overinvestment of human capital that follows from the analysis of the static effects is not evident.

The chapter is organized as follows. Section 6.2 tests for the relevance of sectoral labour productivity levels to explain sectoral trade performance in the Ricardian model of international trade for seven Member States[2] of the European Union. Section 6.3 describes the human capital model that is used to explain labour productivity. Section 6.4 deals with the differences in employment shares of intermediate and highly-skilled labour, i.e. human capital intensities, across the seven countries of the sample. This section reveals that the manufacturing sectors can be classified into low-skill, medium-skill and high-skill sectors. For these categories of sectors, Section 6.5 estimates the effects of human capital on the sectoral labour productivity level, whereas Section 6.6 estimates the effects of human capital on the sectoral labour productivity growth. Moreover, some conclusions are drawn on the overinvestment and underinvestment of human capital in the manufacturing sectors in seven EU Member States. Section 6.7 concludes the chapter.

6.2 Reinterpreting and testing Ricardian theory

The Ricardian theory of international trade is based on Ricardo's original work 'The Principles of Political Economy and Taxation' of 1817 (Ricardo, reprint 1984). The standard Ricardian model assumes two countries, two goods and only one factor of production, i.e. homogeneous labour.[3] Ricardo's merit was to point out that even if one country has an absolute advantage over the other country in producing both goods, it may still be advantageous for both countries to trade as a result of their different *comparative advantages*. If relative prices before trade differ between the two countries, these countries have a comparative advantage in the good of which the relative price is lowest. After trade the relative prices are equalized between both countries. In both countries the relative price of a good equals the wage per hour times the hours required to produce one good, i.e. the input requirement of the good.

The input requirement of a good equals the inverse of the labour productivity of the

2. Belgium, Germany, Denmark, Spain, France, Great Britain and the Netherlands. For data reasons, other Member States are excluded.

3. Other assumptions of the Ricardian model are that labour is mobile between sectors of a country and immobile between countries, and the input requirements of the two goods are constant (i.e. the marginal product of labour is fixed).

good. The ratios of labour productivities of two countries for producing two or more goods determine the 'chain' of comparative advantage, in which the ratios are ranked in descending order (see Jones and Neary, 1984). If the ratio of labour productivities of one to another country with respect to a particular good is higher than the relative wage, the former country specializes in the production of the good and, moreover, exports this good. In other words, a country exports the good which has the lowest relative price in the own country, whereas it imports the good which has the lowest relative price in the other country. If the ratio of labour productivities of a particular good equals the relative wage, both countries produce and export the good.[4]

In the Ricardian model the relative labour productivities depend on technology differences, which also include climatic differences.[5] Nevertheless, as is noticed by e.g. Wood (1994), most Ricardian models do not precisely specify the meaning and causes of international differences in technology, and at the same time treat labour as homogeneous. In the standard Ricardian model of international trade no reference is made to the various skill categories of labour, although the uneven international differences in average labour productivity among sectors could reasonably well result from both *(a)* differences among sectors in the use of the skill categories of labour and *(b)* differences among countries in the relative availability of the skill categories of labour. As Wood (1994) puts it: "the higher relative productivity of labour in certain sectors in a particular country might be due to these sectors being more skill-intensive and the country concerned having a relatively large skilled-labour supply, or vice versa". Thus Wood distinguishes between the skill input at sector level and the skill endowment at country level, which is similar to the distinction that has been made in the introduction of this chapter (see also Chapter 1). In this chapter the sector-specific inputs of low, intermediate and highly-skilled workers determine labour productivity and in turn trade performance, whereas in the next chapter the country-specific endowments of workers with different skill levels determine trade performance.

In the Ricardian theory of international trade the labour productivity level is an important determinant of trade between countries, in particular if it is related to the wage level of these countries. An increase in the labour productivity level given the wage level improves the competitive position of a sector, whereas an increase in the wage level given the labour productivity level deteriorates the competitive position of a sector. Empirical research on the Ricardian model by e.g. MacDougall (1951), Stern (1962) and Balassa (1963) provides remarkably good results.[6] These tests of the Ricardian model concern the regression of the export performance of industries in the United States relative to similar industries in the United Kingdom on the relative labour

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4. See Dornbush et al. (1977) for an elaboration on the Ricardian model for two countries and a continuum of goods. Moreover, they show how technology, preferences and the relative size of countries (measured by the relative labour force) determine the relative wage.

5. In Ricardo's original analysis Portugal specializes in wine, whereas England specializes in cloth.

6. See Bhagwati (1964), Deardorff (1984) and Leamer (1992) for critical reviews of empirical studies testing the Ricardian model.

productivity in these industries.[7] The results show that the United States has a higher productivity than the United Kingdom in all industries. Moreover, the wage ratio was found to be about twice as high in the United States than in the United Kingdom. In accordance with the Ricardian model it turns out that in general the United States has a relative export ratio larger than one for the industries of which the labour productivity is considerably more than twice the British labour productivity. In other words, the United States has a comparative advantage in the export of goods of which the labour productivity ratio is larger than the wage ratio.

However, empirical research reveals that wage ratios themselves are not a significant factor for explaining the relative export performance of industries for two reasons. Firstly, technological competitiveness based on investments in new technologies in order to increase productivity seems to be more important than cost-competitiveness based on relatively low labour costs (e.g. Balassa, 1963; Fagerberg, 1988). The minor importance of labour costs for international competitiveness may be explained by the fact that the hierarchy of wages is largely similar across sectors in different countries (see Balassa, 1963; Kusters and Minne, 1992) and the fact that the wage differences between sectors in a particular country are considerably smaller than the productivity differences. Secondly, the wage level may indicate not only the labour costs but also the human capital of workers (e.g. Dosi et al., 1990; Verspagen and Wakelin, 1993). There is indeed weak evidence in the empirical studies mentioned above that the export performance is positively correlated with high wages. Therefore an increase in the wage level may also indicate an improvement of the competitive position of a sector. This is, according to Leamer (1992, p. 11) "very suggestive of a multi-factor model including human capital as one of the inputs." For these reasons the wage level is not included as an explanatory variable in the empirical analysis of this section.

The empirical tests of the Ricardian model are not conclusive with regard to the explanation of the differing labour productivities between industries and countries. This is in line with the above mentioned difficulties to understand the meaning and causes of technology differences between sectors in the Ricardian model. Other models than the Ricardian model may explain these productivity differences as well: "There must be any number of reasons why success in exporting is related to productivity." (Leamer, 1992, p. 11; see also Deardorff, 1984).

In previous empirical research on the Ricardian model by MacDougall (1951), Stern (1962) and Balassa (1963) the sectoral exports of the United States relative to the United Kingdom are explained by the relative labour productivity level in the various sectors. However, in this section a multi-country analysis is performed due to which the relative exports of the two-country analysis cannot be used as the dependent variable anymore. Instead, the exports divided by imports of similar goods per sector are used as the dependent variable, since the imports in a sector can be regarded as the exports

7. Trade between the US and UK mainly went to third countries due to tariffs in those days (1937, 1950 and 1951 for the samples of data in MacDouglas', Balassa's and Stern's empirical study, respectively). Of course, also transport costs may explain the small volume of bilateral trade between the US and the UK Moreover, tariffs and transport costs may (among other reasons, see Deardorff, 1984) also account for the incomplete specialization of countries, whereas the Ricardian model predicts complete specialization.

from competing sectors in all other countries in the world.[8] Moreover, dividing exports by imports has two advantages. Firstly, sectoral exports are corrected for the sector size, i.e. the exports are scaled. Secondly, exports are corrected for the degree of 'openness' of sectors and countries, since the more important international competition the larger both exports and imports are.

Table 6.1
The impact of relative sectoral labour productivity (*RLP*) on the export/import ratio (*EXIM*) per sector, 1988-1991

	1988 -1991	1988	1991
C (NLD*)		0.39 (2.08)[b]	0.60 (3.30)[c]
RLP		0.57 (3.22)[c]	0.32 (1.82)[a]
DUMBEL	0.08 (0.94)		
DUMDEU	0.42 (5.19)[c]		
DUMDNK	0.32 (3.72)[c]		
DUMESP	-0.13 (1.63)[a]		
DUMFRA	-0.05 (0.68)		
DUMGBR	-0.14 (1.73)[a]		
$\bar{R}^2$	0.18		
F-stat	6.99[c]		
Observations	364		

* The Netherlands is the reference country; *C* represents the constant term.
Notes: The absolute t-values are between brackets. The superscripts *a*, *b* and *c* indicate a significant coefficient at the 10%, 5% and 1% level respectively. BEL, DEU, DNK, ESP, FRA, GBR and NLD stand for Belgium, Germany, Denmark, Spain, France, Great Britain and the Netherlands respectively.

Furthermore, to estimate the impact of productivity on trade performance, the productivity, export and import data of seven countries and four years (1988 till 1991) are pooled. One of the countries (the Netherlands) is chosen as a reference country to calculate the relative labour productivity level (*RLP*) in a multi-country analysis. This implies that the sectoral labour productivity of a particular sector is divided by the sectoral labour productivity of the similar sector in the reference country (so the relative productivity level of all Dutch sectors is set at unity). Labour productivity is measured by value added per worker.[9] To correct for possible country-specific productivity and labour cost differences, dummy variables (*DUM*) are included for the other six countries in the sample. Dummy variables are included for the years 1989, 1990 and 1991 as well. In an analysis without pooling over these years the relative productivity

8. See Dosi et al. (1990) for various measures of export performance in a Ricardian model, including the ratio between exports and imports per sector, which is used in the empirical analysis of this section.

9. See Appendix 6.A and Appendix 6.B for a description of the manufacturing sectors included in the analysis and the data sources, respectively.

level appears to be the only explanatory variable that really differs in its effect on the export/import ratio between 1988 and 1991. For that reason multiplicative year dummies are included for the relative productivity level. The petroleum and other manufacturing sectors are not included in the sample, since these sectors are very heterogeneous between countries (see also Section 6.4). Table 6.1 presents the estimation results.

Table 6.1 shows that the estimated equation is significant at the 1% level, and can explain almost one fifth of the total variance of the export/import ratio. The relative productivity variable is significantly positive at the 1% level for 1988, and significantly positive at the 10% level for 1991.[10] These results imply that there is some evidence for the manufacturing sectors of the countries in our sample to suppose that the relative labour productivity level is a source of international competitiveness for the explanation of trade flows between countries. These results may even be improved if data is available for the use of a more sophisticated model (see also Dosi et al., 1990). The empirical evidence of this section is supplementary to other empirical research that supports the Ricardian model.

6.3 Outline of the human capital model

Suppose that firm i produces net output Y_i according to the Cobb-Douglas production function of equation (6.1) with L_i^* units of effective labour and K_i units of physical capital, and that the efficiency parameter A is given. The parameters α and β represent the physical capital and labour elasticities of output respectively.

$$Y_i = A\, K_i^{\alpha}\, L_i^{*\,\beta} \tag{6.1}$$

The L_i^* units of effective labour of a firm consist of both the number of workers (or hours worked) L_i and human capital. In other words, the effective labour input L_i^* allows for the various characteristics of workers with regard to their human capital. Chapter 2 has discussed the various ways to model the effective labour input.[11] Here the effective labour input L_i^* is represented by the employment shares of low, intermediate and highly-skilled labour (LS_i , IS_i and HS_i respectively) as the input variables, which sum up to 1. The employment shares of intermediate and highly-skilled workers in the firm are used as an approximation for the input of human capital.[12] The following Cobb-Douglas form of effective labour input will be used.

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10. The 1989 and 1990 estimated coefficients of the relative productivity level show that the impact of the relative productivity level on trade performance gradually declines between 1988 and 1991.

11. The major disadvantage of the approach of aggregating human capital inputs is that it is assumed that the separability assumption holds, i.e., the assumption that the levels of non-labour inputs, such as physical capital, have no impact on the relative marginal productivities of the human capital inputs (see Chapter 2).

12. Other human capital inputs which have been mentioned in Chapter 3 (for example participation in training courses and years of experience) are not incorporated in this analysis. These human capital inputs can easily be incorporated if reliable comparative data

$$L_i^* = L_i \cdot LS_i^{\theta_{LS}} IS_i^{\theta_{IS}} HS_i^{\theta_{HS}} \tag{6.2}$$

The parameters θ_{LS}, θ_{IS} and θ_{HS} indicate the contribution of low, intermediate and highly-skilled labour respectively to the effective labour input. The average labour productivity of a sector can be found by substituting the above equation into equation (6.1) and aggregating the N firms of the sector, assuming equal firm sizes, i.e. $\overline{Y} = Y_i$, $\overline{K} = K_i$, $\overline{L^*} = L_i^*$ (see Davies and Caves, 1987).

$$\frac{Y}{L} = \frac{N\overline{Y}}{N\overline{L}} = \frac{A\overline{K}^{\alpha}\overline{L^{*}}^{\beta}}{\overline{L}} = \frac{A\overline{K}^{\alpha}\overline{L}^{\beta}\ \overline{LS}^{\beta\theta_{LS}}\ \overline{IS}^{\beta\theta_{IS}}\ \overline{HS}^{\beta\theta_{HS}}}{\overline{L}} \tag{6.3}$$

From the above assumptions it follows that the capital intensities and the employment shares of low, intermediate and highly-skilled workers are equal across firms, which results in equation (6.4) for a particular sector.

$$\frac{Y}{L} = A\left(\frac{K}{L}\right)^{\alpha}\overline{L}^{\alpha+\beta-1} LS^{\beta\theta_{LS}} IS^{\beta\theta_{IS}} HS^{\beta\theta_{HS}} \tag{6.4}$$

Equation (6.4) shows that the labour productivity of a sector depends on the efficiency parameter, the sector's capital intensity, the average firm size and the employment shares of low, intermediate and highly-skilled workers in a sector. From equation (6.4) it follows that if the assumption of constant returns to scale holds ($\alpha+\beta=1$), the average firm size plays no role.

Substituting LS for $(1-IS-HS)$ and assuming that $\theta_{LS}=1-\theta_{IS}-\theta_{HS}$ gives the following equation:

$$\frac{Y}{L} = A\left(\frac{K}{L}\right)^{\alpha}\overline{L}^{\alpha+\beta-1}(1-IS-HS)^{\beta(1-\theta_{IS}-\theta_{HS})} IS^{\beta\theta_{IS}} HS^{\beta\theta_{HS}} \tag{6.5}$$

Taking the natural logarithm of both sides results in equation (6.6).

$$\ln\frac{Y}{L} = \ln A + \alpha\ln\frac{K}{L} + (\alpha+\beta-1)\ln\overline{L} + \beta(1-\theta_{IS}-\theta_{HS})\ln(1-IS-HS) + \beta\theta_{IS}\ln IS + \beta\theta_{HS}\ln HS \tag{6.6}$$

The above equation enables us to estimate the effects of human capital on the productivity level of a sector. These effects are represented by the coefficients θ_{IS} and θ_{HS} of intermediate-skilled and highly-skilled labour respectively. If net output is measured in value terms instead of volumes, as it is in this chapter, the worker effect and the allocative effect cannot be distinguished from each other (see also Welch, 1970). The coefficients θ_{IS} and θ_{HS} are equal to zero if human capital, represented by the employment shares of intermediate and highly-skilled workers, does not have a combined worker and allocative effect on sectoral labour productivity.

The elasticities of sectoral labour productivity with respect to intermediate and highly-skilled labour (i.e. the elasticities of output) are found by differentiating

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on aspects such as training intensity is available.

equation (6.6) to the natural logarithm of *IS* and *HS* respectively.

$$\frac{d\ln(Y/L)}{d\ln(IS)} = \frac{d(Y/L)}{d(IS)}\,\frac{IS}{Y/L} = \beta\frac{\theta_{IS}(1-HS)-IS(1-\theta_{HS})}{(1-HS-IS)} \tag{6.7}$$

$$\frac{d\ln(Y/L)}{d\ln(HS)} = \frac{d(Y/L)}{d(HS)}\,\frac{HS}{Y/L} = \beta\frac{\theta_{HS}(1-IS)-HS(1-\theta_{IS})}{(1-IS-HS)} \tag{6.8}$$

It follows that the elasticities of output with respect to both intermediate-skilled and highly-skilled labour are positive as long as both $\theta_{IS} > IS$ and $\theta_{HS} > HS$.[13] If both $\theta_{IS} = IS$ and $\theta_{HS} = HS$ then sectoral labour productivity is maximized. In that case the output elasticities with respect to intermediate-skilled labour (equation 6.7) and highly-skilled labour (equation 6.8), and the respective marginal productivities of intermediate skilled labour $d(Y/L)/d(IS)$ and highly-skilled labour $d(Y/L)/d(HS)$ are zero. Thus, in the Cobb-Douglas form of the effective labour input, there are opportunities for increasing the labour productivity of a sector by means of increasing the employment shares of intermediate and highly-skilled labour if the effects[14] of intermediate and highly-skilled labour on the sectoral labour productivity are larger than the employment share of intermediate and highly-skilled labour respectively.

However, the neoclassical theory of production assumes profit maximization rather than the maximization of labour productivity. To maximize profits with perfectly competitive labour and product markets, the marginal productivities of intermediate and highly-skilled workers have to be equal to the respective real wages. If firms have monopsonistic power on the labour market and/or monopolistic power in the product market, the marginal productivity exceeds the real wage (see Chapter 2). Since real wages are larger than zero, the marginal productivities of both intermediate and highly-skilled labour and the respective output elasticities, i.e. equations (6.7) and (6.8), should be positive. These are necessary conditions for profit maximization, which are satisfied if both $\theta_{IS} > IS$ and $\theta_{HS} > HS$.

Next, the diffusion and the research effect on the productivity growth of a sector are modelled. These two effects are incorporated in the production function of equation (6.5) through the efficiency parameter A_t, which indicates the level of technological knowledge actually employed in production (see Chapter 3) at time *t*. Equation (6.9) results if equation (6.6) is rewritten and stated in growth terms. The dots indicate that the variables are denoted in growth terms (first derivatives of natural logarithms). The equation shows that the total factor productivity growth is the difference between the growth of the value added per worker and the growth of the input factors (including the average firm size).

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13. Besides, both α and β are assumed to be larger than zero.

14. As has been argued above, these effects consist of both the worker and the allocative effect.

$$\dot{A}_t = (\dot{\frac{Y}{L}})_t - \alpha(\dot{\frac{K}{L}})_t - (\alpha+\beta-1)\dot{\bar{L}}_t - \beta(1-\theta_{IS}-\theta_{HS})(1-IS-HS)^{\cdot}_t - \beta\theta_{IS}\dot{IS}_t - \beta\theta_{HS}\dot{HS}_t \quad (6.9)$$

The efficiency parameter A_t can be modelled as follows (see e.g. Nelson and Phelps, 1966).

$$A_t = A_0 e^{gt} \quad (6.10)$$

In equation (6.10) g represents the rate of increase in the efficiency parameter and A_0 represents the initial efficiency level. Equation (6.11) is obtained by taking the natural logarithm of equation (6.10) and differentiating the equation to t.

$$\frac{d \ln A_t}{dt} = \dot{A}_t = g \quad (6.11)$$

It follows that the total factor productivity of a sector grows at rate g. As has been argued in Chapter 5 both the diffusion and the research effect directly affect the level of technology that is actually used in production, i.e. the efficiency parameter A_t. Moreover, based on the analysis of Chapter 5 it can be hypothesized that the input *level* of human capital in a sector relative to the input levels of human capital of the competing sectors in other countries explains the *growth* of total factor productivity g, which is calculated from the estimated equation (6.9). In other words, the diffusion effect and the research effect of the relative human capital levels on productivity growth are due to quickly adapting to new production techniques and generating new technological knowledge respectively. The diffusion of new production techniques takes place from competing sectors in other countries, i.e. diffusion of sector-specific best-practices. It is assumed that the diffusion of technological knowledge of a sector is positively dependent on the human capital level relative to the human capital levels of similar sectors in other countries. The relative human capital level of a sector increases if the employment share of intermediate or highly-skilled labour of the particular sector divided by the average sectoral employment share of intermediate or highly-skilled labour across the similar sectors in the other countries increases (*ISREL* and *HSREL* respectively). As is revealed by Chapter 5, intermediate and highly-skilled workers are, in contrast to low-skilled workers, most able to introduce and apply new technological developments. Moreover, research and development (R&D) activities particularly require the input of specialized and highly-skilled R&D workers (NOWT, 1994; Berendsen et al., 1995). These workers contribute directly to the level of technological knowledge of the sector. Since R&D expenditures mainly consist of wage costs of R&D workers (NOWT, 1994), the input of R&D workers can be approximated by the sector's ratio of research and development expenditures to value added. To estimate the impact of the input level of R&D workers on productivity growth in the total sample of very different manufacturing sectors, this ratio is divided by the cross-country average R&D to value added ratio of the similar sectors in the other countries. This results in the relative R&D intensity (*RDREL)*. Explaining the total factor productivity growth of a sector by the diffusion and the research effect altogether results in the following equation.[15]

$$g = \gamma_{IS} ISREL + \gamma_{HS} HSREL + \gamma_{RD} RDREL \tag{6.12}$$

The diffusion effect of intermediate and highly-skilled workers is represented by γ_{IS} and γ_{HS} respectively. Moreover, the research effect of highly-skilled R&D workers is represented by γ_{RD}. The above equation is suited for estimating the diffusion and research effect of human capital on the productivity growth of sectors.

6.4 The human capital intensity of manufacturing sectors

Ranking the manufacturing sectors by the human capital intensities enables us to classify low-skill, medium-skill and high-skill sectors. The section begins with discussing the rankings of the employment shares of intermediate and highly-skilled labour for the fifteen manufacturing sectors and the rank correlations between the rankings of the manufacturing sectors of the countries, followed by a discussion of the level and the growth of the employment shares in each country in the period 1988 to 1991.[16]

Appendix 6.C shows the employment shares of intermediate and highly-skilled workers per sector for seven countries of the European Union in 1988. Table 6.2 shows the cross-country average employment shares of low-skilled workers (*LS*), intermediate-skilled workers (*IS*) and highly-skilled workers (*HS*) for each sector in both 1988 and 1991. For almost all sectors the cross-country average employment shares of intermediate and highly-skilled workers are at least as large in 1991 as in 1988. To distinguish between low-skill, medium-skill and high-skill manufacturing sectors, the sectors are ranked according to the 1988 cross-country average employment share of highly-skilled workers. As will be argued below, this ranking is relatively similar across countries, in contrast with the ranking according to the cross-country average employment shares of intermediate-skilled workers.

The following high-skill sectors were selected from the 15 manufacturing sectors: chemicals, electrical machinery, professional goods and non-electrical machinery. The cross-country average employment share of highly-skilled workers in the high-skill sectors is at least 0.15, and the cross-country average employment share of low-skilled workers in the high-skill sectors is never greater than 0.50. In addition, it is possible to identify four medium-skill sectors: petroleum, transport equipment, paper and printing and basic metals. In the medium-skill sectors the cross-country average employment share of highly-skilled workers is between 0.10 and 0.15 except for the petroleum sector in 1991. The cross-country average employment share of low-skilled workers is between 0.50 and 0.60, except for the basic metals sector in 1988. The remaining sectors are termed 'low-skill' sectors. In these sectors the cross-country average

15. Note that in empirical studies both absolute and relative measures of total factor productivity growth and its explanatory variables are used. See e.g. Wolff (1992), Benhabib and Spiegel (1994) and Leiponen (1995). Furthermore, see e.g. Mayes et al. (1990) for the importance of relative R&D expenditures for trade performance.

16. See Appendix 6.B for the data sources.

employment share of highly-skilled workers is smaller than 0.10, and the cross-country average employment share of low-skilled workers is larger than 0.60, except for the metal products sector in 1991.[17]

Table 6.2

Cross-country average employment shares of low, intermediate and highly-skilled labour, per sector, 1988, 1991

	LS_{88}	IS_{88}	HS_{88}	LS_{91}	IS_{91}	HS_{91}
high-skill sectors						
chemicals	0.48	0.31	0.21	0.42	0.34	0.24
electrical machinery	0.50	0.31	0.19	0.44	0.34	0.21
professional goods	0.49	0.35	0.17	0.50	0.35	0.15
non-electrical machinery	0.49	0.35	0.16	0.44	0.38	0.18
medium-skill sectors						
petroleum	0.56	0.29	0.15	0.52	0.32	0.16
paper and printing	0.57	0.32	0.12	0.52	0.36	0.12
basic metals	0.63	0.26	0.11	0.55	0.32	0.13
transport equipment	0.58	0.32	0.10	0.53	0.36	0.11
low-skill sectors						
rubber and plastic	0.65	0.27	0.08	0.62	0.29	0.09
other manufacturing	0.67	0.26	0.07	0.62	0.31	0.08
metal products	0.63	0.30	0.07	0.57	0.35	0.08
non-metallic minerals	0.66	0.27	0.07	0.62	0.30	0.08
food, beverages and tobacco	0.67	0.26	0.07	0.61	0.30	0.08
textiles, apparel and leather	0.70	0.24	0.06	0.67	0.26	0.07
wood	0.67	0.28	0.05	0.61	0.34	0.05

Note: The sectors are ranked according to the 1988 cross-country average employment share of highly-skilled labour.

However, it deserves mentioning that in some countries particular sectors do not fit in the above ranking and categories of low-skill, medium-skill and high-skill sectors. The figures in Appendix 6.C show the 1988 sector employment shares (1990 for the Netherlands) of intermediate and highly-skilled workers for each country of the sample. The sectors of a country are ranked on the horizontal axis in an ascending order from the left to the right according to the employment shares of highly-skilled workers. The rank order of Spain and France fits perfectly well with the categories of low-skill, medium-skill and high-skill sectors of Table 6.2. However, in Belgium the medium-skill transport equipment sector (tra) has a small employment share of highly-skilled workers, whereas the low-skill food, beverages and tobacco (foo) and the rubber and plastic (rup) sectors have large employment shares of highly-skilled workers. In

17. See Papaconstantinou (1995) for other classifications of sectors, including a similar classification of unskilled and skilled sectors. See OECD (1986) and Verspagen (1995) for a similar classification with regard to the level of technology, which can be measured by the R&D intensity (R&D expenditures relative to production).

Germany the medium-skill basic metals sector (bmi) has a small employment share of highly-skilled workers. On the other hand, the low-skill wood sector (woo) and other manufacturing sector (oma) have large employment shares of highly-skilled workers. In Denmark the medium-skill basic metals (bmi) and petroleum (pet) sectors have large employment shares of highly-skilled workers, whereas the medium-skill transport equipment sector (tra) has a small employment share of highly-skilled workers. Furthermore, in Great Britain the medium-skill petroleum sector (pet) has a large employment share of highly-skilled workers. In the Netherlands the medium-skill petroleum (pet) and transport equipment (tra) sectors have large employment shares of highly-skilled workers, whereas the low-skill non-metallic minerals sector (nme) has a large employment share of highly-skilled workers.

Table 6.3 shows the Spearman rank correlations between the sector rankings of countries according to the 1988 employment shares of intermediate and highly-skilled workers. For intermediate-skilled labour the rank correlations of only three pairs of countries are significant at 5%, whereas for highly-skilled labour the rank correlations of all pairs of countries are significant at 5%. Moreover, most rank correlations for highly-skilled labour are even significant at 1%. This implies that the ranking of the average cross-country employment shares of highly-skilled workers as in Table 6.2 is appropriate for distinguishing between low-skill, medium-skill and high-skill sectors, despite of the exceptions of the sectors listed above. Ranking the sectors of Table 6.2 according to the cross-country average employment shares of intermediate-skilled workers results in a rank order of sectors that differs much more from the rank orders of the individual countries of the sample.

Although the *rankings* of sectors according to the employment shares of highly-skilled workers are relatively similar across countries, the actual employment shares of intermediate and highly-skilled workers themselves can be very different across countries (see the last two Figures 6.C.8 and 6.C.9 in Appendix 6.C). There are particularly striking differences between the employment shares of intermediate-skilled workers in on the one hand France and on the other hand Germany and Denmark, the two countries with by far the largest employment share of intermediate-skilled workers.[18] The employment shares of highly-skilled workers are largest in Germany and Belgium, and smallest in Spain. The differences between the employment shares of highly-skilled workers in the remaining countries are small (about 0.02 at most).

Finally, the last two figures in Appendix 6.C show that between 1988 and 1991 the employment shares of both intermediate and highly-skilled workers increased in almost all countries in the sample.[19] Apart from Belgium and Germany, the growth rates of the employment shares of intermediate and highly-skilled workers do not differ very much

18. France has a large number of workers with ISCED-level 2 (lower secondary education) in the manufacturing sectors. Like the ISCED-levels 0 and 1 (pre-primary and primary education), the ISCED-level 2 corresponds with the level of low-skilled labour. However, the Eurostat data of the employment shares of intermediate-skilled workers in the French manufacturing sectors are so low that they are hard to believe. See for example National Institute of Economic and Social Research (1990) and Mason et al. (1996).

19. The only exceptions are the zero growth rates of the average employment share of highly-skilled workers in France between 1988 and 1989, and of the average employment share of intermediate-skilled workers in Denmark between 1988 and 1991.

between countries. Belgium exhibits a relatively large growth of highly-skilled workers, whereas Germany has a relatively large growth of intermediate-skilled workers.[20]

Table 6.3
Spearman rank correlations between the employment shares of 15 manufacturing sectors, 1988

	BEL	DEU	DNK	ESP	FRA	GBR	NLD
Intermediate-skilled labour (IS)							
Belgium (BEL)	1.00						
Germany (DEU)	0.34	1.00					
Denmark (DNK)	0.03	−0.09	1.00				
Spain (ESP)	0.55	0.38	0.10	1.00			
France (FRA)	0.31	0.36	0.19	0.60	1.00		
Great Britain (GBR)	0.29	0.54	0.16	0.50	0.05	1.00	
Netherlands (NLD)	0.51	0.40	0.19	0.51	0.33	0.36	1.00
Highly-skilled labour (HS)							
Belgium (BEL)	1.00						
Germany (DEU)	0.53	1.00					
Denmark (DNK)	0.54	0.45	1.00				
Spain (ESP)	0.86	0.63	0.76	1.00			
France (FRA)	0.79	0.82	0.73	0.91	1.00		
Great Britain (GBR)	0.74	0.70	0.70	0.91	0.89	1.00	
Netherlands (NLD)	0.59	0.62	0.51	0.75	0.70	0.72	1.00

Note: The rank correlation has 5%-significance at 0.441, 2.5%-significance at 0.525 and 1%-significance at 0.623.

6.5 The static effects of intermediate and highly-skilled workers on productivity

This section presents the results of estimating the worker and the allocative effect on sectoral productivity levels. These effects have been discussed before. Equation (6.6), which will be used to estimate these effects, was derived in Section 6.3. As far as possible, the estimation results will be compared with the results of other empirical studies. Moreover, based on the theoretical insights of Chapters 5 and Section 6.3 conclusions will be drawn on the over- and underinvestment of human capital in the manufacturing sectors in the various countries analysed. It has been argued in Section 6.3 that, from a static point of view, there is overinvestment in human capital if equations (6.7) and (6.8) do not hold. Therefore, from a static point of view, profits are not maximized if these conditions are not satisfied. It has also been argued in Section 6.3 that the conditions (6.7) and (6.8) are satisfied if both $\theta_{IS} > IS$ and $\theta_{HS} > HS$. This section analyses whether these latter conditions hold for the low-skill, medium-skill and high-skill categories of sectors. After that, conditions (6.7) and (6.8) will be considered

20. In general the employment shares of intermediate and highly-skilled workers in individual sectors of a particular country are very similar to the average growth in the employment shares across all fifteen manufacturing sectors of that country.

for each individual sector. However, for a final conclusion on profit maximization and over- or underinvestment in human capital, the dynamic effects should be included. These dynamic effects will be estimated in the next section.

The cross-section regression analysis of this section estimates the elasticities of output with respect to physical capital, firm size and intermediate and highly-skilled labour of 13 manufacturing sectors in six or seven countries.[21] To correct for sectoral differences in production functions the manufacturing sectors are divided into categories of sectors which are assumed to have equal elasticities of output with respect to the explanatory variables. The estimated effects on intermediate and highly-skilled labour on sectoral labour productivity are assumed to be equal within the categories of low-skill, medium-skill and high-skill sectors. These categories have been presented in Table 6.2. However, with respect to estimating the capital elasticities of output this skill-based classification is not applicable. Therefore the capital elasticities of output are assumed to be equal within the categories of the low, medium and high capital-intensive sectors. This classification is based on the fixed capital stock per worker and is included in Appendix 6.A (Table 6.A.1). This classification indeed appears to be different from the skill-based classification presented in Table 6.2. The capital elasticity of the high capital-intensive sectors (food, beverages and tobacco, paper and printing, basic metals, non-metallic minerals) is expected to be the largest, followed by the capital elasticity of the medium capital-intensive sectors (rubber and plastic, electrical machinery and transport equipment) and the capital elasticity of the low capital-intensive sectors (textiles, apparel and leather, wood, metal products, non-electrical machinery, professional goods). Additionally, the elasticities of output with respect to the average firm size for the medium firm size sectors (chemicals, electrical machinery) and the large firm size sectors (basic metals, transport equipment) may differ from the other sectors (see Table 6.A.1).

Tables 6.4a and 6.4b show the results when least squares regressions are applied to equation (6.6) in a dummy variable model (see e.g. Judge et al., 1985 and Gujarati, 1988).[22] Since the model of this chapter only analyses the impact of sector-specific variables on sectoral labour productivity, country-specific dummy variables are incorporated to allow for country-specific differences in labour productivity.[23] Tables

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21. The petroleum and other manufacturing sectors are not included in the sample of 15 manufacturing sectors of the last section, since the value added per worker and the capital intensity of these sectors vary widely between countries which indicates that they are very heterogeneous between countries. France cannot be included if the average firm size is an explanatory variable.

22. Since the coefficients of capital intensity, average firm size and the shares of low, intermediate and highly-skilled labour are constrained as shown by equation (6.6), non-linear least squares regression is applied to estimate the coefficients of equation (6.6) directly. Note that also α and β are restricted. The software used is Micro TSP version 7.0.

23. The single-equation estimations of this chapter may suffer from the simultaneous equation bias, due to which the estimators are biased and inconsistent (see for a discussion Intriligator, 1978). However, as is shown by e.g. Hoch (1962) and Zellner et al. (1966), specific characteristics of the disturbance term of the single equation (e.g. that the disturbance term is not correlated with the explanatory variables) justifies single-equation regression.

Table 6.4a
Estimated elasticities and estimated worker and allocative effect, equation (6.6), 1988

	$\hat{\alpha}$	$\widehat{(\alpha+\beta-1)}$	$\hat{\beta}$	$\hat{\theta}_{IS}$	$\hat{\theta}_{HS}$
high-skill sectors				0.64 (4.27)^{c}	0.06 (0.46)
chemicals	0.28 (3.30)^{c}	0.16 (2.78)^{c}	0.88		
electrical machinery	0.27 (2.95)^{c}	0.16 (2.78)^{c}	0.89		
professional goods	0.25 (2.75)^{c}	0.19 (3.13)^{c}	0.94		
non-electrical machinery	0.25 (2.75)^{c}	0.19 (3.13)^{c}	0.94		
medium-skill sectors				0.50 (3.38)^{c}	0.18 (1.69)^{a}
paper and printing	0.27 (2.95)^{c}	0.19 (3.13)^{c}	0.92		
basic metals	0.28 (3.30)^{c}	0.12 (2.71)^{c}	0.84		
transport equipment	0.27 (2.95)^{c}	0.12 (2.71)^{c}	0.85		
low-skill sectors				0.42 (3.53)^{c}	0.13 (2.07)^{b}
rubber and plastic	0.27 (2.95)^{c}	0.19 (3.13)^{c}	0.92		
metal products	0.25 (2.75)^{c}	0.19 (3.13)^{c}	0.94		
non-metallic minerals	0.28 (3.30)^{c}	0.19 (3.13)^{c}	0.91		
food, beverages and tobacco	0.28 (3.30)^{c}	0.19 (3.13)^{c}	0.91		
textiles, apparel and leather	0.25 (2.75)^{c}	0.19 (3.13)^{c}	0.94		
wood	0.25 (2.75)^{c}	0.19 (3.13)^{c}	0.94		
country dummies					
C (NLD*)	7.58 (7.31)^{c}				
DUMBEL	0.36 (3.08)^{c}				
DUMDEU	−0.21 (1.93)^{a}				
DUMDNK	−0.31 (2.82)^{c}				
DUMESP	0.73 (4.08)^{c}				
DUMGBR	0.35 (2.51)^{b}				
$\bar{R}^2$	0.77				
F-stat	15.6^{c}				
Observations	76				

* The Netherlands is the reference country; *C* represents the constant term.

Notes: The labour elasticities of output ($\hat{\beta}$) are calculated from the previous two columns. The sectors are ranked according to the cross-country average employment share of highly-skilled workers (see Table 6.2). See Table 6.3 for the abbreviations of the countries. The absolute t-values are between brackets. The superscripts *a*, *b* and *c* indicate a significant coefficient at the 10%, 5% and 1% level respectively.

6.4a and 6.4b present the estimation results of equation (6.6) for 1988 and 1991, respectively.[24] The manufacturing sectors are presented in a descending order with regard to the skill intensity of highly-skilled labour (as in Table 6.2). The columns show the estimated coefficients and the t-values between brackets. The estimated coefficients $\hat{\theta}_{IS}$ and $\hat{\theta}_{HS}$ indicate the combined worker and allocative effect of

24. See Appendix 6.B for a description of the data sources. The results of the estimations for 1989 and 1990 generally do not differ very much from the 1988 and 1991 results.

intermediate and highly-skilled labour respectively.

Table 6.4b
Estimated elasticities and estimated worker and allocative effect, equation (6.6), 1991

	$\hat{\alpha}$	$(\widehat{\alpha+\beta-1})$	β	$\hat{\theta}_{IS}$	$\hat{\theta}_{HS}$
high-skill sectors				0.54 (3.04)[c]	0.16 (0.92)
chemicals	0.34 (3.49)[c]	0.10 (1.54)	0.76		
electrical machinery	0.33 (3.17)[c]	0.10 (1.54)	0.77		
professional goods	0.31 (3.05)[c]	0.15 (2.19)[b]	0.84		
non-electrical machinery	0.31 (3.05)[c]	0.15 (2.19)[b]	0.84		
medium-skill sectors				0.54 (3.09)[c]	0.32 (2.02)[b]
paper and printing	0.33 (3.17)[c]	0.15 (2.19)[b]	0.82		
basic metals	0.34 (3.49)[c]	0.10 (1.91)[a]	0.76		
transport equipment	0.33 (3.17)[c]	0.10 (1.91)[a]	0.77		
low-skill sectors				0.41 (2.89)[c]	0.23 (2.48)[b]
rubber and plastic	0.33 (3.17)[c]	0.15 (2.19)[b]	0.82		
metal products	0.31 (3.05)[c]	0.15 (2.19)[b]	0.84		
non-metallic minerals	0.34 (3.49)[c]	0.15 (2.19)[b]	0.81		
food, beverages and tobacco	0.34 (3.49)[c]	0.15 (2.19)[b]	0.81		
textile, apparel and leather	0.31 (3.05)[c]	0.15 (2.19)[b]	0.84		
wood	0.31 (3.05)[c]	0.15 (2.19)[b]	0.84		
country dummies					
C (NLD*)	7.19 (6.00)[c]				
DUMBEL	0.24 (1.98)[b]				
DUMDEU	−0.16 (1.02)				
DUMDNK	−0.34 (3.09)[c]				
DUMESP	0.56 (3.32)[c]				
DUMGBR	0.29 (2.08)[b]				
$\bar{R}^2$	0.71				
F-stat	12.0[c]				
Observations	76				

* The Netherlands is the reference country; *C* represents the constant term.
Notes: See Table 6.4a.

The results show that the estimated equations with respect to the static effects of the production factors on productivity perform very well. Tables 6.4a and 6.4b show that the employment share of intermediate-skilled workers, *IS*, has a significant effect on the labour productivity in all sectors, which implies that the combined worker and allocative effect is significant for intermediate-skilled labour. For the low-skill sectors the estimated (worker and allocative) effect of intermediate-skilled workers, $\hat{\theta}_{IS}$, is 0.42 in 1988 and 0.41 in 1991. For the high-skill sectors $\hat{\theta}_{IS}$ is even larger, 0.64 in 1988 and 0.54 in 1991. For the medium-skill sectors $\hat{\theta}_{IS}$ is approximately in between the effects in the low-skill and the high-skill sectors in 1988 (0.50), and equal to the effects in the high-skill sectors in 1991 (0.54). Usually the estimated effect with respect to intermediate-skilled labour is not significantly different between the low-skill, the medium-skill and the high-skill sectors (except for the high-skill relative to the low-skill sectors in 1988).

As pointed out in Section 6.2, in order to see if the condition of profit maximization with respect to intermediate-skilled labour, $\hat{\theta}_{IS} > IS$, is fulfilled, the estimated worker and allocative effect are compared to the employment shares of intermediate-skilled labour. It can be seen from the cross-country averages in Table 6.2 that the low-skill, medium-skill as well as the high-skill sectors have smaller average cross-country employment shares of intermediate-skilled workers than the estimated effects of intermediate-skilled labour above. This implies that the condition for profit maximization with regard to intermediate-skilled labour is fulfilled in all three categories of manufacturing sectors distinguished.

Next, Tables 6.4a and 6.4b show that $\hat{\theta}_{HS}$ is significantly positive in the low-skill sectors in both 1988 and 1991: 0.13 and 0.23 respectively. Also for the medium-skill sectors the estimated worker and allocative effect is significant for both years: 0.18 and 0.32 respectively. In order to fulfill the condition of profit maximization with respect to highly-skilled labour, $\hat{\theta}_{HS} > HS$, the estimated worker and allocative effect are compared to the employment shares of highly-skilled labour. From the cross-country average employment share of highly-skilled labour in Table 6.2 may be concluded that this condition is fulfilled for the low-skill and the medium-skill sectors in both 1988 and 1991. However, the high-skill category of sectors of the countries in the sample has a relatively small and insignificant $\hat{\theta}_{HS}$ in both 1988 and 1991. Since the cross-country average employment shares of highly-skilled labour are large in the high-skill sectors, one could have expected a relatively large $\hat{\theta}_{HS}$. On the contrary, the above condition is not fulfilled for the category of high-skill sectors. This means that there is no evidence for the worker and allocative effect in the high-skill sectors. Therefore from a static point of view overinvestment in highly-skilled labour is apparent in these high-skill sectors. Finally, for all categories of sectors $\hat{\theta}_{HS}$ is at least 0.10 larger in 1991 than in 1988 and that $\hat{\theta}_{HS}$ is smaller than $\hat{\theta}_{IS}$ in both 1988 and 1991.

As expected, the higher the sectoral capital intensity, the higher the estimated capital elasticity of output $\hat{\alpha}$, although the differences between the categories of sectors are relatively small. Nevertheless, the estimated elasticities in Tables 6.4a and 6.4b vary significantly between the categories of sectors with different capital intensities in almost all cases. The estimated sectoral elasticities of capital are all significant at the 1%-level, and are comparable to the sectoral capital elasticities reported in Davies and Caves (1987)[25] and in Cörvers et al. (1995); studies which also use a Cobb-Douglas

25. Davies and Caves estimate output elasticities with respect to physical capital, using gross fixed capital stock per worker as an indicator of capital intensity. These elasticities varied between 0.10 and 0.27 for a sample of British and US industries in 1967/1968 and 1977. However, their time-series estimates for the period between 1968 and 1977 are 0.43 for the United Kingdom and 0.22 for the United States. In this section we prefer cross-sectional estimates, since the period of time on which the regression analysis should be based is relatively short (see also Section 6.6).

production function.[26] Furthermore, a survey of econometric studies using Cobb-Douglas production functions at the firm level by Mairesse and Sassenou (1991) shows that most cross-sectional estimates of capital elasticities for manufacturing firms in the US, France and Japan are between 0.20 and 0.45.[27]

Moreover, the estimated scale elasticity of output, $(\widehat{\alpha+\beta-1})$, is significantly positive in 1988, which indicates economies of scale at the firm level.[28] An increase in the sector's average firm size of 1% results in a 10% to 19% increase in labour productivity, dependent on the category of sectors and the year of analysis. The estimated scale elasticities of the medium and large firm size sectors are mostly not significantly different from those of the small firm size sectors. The latter category of sectors reveals the largest point estimates of the scale elasticities of output. The estimated scale elasticities of 1988 and 1991 are rather large compared to the cross-sectional estimates of 0.06 to 0.08 in Davies and Caves (1987).[29] However, Davies and Caves (1987) report time-series estimates of 0.23 for both the United States and the United Kingdom.

Since equation (6.6) is estimated under restrictions on estimated coefficients, the labour elasticities of output can be calculated from the capital elasticity of output $\hat{\alpha}$ and the scale elasticity of output $(\widehat{\alpha+\beta-1})$. A study by Fecher and Perelman (1992) reports sectoral elasticities with respect to labour and capital for a cross-section time-series sample of 11 manufacturing sectors and 11 OECD countries, using a Cobb-Douglas production function under constant returns to scale. The reported labour and capital elasticities in Tables 6.4 vary less between sectors than those reported by Fecher and Perelman. Nevertheless, the same categories of capital-intensive sectors as in our study could be classified from the estimated elasticities in Fecher and Perelman (1992). In their study the basic metals, chemicals and food, beverages and tobacco have labour elasticities of 0.36, 0.52 and 0.56 respectively, and are found to be the most capital-intensive sectors. These elasticities are, however, much smaller than the elasticities reported below. The most labour-intensive sectors in the study of Fechel and Perelman are textiles, apparel and leather and wood with labour elasticities of 0.93 and 0.87, which are comparable to those listed in the Tables 6.4a and 6.4b. The other sectors in the study of Fechel and Perelman, i.e. the paper and printing, machinery and non-metallic minerals sectors have labour elasticities between 0.74 and 0.80, which is slightly below the calculated elasticities of these sectors in Tables 6.4a and 6.4b.

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26. This study found estimated coefficients of 0.27 for Germany and 0.32 for the Netherlands for 1989, using the stock of physical capital per worker as a proxy for capital intensity. The estimated coefficients in the study are larger, but not significantly larger, if gross investments in fixed capital per worker is used as a proxy for the capital intensity.

27. As is argued by Mairesse and Sassenou (1991), time-series estimates of capital elasticities are usually smaller than cross-sectional estimates due to the collinearity of physical capital with the time trend.

28. This variable was only available for 1988. This may explain the decreased significance (relative to 1988) of the average firm size in 1991. Moreover, due to increasing returns to scale the assumption of perfect competition cannot be maintained.

29. But note that the distribution of firms with regard to firm size may be more important than the average firm size (see Davies and Caves, 1987).

Table 6.5a

Output elasticities with respect to intermediate-skilled labour, $d\ln(Y/L)/d\ln(IS)$, equation (6.7), 1988 and 1991

	BEL	DEU	DNK	ESP	FRA	GBR	NLD
1988							
high-skill sectors							
chemicals	0.40	0.18	−0.09	0.48	-	0.49	0.23
electrical machinery	0.41	0.24	0.02	0.47	-	0.46	0.30
professional goods	0.32	0.10	0.28	0.45	-	0.50	0.26
non-electrical machinery	0.43	0.14	−0.01	0.48	-	0.46	0.27
medium-skill sectors							
paper and printing	0.32	0.04	−0.01	0.38	-	0.36	0.24
basic metals	0.34	0.12	0.13	0.34	-	0.33	-
transport equipment	0.35	0.10	−0.33	0.36	-	0.31	0.19
low-skill sectors							
rubber and plastic	0.22	0.00	−0.07	0.31	-	0.30	0.16
metal products	0.22	−0.15	−0.25	0.31	-	0.27	0.14
non-metallic minerals	0.25	−0.03	−0.41	0.33	-	0.31	0.20
food, beverages and tobacco	0.22	−0.01	−0.05	0.32	-	0.31	0.13
textile, apparel and leather	0.29	0.02	−0.09	0.35	-	0.35	0.16
wood	0.22	−0.15	−0.01	0.35	-	0.25	0.18
1991							
high-skill sectors							
chemicals	0.24	−0.16	0.06	0.30	-	0.33	0.07
electrical machinery	0.25	−0.17	0.03	0.30	-	0.32	0.10
professional goods	0.21	−0.16	−0.25	0.36	-	0.36	0.29
non-electrical machinery	0.26	−0.22	−0.16	0.33	-	0.31	0.14
medium-skill sectors							
paper and printing	0.36	0.20	0.26	0.41	-	0.40	0.34
basic metals	0.36	0.18	0.27	0.36	-	0.38	-
transport equipment	0.37	0.15	0.19	0.38	-	0.37	0.31
low-skill sectors							
rubber and plastic	0.17	0.10	0.11	0.28	-	0.25	0.16
metal products	0.21	0.04	−0.34	0.26	-	0.24	0.12
non-metallic minerals	0.18	0.09	0.03	0.28	-	0.25	0.15
food, beverages and tobacco	0.19	0.04	0.01	0.29	-	0.26	0.13
textile, apparel and leather	0.26	0.10	0.05	0.30	-	0.31	0.19
wood	0.21	0.04	−0.08	0.30	-	0.21	0.10

Notes: See Table 6.3 for the abbreviations of the countries. France has been excluded from the regression analysis of equation (6.6). Including France in the regression analysis (and thereby excluding the scale variable) does not seriously affect the estimation results.

The coefficients of the country-specific dummy variables (*DUM*) show that the average labour productivity rates across the manufacturing sectors are relatively low in Germany and Denmark, and relatively high in Spain. These differences cannot be explained by the sector-specific variables incorporated in the equation. Also Englander and Gurney (1994a) find that the labour productivity rates in Germany and Denmark are lower than expected. Only for the relatively low Danish productivity they can offer an explanation, namely the relative high employment share of part-time workers in Denmark.[30] Moreover, they find a higher than expected labour productivity in Spain. They explain this by stating that the low employment level in Spain results in a relatively large input of the most productive workers who are selected first. There is however no evidence for this explanation.

To judge whether there is underinvestment or overinvestment of human capital within the individual sectors of the categories of sectors distinguished above it is required to take a closer look at the output elasticities of intermediate and highly-skilled labour for each individual sector. As stated in Section 6.3, necessary conditions for profit maximization are that output elasticities with respect to the employment shares of both intermediate and highly-skilled labour are than zero. These elasticities can be calculated by substituting the sectoral employment shares of Appendix 6.C and the estimated worker and allocative effect of Tables 6.4a and 6.4b into the equations (6.7) and (6.8).

Table 6.5a presents the output elasticities with respect to the employment shares of intermediate-skilled labour.[31] It follows that the German and Danish output elasticities are very small or negative, except for the 1988 output elasticities of the high-skill sectors in Germany and the 1991 output elasticities of the medium-skill sectors in both Germany and Denmark. In general the output elasticities with respect to intermediate-skilled labour indicate that there is overinvestment in intermediate-skilled labour in the German and Danish manufacturing sectors (from a static point of view, see below). On the contrary, the output elasticities with respect to intermediate-skilled labour in many manufacturing sectors in Spain and Great Britain are very large relative to the other countries of the sample. Although in Section 6.3 no formal conditions are derived to detect underinvestment in human capital, these relatively large output elasticities may point to underinvestment in intermediate-skilled labour. Increasing the sectoral employment share of intermediate-skilled workers may raise both profits and the sectoral labour productivity level in many manufacturing sectors of these countries.

Table 6.5b shows that most output elasticities with respect to the employment share of highly-skilled labour are negative or very small for the high-skill sectors in all countries, except for the 1991 output elasticities of the high-skill sectors in Spain and France. This implies that one of the before mentioned conditions for profit maximization is not satisfied for most manufacturing high-skill sectors. This is in line with the more aggregated analysis with regard to the categories of sectors in Tables 6.2 and 6.4,

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30. See e.g. De Grip et al. (1997). However, the Netherlands and Great Britain also have high shares of part-time workers.

31. As stated in Section 6.4 the employment shares of intermediate-skilled labour in the French manufacturing sectors are found to be too low relative to other data sources. Therefore the output elasticities of intermediate-skilled labour in France are not presented.

Table 6.5b
Output elasticities with respect to highly-skilled labour, $d\ln(Y/L)/d\ln(HS)$, equation (6.8), 1988 and 1991

	BEL	DEU	DNK	ESP	FRA	GBR	NLD
1988							
high-skill sectors							
chemicals	-0.07	-0.11	-0.24	-0.00	-0.02	-0.02	-0.16
electrical machinery	-0.08	-0.12	-0.13	0.02	-0.02	-0.01	-0.14
professional goods	-0.14	-0.13	-0.05	0.00	0.01	-0.01	-0.05
non-electrical machinery	-0.06	-0.11	-0.11	0.02	-0.00	-0.04	-0.03
medium-skill sectors							
paper and printing	0.08	0.07	0.04	0.14	0.12	0.12	0.11
basic metals	0.12	0.08	-0.01	0.13	0.12	0.12	-
transport equipment	0.13	0.06	0.10	0.13	0.12	0.10	0.07
low-skill sectors							
rubber and plastic	0.03	0.05	0.06	0.09	0.09	0.08	0.06
metal products	0.07	0.01	0.04	0.10	0.10	0.09	0.07
non-metallic minerals	0.07	0.04	0.06	0.10	0.10	0.08	0.05
food, beverages and tobacco	0.04	0.02	0.08	0.10	0.10	0.08	0.08
textile, apparel and leather	0.09	0.05	0.05	0.11	0.11	0.11	0.06
wood	0.08	-0.01	0.09	0.11	0.11	0.09	0.11
1991							
high-skill sectors							
chemicals	-0.07	-0.39	-0.11	0.06	0.06	0.03	-0.09
electrical machinery	-0.02	-0.23	-0.04	0.07	0.05	0.05	-0.06
professional goods	0.03	-0.45	-0.11	0.12	0.12	0.06	0.05
non-electrical machinery	0.01	-0.56	-0.03	0.09	0.08	0.05	0.02
medium-skill sectors							
paper and printing	0.22	0.09	0.22	0.25	0.25	0.24	0.23
basic metals	0.22	0.10	0.19	0.22	0.23	0.22	-
transport equipment	0.23	0.08	0.22	0.24	0.23	0.22	0.21
low-skill sectors							
rubber and plastic	0.13	-0.19	0.14	0.17	0.16	0.15	0.15
metal products	0.14	-0.51	0.10	0.18	0.17	0.17	0.16
non-metallic minerals	0.11	-0.24	0.14	0.17	0.17	0.16	0.14
food, beverages and tobacco	0.13	-0.35	0.14	0.17	0.17	0.16	0.14
textile, apparel and leather	0.16	-0.26	0.13	0.19	0.18	0.17	0.15
wood	0.16	-0.50	0.16	0.19	0.18	0.17	0.17

Notes: See Table 6.5a. Although France is not included in the regression analysis, equation (6.8) is used to calculate the output elasticities of highly-skilled labour in the French manufacturing sectors.

which is based upon average cross-country employment shares of highly-skilled labour. Thus, from a static point of view overinvestment of highly-skilled labour is likely in the high-skill sectors in almost all countries of the sample. Moreover, the German output elasticities with respect to highly-skilled labour are also negative or very small for the low-skill sectors. In general the medium-skill sectors have the largest output elasticities with respect to highly-skilled labour, whereas the output elasticities with respect to highly-skilled labour are usually larger in 1991 than in 1988. However, to draw a final conclusion on the over- and underinvestment of human capital, the dynamic effects of human capital have to be considered first.

6.6 The dynamic effects of intermediate and highly-skilled labour on productivity

This section estimates the diffusion and the research effect on productivity growth. As pointed out by equation (6.12) of Section 6.3 the diffusion effect of human capital can be measured by the effect of the relative employment shares of intermediate and highly-skilled labour on total factor productivity growth, whereas the research effect of highly-skilled R&D workers can be measured by the effect of the relative R&D intensity on total factor productivity growth. These two effects will be estimated for the low-skill, medium-skill and high-skill categories of sectors distinguished in Section 6.4.

Total factor productivity growth g is found by use of equations (6.9) and (6.11). The variables included in equation (6.9) are the average annual growth rates between 1988 and 1991 of sectoral labour productivity growth and of the same factor input variables as specified in the estimation of equation (6.6), i.e. capital intensity growth and the growth rates of the employment shares of intermediate and highly-skilled workers.[32] Total factor productivity growth of each sector is calculated by substituting the estimated 1988 parameters of Table 6.4a and the growth rates of the variables mentioned above into equation (6.9) and (6.11).[33]

Table 6.6a shows the OLS-estimation results of equation (6.12) by means of a dummy variable model. The estimated equation is significant at the 1% level, although the adjusted R-squared is only 32%. This may be due to the fact that the time period of analysis is only four years, so that short term exogenous fluctuations may disturb the estimation. The estimated diffusion effect of intermediate-skilled workers $\hat{\gamma}_{IS}$ is positive for all sectors, though only significantly positive for the low-skill sectors. Furthermore, the diffusion effect of highly-skilled workers $\hat{\gamma}_{HS}$ is significantly positive for the medium-skill and the high-skill sectors. In particular for the high-skill sectors the estimated diffusion effect is relatively large and significantly different from the estimated diffusion effect in the low-skill sectors. However, the estimated research effect of R&D workers $\hat{\gamma}_{RD}$ is not significant for any of the categories of sectors.

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32. However, the growth of the average firm size is excluded since this variable is only available for 1988. The average firm size is assumed not to change over the estimation period. Since this variable is missing for the French manufacturing sectors, France is included into the regression analysis of equation (6.12).

33. Note that usually the factor shares of the inputs in total production, or best guesses of these factor shares, are taken to calculate total factor productivity growth in equation (6.9) (see e.g. Mohnen, 1992; Wolff, 1992; Hahn, 1995). However, due to data restrictions the calculation of total factor productivity growth is based on the cross-sectional parameters estimated in Section 6.5. Moreover, note that total factor productivity growth is explained over a relatively short period of time.

Table 6.6a
Estimated diffusion and research effect, equation (6.12), including country-dummies, 1988-1991

	$\hat{\gamma}_{IS}$	$\hat{\gamma}_{HS}$	$\hat{\gamma}_{RD}$
high-skill sectors	0.04 (1.10)	0.08 (2.50)[b]	-0.02 (0.73)
medium-skill sectors	0.05 (1.38)	0.06 (1.76)[a]	-0.01 (0.68)
low-skill sectors	0.05 (1.73)[a]	0.02 (1.07)	0.02 (1.56)
country-dummies			
C (NLD*)	-0.11 (2.61)[b]		
DUMBEL	0.01 (0.41)		
DUMDEU	-0.00 (0.16)		
DUMDNK	-0.03 (1.10)		
DUMESP	-0.00 (0.01)		
DUMFRA	0.03 (0.87)		
DUMGBR	0.03 (1.44)		
$\bar{R}^2$	0.32		
F-stat	3.69[c]		
Observations	86		

* The Netherlands is the reference country; *C* represents the constant term.
Notes: See Table 6.3 for the abbreviations of the countries. The absolute t-values are between brackets. The superscripts *a*, *b* and *c* indicate a significant coefficient at the 10%, 5% and 1% level respectively.

As the country-specific dummy variables are not significant,[34] the regression analysis has been repeated without the country dummies. Table 6.6b reports the estimation results of this analysis. It appears that the adjusted R-squared has not changed due to the omission of the dummy variables, whereas the F-statistic has increased. Moreover, for the low-skill sectors the three estimated effects are all significant, whereas for the medium-skill sectors none of the estimated effects is significant anymore. For the high-skill sectors the estimated diffusion effect of highly-skilled labour is even larger and more significant than the estimated diffusion effect of highly-skilled labour in Table 6.6a, whereas the estimated research effect of R&D workers is not significant. The result that the research effect is only significant for the low-skill sectors is difficult to explain. Moreover, in contrast with the results of Verspagen (1995), who finds that the R&D capital stock has a relatively large and significantly positive effect on output growth in the high-tech sectors (which are almost similar to the high-skill sectors) and a smaller and insignificant effect on output growth in the low-tech and the medium-tech sectors. This may be due to the differences in the specification of the estimated production function and in the measurement of the R&D input (e.g. Verspagen uses R&D stocks as input variable). On the other hand, the results of Tables 6.6 also emphasize the relevance of the diffusion effect instead of the

34. Moreover, the null hypothesis that all dummy variables are zero could not be rejected.

research effect of human capital for the high-skill sectors. Diffusion of technological knowledge could be more important for productivity growth than active involvement in research and development of the sector itself.

Furthermore, the results of Tables 6.6 show that one should be very careful to draw conclusions on overinvestment in human capital from a static point of view. In particular, the static (worker and allocative) effect of highly-skilled labour relative to the employment share of highly-skilled labour is very small and insignificant in the high-skill sectors, which leads to the apparent conclusion of overinvestment of highly-skilled labour in these sectors. This conclusion is, however, wrong from a dynamic point of view, since highly-skilled labour has a large and significantly positive effect on the sectoral productivity growth of high-skill sectors. Moreover, since there is also some evidence for the diffusion effect of intermediate and highly-skilled workers in the low-skill and the medium-skill sectors, one should be very careful to draw conclusions on the overinvestment of intermediate skilled labour in Germany and Denmark, as indicated by Table 6.5a. The positive dynamic effects of human capital on productivity growth may outweigh the losses caused by the suboptimal skill structure in the static sense.

Table 6.6b
Estimated diffusion and research effect, equation (6.12), excluding country-dummies, 1988-1991

	$\hat{\gamma}_{IS}$	$\hat{\gamma}_{HS}$	$\hat{\gamma}_{RD}$
high-skill sectors	0.01 (0.31)	0.10 (3.06)[c]	-0.01 (0.50)
medium-skill sectors	0.03 (1.43)	0.05 (1.49)	-0.00 (0.11)
low-skill sectors	0.02 (2.09)[b]	0.03 (1.79)[a]	0.02 (1.93)[a]
C	-0.09 (6.74)[c]		
$\bar{R}^2$	0.32		
F-stat	5.34[c]		
Observations	86		

Notes: See Table 6.6a.

On the other hand, the manufacturing sectors in countries that seem to have underinvestment in human capital from a static point of view are even worse off if the dynamic effects are also considered. This holds for example for the employment shares of intermediate-skilled labour in the low-skill sectors of Spain and Great Britain.

6.7 Conclusions

This chapter tests for the four effects of human capital on sectoral labour productivity that have been discussed in Chapter 5, i.e. the worker effect, the allocative effect, the diffusion effect and the research effect. Sectoral labour productivity can be regarded as an indicator of competitiveness and differences in sectoral labour productivity are, in a Ricardian model of international trade, a determinant of trade flows. This chapter shows that there is some empirical evidence for the proposition that relative sectoral labour productivity determines trade flows. Therefore investments in human capital, which increase labour productivity, can be important for increasing the international competitiveness of manufacturing sectors within the EU Member States. It has been argued that the static (i.e. worker and allocative) effects of human capital increase the productivity *level*, whereas the dynamic (i.e. diffusion and research) effects of human capital increase the productivity *growth*. Human capital is measured by the employment shares of intermediate and highly-skilled workers. Other variables that are relevant in explaining labour productivity at sector level are capital intensity and average firm size.

The theoretical analysis reveals two necessary conditions for profit maximization with respect to the static effects of intermediate and highly-skilled workers. If the worker and allocative effect are larger than the employment shares of intermediate or highly-skilled workers both profits and productivity can be increased by further raising the employment shares of intermediate and highly-skilled labour. If these effects are much larger than the respective employment shares, underinvestment in human capital may be indicated. If these effects are smaller than the respective employment, then there is overinvestment in human capital from a static point of view. However, once the positive dynamic effects of human capital on productivity growth are also included in the analysis overinvestment in human capital may not be evident anymore.

The data show that the rankings of 15 manufacturing sectors by the employment shares of highly-skilled workers are relatively similar across various Member States of the European Union. There is less congruence between the rankings with regard to the employment shares of intermediate-skilled workers. The fifteen manufacturing sectors distinguished are divided into three categories of sectors with different employment shares of highly-skilled workers: low-skill sectors, medium-skill sectors and high-skill sectors. Despite the relatively similar rank orders of manufacturing sectors across countries, the sectoral employment shares of intermediate and highly-skilled workers differ to a large extent between countries.

Least squares estimations for thirteen manufacturing sectors of the sample countries showed that the effects of intermediate and highly-skilled labour on sectoral labour productivity, which reflect the worker and allocative effect, are significantly positive for all categories of sectors, except for the effect of highly-skilled labour in the category of high-skill sectors. The effects are large relative to the employment shares of intermediate and highly-skilled labour, except for highly-skilled labour in the high-skilled sectors. The latter implies that, from a static point of view there is over-investment of highly-skilled labour in the high-skill sectors. A closer look at the individual sectors is taken to judge whether there is under- or overinvestment of intermediate and highly-skilled labour. Therefore the output elasticities with respect to the employment shares of intermediate and highly-skilled labour are calculated. The output elasticities with respect to the employment shares of intermediate-skilled workers are negative or small for most manufacturing sectors in Germany and Denmark. It implies that from a static point of view there is overinvestment of intermediate-skilled labour in most German and Danish manufacturing sectors. On the contrary, the output elasticities with respect to the employment shares of intermediate-skilled labour are relatively large in the manufacturing sectors of Spain and Great Britain, which may indicate underinvestment of intermediate-skilled labour in these sectors. The output elasticities with respect to the employment shares of highly-skilled labour are negative or small for the manufacturing sectors in the high-skill category of sectors of all countries, which confirms the more aggregated analysis, and also negative or small for the low-skill sectors in Germany. However, a static analysis estimating the worker and allocative effect of the employment shares of intermediate and highly-skilled workers does not account for the dynamic effects of the various production factors on productivity growth.

Least squares estimations to explain sectoral productivity growth shows that the diffusion effect of highly-skilled labour in the high-skill category of sectors is significantly positive. Moreover, there is some evidence for the diffusion effect of intermediate and highly-skilled labour in the low-skill category of sectors and for the diffusion effect of highly-skilled labour in the medium-skill category of sectors. Therefore the diffusion effect of intermediate-skilled and highly-skilled labour on productivity growth questions both the apparent overinvestment of intermediate-skilled labour in the German and Danish manufacturing sectors and the apparent overinvestment of highly-skilled labour in most high-skill sectors and in the German low-skill sectors. In other words, it is wrong to conclude from a static analysis alone that there is overinvestment of intermediate and highly-skilled labour in some manufacturing sectors. Moreover, the diffusion effect of intermediate-skilled labour provides additional evidence on the conclusion that the employment share of intermediate-skilled workers in Spanish and British manufacturing sectors is too small. From a static point of view, an increase in the employment share of intermediate-skilled workers may raise both profits and the productivity level in these countries, whereas from a dynamic point of view, an increase in the employment share of intermediate-skilled labour may stimulate the introduction of new technologies and thus productivity growth. Finally, there is some evidence to support a research effect of highly-skilled R&D workers. However, this effect has been found in the low-skill category of sectors only, while no evidence for the research effect was found for the medium-skill and high-skill categories of sectors.

Appendix 6.A Classifications of sectors

Table 6.A.1
Categories of sectors

	capital-intensity	average firm size
high-skill sectors		
chemicals	high	medium
electrical machinery	medium	medium
professional goods	low	small
non-electrical machinery	low	small
medium-skill sectors		
petroleum	high	medium
paper and printing	medium	small
basic metals	high	large
transport equipment	medium	large
low-skill sectors		
rubber and plastic	medium	small
other manufacturing	medium	small
metal products	low	small
non-metallic minerals	high	small
food, beverages and tobacco	high	small
textiles, apparel and leather	low	small
wood	low	small

Notes: The sectors are ranked according to the 1988 cross-country average employment share of highly-skilled labour (see Table 6.2). High capital-intensive sectors have a capital stock per employee which is higher than 45,000 US dollars (1985 prices) per employee in 1988. Low capital-intensive sectors have a capital stock per employee which is lower than 30,000 US dollars (1985 prices) per employee in 1988. The remaining sectors are medium capital-intensive. The average firm size of large scale sectors is larger than 200 workers per establishment in 1988. The average firm size of small scale sectors is smaller than 100 workers per establishment in 1988. The remaining sectors have a medium scale firm size.

Table 6.A.2
Classification of ISIC (1977) sectors

foo	3100	Food, beverages and tobacco
tex	3200	Textile, wearing apparel and leather industries
woo	3300	Wood and wood products, including furniture
pap	3400	Paper and paper products, printing and publishing
che	3510+20	Industrial chemicals and other chemical products
pet	3530+40	Petroleum refineries and miscellaneous products of petroleum and coal
rup	3550+60	Rubber products and plastic products not classified elsewhere
nme	3600	Non-metallic mineral products, except products of petroleum and coal
bmi	3710+20	Iron and steel basic industries and non-ferrous metal basic industries
pme	3810	Fabricated metal products, except machinery and equipment
mac	3820	Machinery except electrical
ele	3830	Electrical machinery apparatus, appliances and supplies
tra	3840	Transport equipment
opt	3850	Professional, scientific, measuring, controlling equipment not classified elsewhere, photographic and optical goods
oma	3900	Other manufacturing industries

Table 6.A.3
Concordances between ISIC 1977 (rev. 2) and NACE 1970 classifications

Abbreviation	ISIC 1977	NACE 1970
foo	3100	41+42
tex	3200	43+44+45
woo	3300	46
pap	3400	47
che	3510+3520	25+26
pet	3530+3540	11+12+13+14+15+21+23
rup	3550+3560	48
nme	3600	24
bmi	3710+3720	22
pme	3810	31
mac	3820	32+33
ele	3830	34
tra	3840	35+36
opt	3850	37
oma	3900	49

Appendix 6.B Data sources

Employment shares of low, intermediate and highly-skilled labour
The data for calculating these employment shares are drawn from Eurostat's *Labour Force Survey* (1988-1991). The classification of the skill level is analogous to UNESCO's International Standard Classification of Education (ISCED). ISCED levels 0/1 (pre-primary and primary education) and 2 (lower secondary education) correspond to the skill level of low-skilled labour. ISCED level 3 (higher secondary education) corresponds to the skill level of intermediate-skilled labour, and ISCED levels 5 to 7 (higher university and non-university education) correspond with the skill level of highly-skilled labour. The numbers of workers in the various NACE[35] classes (at the 2-digit level) have been aggregated to ISIC[36] sectors according to the concordance table listed below. The numbers of intermediate or highly-skilled workers in the NACE classes which are below the threshold value of Eurostat are estimated using the number of intermediate and highly-skilled workers in the NACE divisions (at the 1-digit level). Since there are no data available for France in 1990 and 1991, the 1989 employment shares of highly-skilled labour have been used as an approximation for 1990 and 1991. The French employment shares of intermediate-skilled labour are found very low to serve as reliable data input, for which reason these employment shares are not presented. Conversely, since there are no data available for the Netherlands in 1988 and 1989, the employment shares of 1990 have been used as an approximation for 1988 and 1989.

Sectoral labour productivity
The variable indicating the average labour productivity per worker in a sector has been calculated by dividing the value added per sector by the number of workers employed per sector. Data on both the value added and the numbers of workers employed was drawn from the OECD Structural Analysis (STAN) industrial database. The STAN database expresses value added in local currencies at constant 1985 prices, except for Spain. The values for Spain have been converted into 1985 prices using sector prices from the United Nations Industrial Statistics (UNIDO) database. Purchasing power parities based on GDP figures, and drawn from the Penn World Tables, have then been used to convert the local currencies into 1985 dollar prices. For Spain, the value added per worker in 1990 is used as an approximation for the value added per worker in 1991.

Export/Import ratio
The export and import data are drawn for the STAN industrial database. Sectoral exports in local currencies and current prices are divided by sectoral imports in local currencies and current prices.

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35. General Industrial Classification of Economic Activities, which is used within the European Union.

36. International Standard Industrial Classification of the United Nations, which is used for the classification of sectors in the STAN database (see below).

Capital intensity
The capital intensity variable has been approximated by the fixed stock of physical capital per worker. Data on gross investments in fixed capital and the number of workers employed are drawn from the STAN industrial database. Stocks of physical capital per sector are constructed using a perpetual inventory method (PIM) for the period of 1970 - 1991, with a depreciation rate of 0.1. The initial stock of capital (in most cases 1970) is calculated as the value of investment of next year, divided by the depreciation rate plus an assumed growth rate of 0.05. Since investments are expressed in local currencies at current prices, these values have been converted into 1985 prices using sector prices from the United Nations Industrial Statistics (UNIDO) database. Purchasing power parities of gross investments, drawn from the Penn World Tables, have then been used to convert the local currencies into 1985 dollar prices. For Spain, the capital intensity in 1990 is used as an approximation for the capital intensity in 1991.

Average firm size
The data on the number of establishments in each sector are drawn from the Industrial Structure Statistics (ISS) of the OECD. For most countries data are only available up to 1988. The average firm size has been calculated by dividing the number of workers employed by the number of establishments per sector. The data of the numbers of workers are drawn from the STAN industrial database. For France, no data are available for the number of establishments per sector.

R&D expenditures
The variable indicating the level of technological knowledge in a particular sector is measured using data on research and development expenditures. The R&D expenditures are drawn from the Basic Science and Technology Statistics. Purchasing power parities, drawn from the Penn World Tables, have been used to convert the local currencies into 1985 dollar prices.

Appendix 6.C Data of employment shares of intermediate and highly-skilled labour

Figure 6.C.1
Belgium (BEL), shares of intermediate (IS) and highly-skilled (HS) workers, 1988

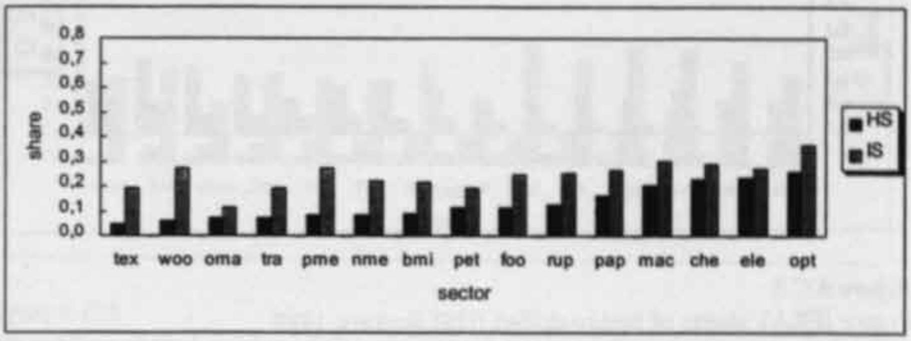


Figure 6.C.2
Germany (DEU), shares of intermediate (IS) and highly-skilled (HS) workers, 1988

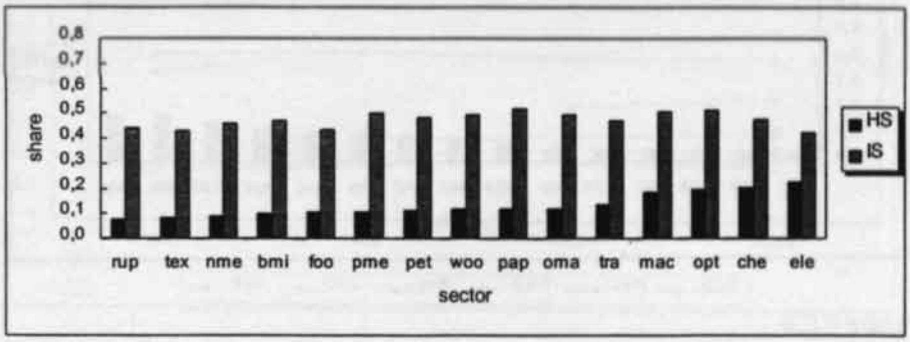


Figure 6.C.3
Denmark (DNK), shares of intermediate (IS) and highly-skilled (HS) workers

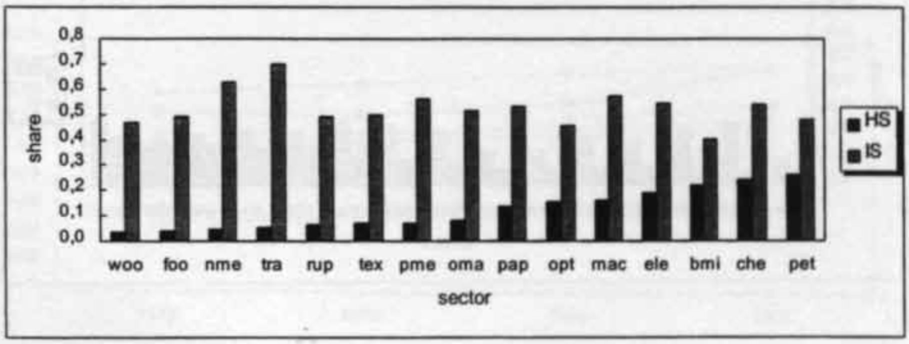


Figure 6.C.4
Spain (ESP), shares of intermediate (IS) and highly-skilled (HS) workers, 1988

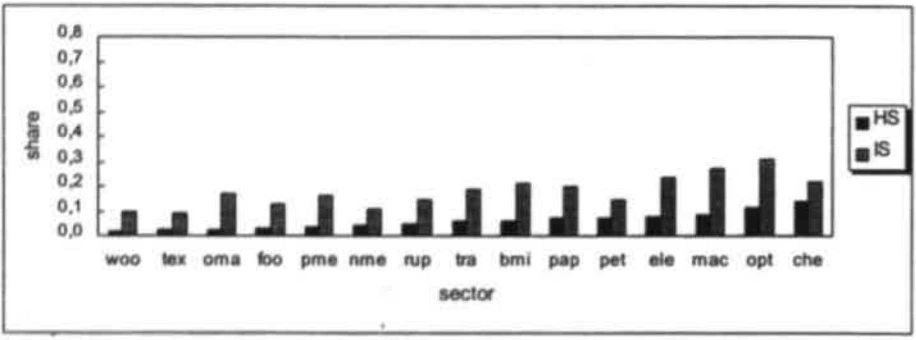


Figure 6.C.5
France (FRA), shares of highly-skilled (HS) workers, 1988

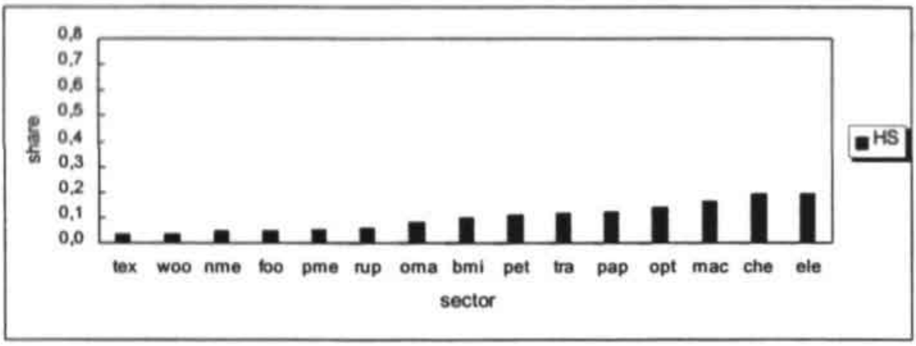


Figure 6.C.6
Great Britain (GBR), shares of intermediate (IS) and highly-skilled (HS) workers, 1988

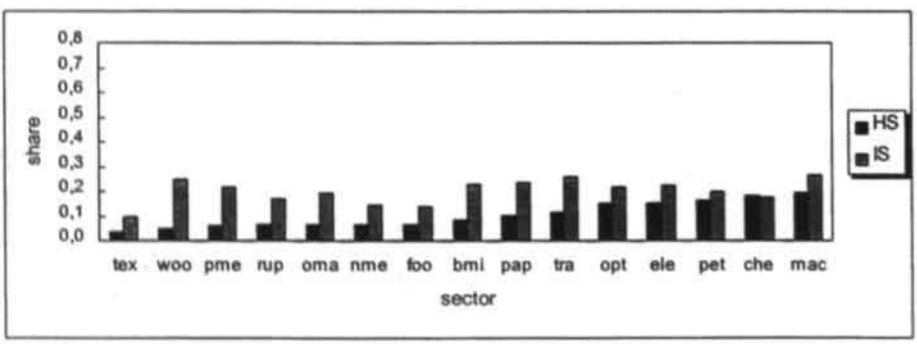


Figure 6.C.7
Netherlands (NLD), shares of intermediate (IS) and highly-skilled (HS) workers, 1990

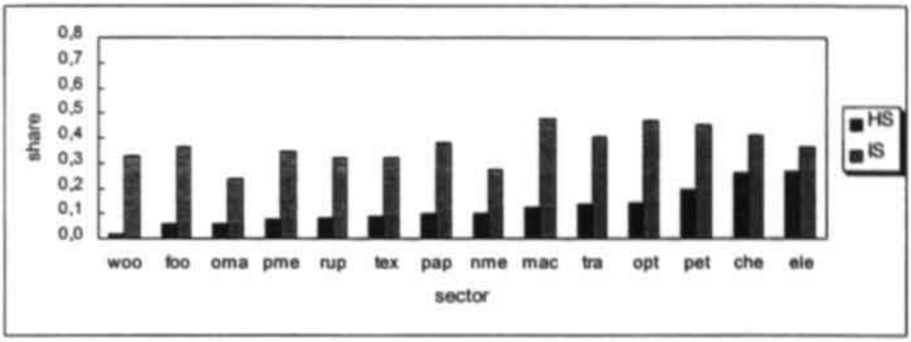


Figure 6.C.8
Intermediate-skilled workers (IS), unweighted mean of manufacturing sectors per country

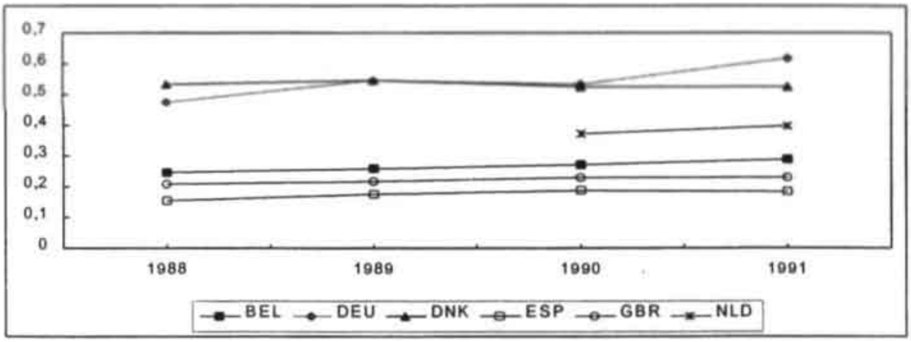
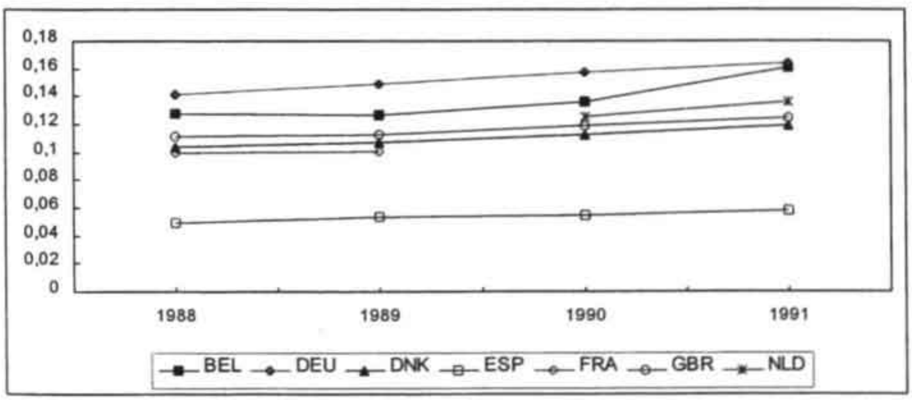


Figure 6.C.9
Highly-skilled workers (HS), unweighted mean of manufacturing sectors per country



Chapter 7

Country-specific human capital endowments and trade performance[1]

7.1 Introduction

This chapter focuses on the relevance of country-specific human capital endowments for the trade performance of industrialized countries. There are good reasons to assume that human capital endowments are dependent on country-specific circumstances, such as the educational system or the technology policies of the government. The relevance of country-specific human capital endowments for trade performance is already mentioned in Chapter 1. The current chapter conducts the theoretical and empirical analysis along the upper line of research of the general framework of Figure 1.1. This upper line of research indicates that differences in human capital endowments of low-skilled, intermediate-skilled and highly-skilled labour across countries determine the sectoral trade performance.

The model used in this chapter is the Heckscher-Ohlin-Vanek model (Vanek, 1968; Leamer, 1980; Leamer and Bowen, 1981 and Deardorff, 1982),[2] which demonstrates that countries with relatively large stocks of a particular factor endowment will export the services of this factor endowment. The chapter incorporates different country-specific endowments of skilled labour to analyse the impact of human capital on trade performance. The model used is analogous to the *neo-factor endowments models*, which include not only the traditional production factors of labour and physical capital, as in the studies of Leontief (1953, 1956), but also human capital and technological knowledge.[3]

The Heckscher-Ohlin-Vanek (HOV) model shows that country-specific factor endowments rather than sector-specific factor inputs determine international trade flows (e.g. Leamer and Bowen, 1981, and Leamer, 1992). However, in many empirical studies of the HOV model sector-specific factor inputs are used as the determinants of trade, which is wrong from a theoretical point of view when applying the HOV model.[4]

1. This chapter is largely based on Cörvers and De Grip (1997).

2. This model is also known as the factor content version of the more familiar Heckscher-Ohlin model.

3. For overviews see Deardorff (1984), Hughes (1986) and Memedovic (1994).

4. See e.g. Baldwin (1971), Katrak (1973), Branson and Monoyios (1977), Stern and Maskus (1981) and Courakis (1991). However, Chapter 8 notes that these studies may still have empirical relevance.

The relevance of sector-specific factor inputs, including human capital inputs, for productivity and trade performance has been analysed in the preceding chapter by making use of both the Ricardian model of trade and the human capital model. The emphasis in this chapter is on the country-specific factor inputs, for which the HOV model is particularly suited.

It has been argued in Chapters 5 and 6 that the distinction between the skill groups of low, intermediate and highly-skilled labour is very important for explaining average productivity differences between sectors. These differences are based on the worker effect, the allocative effect and the diffusion effect of intermediate and high skills. In turn, the average productivity differences are held responsible for trade flows between sectors across countries. However, in this chapter the productivity rates of the three skill groups, and as a consequence their input-output ratios, are supposed to be given. Trade flows are explained from another point of view, namely the skill endowments at the country level. These skill endowments are generated by the national educational systems of the countries. Apart from the use of country-specific instead of sector-specific determinants of trade, this is another difference between the models used in the current and the preceding chapter. The HOV model used in this chapter stresses the relevance of the skill endowments generated by the educational system of a country, whereas the human capital model used in Chapter 6 stresses the relevance of the skill inputs in the firms of a sector.

The fourth human capital factor distinguished in this chapter, labour participating in R&D activities, embodies an important part of the country's stock of technological knowledge. The relevance of R&D workers for productivity growth, i.e. the research effect, has been discussed in Chapters 3, 5 and 6. The country-specificity of technological knowledge is shown by for example Daniels (1993). He finds evidence for the importance of national differences in technological capabilities as a determinant of the trade performance of technology-intensive sectors. Again, it is the availability of technological knowledge at the country level that directly determines trade performance in this chapter, whereas in Chapter 6 the impact of sector-specific technological knowledge on productivity growth indirectly determines trade performance.

Empirical studies often show poor results if, in accordance with the HOV model, net trade flows at sector level are explained by country-specific factor endowments (e.g. Bowen, Leamer and Sveikauskas, 1987, and Bowen and Sveikauskas, 1992). This chapter will point to some reasons why empirical research may fail to explain trade performance if the HOV model is used. Furthermore, it is often argued that trade models assuming economies of scale and product differentiation are best suited to explain trade flows between industrialized countries. However, these intra-industry trade models explain only the *amount* of trade between countries, whereas the HOV model has the potential to explain the *direction* of net trade flows (see Helpman, 1981). Net trade flows are particularly important, since they determine the surplus or shortage in the trade balance, which is a hot item in the trade negotiations between the United States, Japan and the European Union. Furthermore, 40% of total trade in industrialized countries is still inter-industry trade (OECD, 1987; Papaconstantinou, 1995).[5]

The structure of the remainder of the chapter is as follows. Section 7.2 presents a derivation of the most important implication of the HOV model: that the trade performance of sectors is dependent on country-specific relative factor endowments rather than on sector-specific factor inputs. Section 7.3 presents the empirical model, which is based on the preceding theoretical exposition. Section 7.4 develops hypotheses regarding the impact of the relative factor endowments of labour, physical capital and human capital on the trade performance of four different categories of sectors. These hypotheses are based on the four productivity effects of skills discussed in Chapter 5. Section 7.5 presents the results of the empirical analysis. Section 7.6 summarizes the main conclusions of the chapter.

7.2 The Heckscher-Ohlin-Vanek (HOV) model

One of the theorems following from the HOV model, the Heckscher-Ohlin-Vanek theorem, says that countries tend to export the factor services of their relatively abundant production factors and tend to import the factor services of their relatively scarce production factors.[6] It emphasizes that factor services are exchanged through trade. The traded goods that embody or contain the services of the production factors merely conduct that exchange.

The *assumptions* of the HOV model are (Leamer, 1980) (a) perfect competition in the goods and factors markets, (b) zero cost of transport of commodities and no other impediments to trade, (c) immobility of production factors between countries, but complete mobility of production factors between sectors within a country, (d) identical input-output (technology) relations in all countries, (e) production functions showing constant returns to scale, (f) factor price equalization across countries, (g) equal numbers of factors and goods, (h) consumers maximize their identical homothetic utility functions.

In particular the assumptions of identical input-output relations[7] and factor price equalization across countries may be crucial for the relevance of the HOV model. Deardorff (1982) shows that if these assumptions are both met, factor intensity reversals cannot occur. These assumptions of the HOV model are more valid for a group of industrialized countries than for a mixed group of industrialized and developing countries.[8] Therefore the HOV model might usefully be applied to a group

5. Inter-industry trade can be measured by the industry's absolute value of net exports expressed as a percentage of the industry's total trade (i.e. sum of exports and imports).

6. The use of the verb 'tend' indicates that this theorem holds *on average* (see Deardorff, 1982, and Forstner, 1985).

7. In Chapter 6 we have seen that the human capital inputs and the related actual input-output relations differ between similar sectors across countries. It has been argued that these differences may result from under- or overinvestment in intermediate or high skills. However, the model of this chapter does not allow for non-optimal investment decisions.

8. Generalizations of the HOV theorem without assuming factor price equalization are found in Brecher and Choudhri (1982), Deardorff (1982) and Helpman (1984).

of industrialized countries, as in this chapter.[9] Moreover, models assuming constant returns to scale, like the HOV model, must be distinguished from models that allow for economies of scale. As mentioned in the introduction of this chapter, economies of scale are relevant for explaining intra-industry trade between industrialized countries (see also Deardorff, 1984). Following Leamer (1984), who also uses the HOV model, and contrary to Chapter 6, this chapter does not incorporate such economies into the model since the model explains net trade, i.e. exports minus imports, instead of exports and imports separately.[10] As for other assumptions of the HOV model, Leamer concludes that, if the assumptions with regard to trade impediments, international factor mobility, non-traded and intermediate goods, transportation costs, factor market distortions and consumer preference dissimilarities are not fulfilled, outcomes from the HOV model are not seriously affected.[11]

For each country i the vector AQ_i is the vector of factors required to produce the nx1 vector of goods Q_i (see e.g. Leamer, 1980), where matrix A is the mxn input-output (factor intensity) matrix with input (or factor) requirements a_{kj}. These input requirements indicate the amount of factor k used to produce one unit of good j.[12] Due to assumptions (d), (e) and (f), matrix A is identical for all countries. AQ_i also represents the factors embodied in the production of Q_i. Equilibrium in the factor markets requires that factor demand AQ_i is equal to factor supply V_i, so $AQ_i = V_i$. The summation of this equation across all countries gives $AQ_w = V_w$ (since $Q_w = \sum Q_i$ and $V_w = \sum V_i$). Because of assumption (a), the vector of goods prices is equal across all countries. Equalization of goods prices and assumption (h) imply that each country i will consume a proportion β_i of all world-wide produced goods that is the same for all goods. So for the n x 1 vector of goods consumed in country i holds that $C_i = \beta_i Q_w$, where β_i is a scalar. The net exports of country i equal the difference between its production and its consumption, $T_i = Q_i - C_i$. The factors embodied in the net exports are $AT_i = A(Q_i - C_i) = V_i - A\beta_i Q_w = V_i - \beta_i V_w$. This also implies that $\beta_i V_w$ indicates the extent to which the world's factor endowments are used by country i 's consumption. Therefore equation (7.1) represents the Heckscher-Ohlin-Vanek theorem.

$$AT_i = V_i - \beta_i V_w \tag{7.1}$$

Following Bowen and Sveikauskas (1992), equation (7.1) can be corrected for trade imbalances B_i, where B_i is a scalar which equals $P'T_i$ (vector P is the n x 1 vector of goods prices). Therefore $\beta_i V_w$ has to be written as $(GDP_i - B_i)/GDP_w V_w = (GDP_i/GDP_w)V_w - (B_i/GDP_w)V_w = \alpha_i V_w - (B_i/GDP_w)V_w$, where GDP_i stands for the gross domestic product of country i and α_i is country i 's share of world income GDP_w. When $(B_i/GDP_w)V_w$ is subtracted from each side of equation (7.1) it follows that:

9. The same argument is used by James and Elmslie (1996).

10. According to Leamer (1984) "The apology is that the level of aggregation and the use of net exports rather than exports and imports separately reduce the possibility that scale effects are important."

11. Moreover, the results of the HOV model are less distorted by trade barriers now than they once were, as the barriers are gradually broken down by free trade agreements.

12. This matrix does not allow for intermediate inputs.

$$AT_i - (B_i/GDP_w)V_w = V_i - \alpha_i V_w \quad (7.2)$$

Vector AQ_w can be substituted for V_w. If vector S is defined as the n x 1 vector of world shares of each good, Q_w/GDP_w, equation (7.3) results:

$$A(T_i - B_i S) = V_i - \alpha_i V_w \quad (7.3)$$

Subtracting $B_i S$ from T_i implies that the excess or deficit for a country's net exports per sector is corrected by $B_i S$. The term $B_i S$ indicates how the trade imbalance is distributed over the various sectors. If a country's consumption level is too high or too low relative to its income level, the difference is assumed to be distributed over the various sectors according to the share of the production (or consumption, because $Q_w = C_w$) of each good (or sector) on the world market. This follows from the assumption of homothetic utility functions (assumption h). Moreover, if T_{Bi} is defined as $T_i - B_i S$, this results in:

$$AT_{Bi} = V_i - \alpha_i V_w \quad (7.4)$$

A definition of factor abundance can be derived from equation (7.4). The vector V_i represents the factor endowments $(V_{1i} ..., V_{ki} ... V_{mi})'$ of country i. Similarly, the vector V_w represents the world's factor endowments $(V_{1w} ..., V_{kw} ... V_{mw})'$. The quotient of V_{ki} and V_{kw} represents the factor endowment of country i in factor k relative to the world's factor endowment. If the right-hand side of equation (7.1) is positive for factor k, i.e. if country i is abundant in factor k, then it also holds that $V_{ki} / V_{kw} > \alpha_i$. This result can be used to define factor abundance. Following Leamer (1984), country i is abundant in factor k if its share of the world's supply of factor k, V_{ki} / V_{kw}, exceeds its share of the world's income α_i, i.e. $V_{ki} / V_{kw} > \alpha_i$. It follows that country i is abundant in factor k if:

$$(V_{ki}/V_{kw})/(GDP_i/GDP_w) > 1 \quad (7.5)$$

The larger the left-hand side of (7.5), the larger the relative factor endowment of country i in factor k.

Finally, equation (7.4) can be rewritten as:

$$T_{Bi} = A^{-1}V_i - A^{-1}\alpha_i V_w \quad (7.6)$$

Equation (7.6) indicates that the net exports of country i are dependent on the vector of factor endowments V_i. The inverse of matrix A only exists if there are equal numbers of factors and goods (assumption g).[13] If there are more sectors (goods) than production factors, it is not possible to determine the net trade flows for each sector on theoretical grounds, because the system of equations for country i is under-determined. The input-output matrix A is not square and therefore it has no inverse. However, Leamer (1984)

13. Furthermore, notice that each row and column of the inverse matrix has to contain both positive and negative elements, since matrix A contains only positive elements.

states that this is not a cause for concern, because in an empirical analysis the number of goods or sectors depends on the level of aggregation, and the observed production factors are just a selection from a larger set of production factors.

A few more steps have to be inserted to derive the final equation of this section.[14] First note that $GDP_i = P'Q_i$, $\alpha_i = GDP_i / GDP_w$ (where α_i, GDP_i and GDP_w are scalars), and $V_w = AQ_w$. From equation (7.6) it follows that:

$$T_{Bi} = A^{-1} V_i - A^{-1} V_w \alpha_i = A^{-1} V_i - A^{-1} A Q_w \alpha_i = A^{-1} V_i - Q_w GDP_i / GDP_w =$$

$$A^{-1} V_i - Q_w P' Q_i / GDP_w = A^{-1} V_i - Q_w P' A^{-1} V_i / GDP_w = (I - Q_w P' / GDP_w) A^{-1} V_i ,$$

where I represents the identity matrix. As a result, it holds for each sector j of the vector T_{Bi} that:

$$T_{Bji} = \sum_{k=1}^{m} b_{jk} V_{ki} \tag{7.7}$$

The b_{jk} coefficients of equation (7.7) represent the matrix $(I - Q_w P' / GDP_w) A^{-1}$. It follows that these coefficients are derived from the factor intensities of matrix A, which is equal for all countries.[15] Furthermore, equation (7.7) clearly shows the main point of the HOV theorem, that the net exports of sector j in country i are dependent on country's i vector of factor endowments V_{ki} rather than on the sector-specific factor inputs of sector j. This equation will be used for developing the empirical model of Section 7.3.

7.3 The HOV model with country-specific human capital endowments

From the theoretical exposition in Section 7.2 it follows that differences in country-specific factor endowments have implications for the pattern of net trade flows. The empirical analysis in this chapter does not follow previous empirical studies on international trade, which measure human capital from discounted sector-wage differentials (e.g. Branson and Monoyios, 1977 and Stern and Maskus, 1981), especially as these differentials have the disadvantage of being only an indirect measure of labour skills (see also Chapter 2). Nor is human capital measured by occupational categories of workers (e.g. Keesing, 1966, 1968; Baldwin, 1971; Leamer, 1984 and Bowen et al., 1987), since the latter measure is based on the type of work done rather than on the skill level of the workforce.

In order to allow for the different impact of the skill endowments on trade performance the shares of low-skilled, intermediate-skilled and highly-skilled workers in the total workforce of a country will be used. One would also like to use the proportion of a country's workforce who are engaged in research and development (R&D) as a measure of the country's stock of technological knowledge. However, comparable data on these employment shares is not available for all countries. Nevertheless, the proportion of a country's labour force that is employed in R&D

14. See Leamer (1984) for the two-dimensional case.

15. Moreover, it follows that these coefficients can be positive as well as negative.

activities can be approximated by the R&D intensity of a country (R&D expenditures divided by GDP), since R&D expenditures consist largely of wage costs for R&D workers.[16] The technological knowledge that countries buy from abroad, which is expressed by the technological balance-of-payments, is also taken into account to construct a reliable proxy of the level of technological knowledge in a country (see Appendix 7.B).

To test the relevance of the various human capital endowments with regard to the level of education for the pattern of net trade flows, two equations will be considered. Both equations follow directly from equation (7.7), although the first equation does not distinguish between the various levels of education, whereas the second equation distinguishes the three skill categories discussed above.

$$RCA_{ji} = b_{j0}+b_{j1}LAB_i +b_{j5}TEC_i+b_{j6}CAP_i+b_{j7}RCA_i+\mu_{ji} \tag{7.8a}$$

$$RCA_{ji} = b_{j0}+b_{j2}LSW_i+b_{j3}ISW_i+b_{j4}HSW_i +b_{j5}TEC_i+b_{j6}CAP_i+b_{j7}RCA_i+\mu_{ji} \tag{7.8b}$$

where

RCA_{ji}	=	the revealed comparative advantage of sector *j* in country *i*;
LAB_i	=	the relative factor endowment of labour in country *i*;
LSW_i	=	the relative factor endowment of low-skilled workers in country *i*;
ISW_i	=	the relative factor endowment of intermediate-skilled workers in country *i*;
HSW_i	=	the relative factor endowment of highly-skilled workers in country *i*;
TEC_i	=	the relative factor endowment of technological knowledge in country *i*;
CAP_i	=	the relative factor endowment of physical capital stock in country *i*.
RCA_i	=	the revealed comparative advantage of all sectors of country *i* (excluding those belonging to the same factor-intensity category as sector *j*);[17]
b_{jk}	=	estimated coefficients;[18]
μ_{ji}	=	disturbance term.

Equations (7.8a) and (7.8b) are estimated sector-by-sector. Due to assumptions (d) and (e) of Section 7.2, each sector has the same regression coefficient, for a particular relative factor endowment, in all the industrialized countries. The HOV theorem states

16. The wage costs of R&D workers comprise between 80 and 90% of total R&D expenditures in most industrialized countries (see Appendix 7.B for data sources on technological knowledge).

17. In fact the trade balance variable represents the total of ISIC sectors listed in Appendix 7.A. When calculating the total revealed comparative advantage measure (RCA_i) the category of economic sectors to which a particular sector belongs is excluded. For example, when calculating the total revealed comparative advantage RCA_i of the textile sector (tex), labour-intensive sectors are excluded.

18. The constant term b_{j0} is added to correct for net trade flows between the sample of fourteen countries and the rest of the world.

that countries tend to export the services of their abundant factors. By estimating equations (7.8a) and (7.8b) it will be possible to indentify which sectors are mainly responsible for the export of those factor services. In other words, the estimates of equations (7.8a) and (7.8b) show which factor endowments contribute to the success of the export performance of a particular sector.

Moreover, it is important to scale both the countries' factor endowments and net exports per sector in equation (7.7). Otherwise the results might be influenced by variations in industry and country size.[19] The factor endowments are scaled by means of the factor abundance definition from equation (7.5). Using this equation and the data sources listed in Appendix 7.B, the *relative* factor endowments are calculated. The factor endowments of country i are in fact *double scaled*, i.e., first with regard to the total amount of the factor endowment k in the world, and second with regard to the share of country i in the total GDP of the world. The total factor endowment of the world, and total world income, are both approximated by the sum of the factor endowments of the fourteen countries in the sample and the sum of their GDPs respectively. The values of the relative factor endowments are presented in Appendix 7.C.[20]

The dependent variable, net exports per sector, is double scaled, as proposed by Minne (1988). This implies that the net exports of sector j are first standardized with regard to total trade by country i,[21] and that this ratio is then standardized again according to the proportion of total world trade in all sectors which takes place in sector j. Again, world trade is approximated by the sum of trade of the fourteen countries in the sample. The revealed comparative advantage of sector j in country i is shown in the following equation:

$$RCA_{ji} = (T_{ji}/U_i) / (U_{jw}/U_w) \tag{7.9}$$

where

- T_{ji} = net exports of sector j in country i;
- U_i = half of the sum of exports and imports of country i, to indicate the total trade of the country if there are no trade imbalances;
- U_{jw} = half of the sum of world exports and world imports of sector j;
- U_w = half of the sum of total world exports and total world imports.

Equation (7.9) implies that if exports equal imports for a particular industry, so that

19. On this topic see, for example, Stern (1976) and Memedovic (1994). The latter also gives an overview of the various ways to scale net exports, which result in indicators for revealed comparative advantage.

20. Scaling the human capital endowments according to equation (7.5) means that the relative factor endowment of labour, LAB_i, is a linear combination of the three relative factor endowments of human capital, i.e. LSW_i, ISW_i, HSW_i. The weights of the linear combination are equal to the labour endowment of workers with the relevant level of education, in the sample, divided by the total labour endowments of all workers in the sample.

21. Total trade is approximated by the mean of exports and imports.

intra-industry trade is 100%, the *RCA* of the industry is zero.[22]

Finally, equation (7.7) says that net exports have to be corrected for trade imbalances. However, it is hard to find appropriate data to correct for trade imbalances (see Appendix 7.B). For this reason the value of a country's trade balance (B_i) is added to the factor endowment variables on the right side of equation (7.7) and double scaled according to equation (7.9). Therefore, after double scaling, the uncorrected net exports can be used as the dependent variable, as in equations (7.8a) and (7.8b).[23]

7.4 Hypotheses on factor endowments and trade performance

This section develops hypotheses on the consequences of countries' different relative factor endowments for their revealed comparative advantages. These hypotheses are based on the four productivity effects of intermediate and high skills that have been discussed in Chapter 5. For testing these hypotheses it is useful to distinguish between four categories of economic sectors with different factor intensities: labour-intensive, capital-intensive low/medium-tech, capital-intensive high-tech and technology-intensive sectors.[24] This classification is based on OECD (1986), OECD (1987) and Verspagen (1995). The resulting classification scheme is shown in Appendix 7.A.

Tables 7.1a and 7.1b give an overview of the hypotheses that will be tested with regard to the coefficients of the relative factor endowments of equations (7.8a) and (7.8b).[25] With regard to the signs of the estimated coefficients, relative abundances of labour, physical capital and technological knowledge would be expected to be positively related to revealed comparative advantages in the labour-intensive sectors, the capital-intensive sectors and the technology-intensive sectors respectively. In addition, the research effect causes the expectation that technological knowledge, partly embodied in R&D workers, is in particular relevant for the technology-intensive sectors. A relatively large factor endowment of R&D workers leads to the export of high-technology services, which are bundled in technology-intensive goods. Specialized R&D workers are essential to produce in the complex and continuing changing environment of research and development activities.

The above expectations are represented by the positive signs of the virtual diagonal running from upper left to lower right of the matrix in Table 7.1a. The other elements of this matrix of signs are not clearly positive or negative, excluding the bottom left-hand corner and the top right-hand corner of the matrix. The latter two negative signs indicate that labour-abundant countries are assumed to import technology-intensive

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22. See Minne (1988) for a further discussion of this measure.

23. See Appendix 7.C for a figure presenting the uncorrected revealed comparative advantages of four categories of sectors of the countries in the sample.

24. The classification differs from the classification of Chapter 6 due to the use of different models and hypotheses. Here, the resource-intensive sectors are not considered, since the trade performance of these sectors is strongly dependent on the abundance of natural resources, which are excluded in the analysis.

25. Note that both matrices of signs contain symmetric properties.

goods (i.e. net exports are negative), and technology-abundant countries are assumed to import labour-intensive goods.[26]

Table 7.1a
Hypotheses regarding the coefficients of the relative factor endowments of labour, capital and technological knowledge

Sectors	LAB_i	CAP_i	TEC_i
labour-intensive	+	0	-
capital-intensive, low/medium-tech	0/+	+	0/-
capital-intensive, high-tech	0/-	+	0/+
technology-intensive	-	0	+

Table 7.1b
Hypotheses regarding the coefficients of the relative factor endowments of three skill levels

Sectors	LSW_i	ISW_i	HSW_i
labour-intensive	+	0/-	-
capital-intensive, low/medium-tech	0/+	0/-	0/-
capital-intensive, high-tech	0/-	0/+	0/+
technology-intensive	-	0/+	+

Table 7.1b gives an overview of the expected signs of the factor endowments of labour skills in the four classes of sectors mentioned above. In general it is expected that the higher the capital-intensity or the technology-intensity of sectors, the higher the impact of the factor endowments of intermediate-skilled labour and highly-skilled labour. If production processes are capital-intensive and/or technology-intensive, they are more complex and more often subject to changes than labour-intensive production

26. There is no negative sign in the column for physical capital, as physical capital is expected to be strongly negatively related to the trade performance of service sectors, which are excluded from the analysis.

processes. Intermediate and highly-skilled workers can, due to the worker, allocative and diffustion effect of skills, better cope with these complexities and changes than low-skilled workers (see Chapter 5). In other words, complementarities between the input of skills on the one hand, and the degree of capital- and technology-intensity on the other are expected. In particular the diffusion effect of highly-skilled labour in the technology-intensive sectors is expected to be large.[27] Therefore a relatively large endowment of highly-skilled labour in a particular country is expected to contribute positively to the net exports of technology-intensive goods in this country.

In Table 7.1b the above reasoning implies that the signs in the columns for intermediate and highly-skilled labour increase from the first to the last row, in contrast to the signs in the column for low-skilled labour. As can be seen from Table 1b, clear positive or negative expected signs result only for the four corner elements of the matrix. This implies that a relative abundance of low-skilled labour is expected to be positively related to revealed comparative advantage of the labour-intensive sectors, and negatively related to revealed comparative advantage of the technology-intensive sectors. Moreover, a relative abundance of highly-skilled labour is expected to be positively related to revealed comparative advantage of technology-intensive sectors and negatively related to revealed comparative advantage of labour-intensive sectors. For the column of intermediate-skilled labour, and for the two rows of capital-intensive sectors, the expected signs are less evident.

7.5 Explaining trade performance by human capital endowments

One of the attractive features of the HOV model is that the pattern of relative factor endowments in each country determines the pattern of sectoral net exports from that country. For example, countries that are relatively capital abundant should have a surplus of net exports in the capital-intensive sectors. As has been discussed in Section 7.3, the variables in the model have to be scaled properly, resulting in equations (7.8a) and (7.8b). By estimating these equations, we can test to what extent the hypotheses formulated in Section 7.4 hold. The empirical analysis is applied to fourteen industrialized countries: eleven European Union member states, Japan, Canada and the USA (see Appendix 7.C). The reference year is 1985.

Tables 7.2a and 7.2b show the results of the OLS regression of the revealed comparative advantages per category of sectors[28] on the relative factor endowments per country, according to equations (7.8a) and (7.8b) respectively.[29]

The results in Table 7.2a, in particular the F-statistics, indicate that the estimated

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27. The difference between intermediate and high skills with regard to the diffusion effect was one of the empirical results of Chapter 6.

28. See Figure C.1 of Appendix 7.C for an impression of the RCAs of the four categories of sectors in the analysis.

29. As expected, the resource-intensive category of economic sectors, which is excluded from the analysis for the reason mentioned above, revealed very poor results. See Figure C.2 of Appendix 7.C for an impression of the RCAs of the resource-intensive category of sectors in the analysis.

equation (7.8a) is significant at the 5% level for these four categories of sectors. Moreover, the signs and the significance of the coefficients of the relative factor endowments generally confirm the hypotheses of Table 7.1a. However, the relative factor endowment of labour does not produce a significant result for any category of economic sectors, which may point to the relevance of distinguishing the various levels of human capital. On the other hand, the coefficient of the technological knowledge variable is, in accordance with the hypotheses, negative and significant for both the labour-intensive and the capital-intensive low/medium-tech economic sectors. The magnitude of the coefficient for the latter category is somewhat smaller, in line with the hypotheses. Furthermore, confirming the hypotheses, the estimated technological knowledge coefficients for the capital-intensive high-tech and the technology-intensive economic sectors are zero, and significantly positive respectively. Finally, the estimated coefficients for the physical capital variable are only significantly positive for the capital-intensive sectors of industry, which is again in accordance with the hypotheses of Table 7.1a. These results generally confirm the value of the HOV model for explaining net trade flows between industrialized countries.

Table 7.2a
Estimation results for four categories of economic sectors with different factor intensities, excluding skill levels (equation 7.8a)

Category	C	LAB_i	TEC_i	CAP_i	RCA_i	$\bar{R}^2$	F-stat
labour-intensive	-0.45 (-0.43)	0.36 (0.81)	-1.57 (-2.49)[b]	1.27 (1.51)	-0.03 (-0.07)	0.47	3.84[b]
capital-intensive, low/med.-tech	-0.34 (-0.37)	-0.29 (-0.76)	-1.20 (-2.14)[a]	1.73 (2.37)[b]	0.69 (1.62)	0.45	3.70[b]
capital-intensive, high-tech	-1.31 (-1.50)	-0.34 (-0.97)	0.19 (0.35)	1.66 (2.57)[b]	0.41 (1.23)	0.46	3.78[b]
technology-intensive	-1.74 (-2.72)[b]	0.21 (0.77)	0.79 (1.93)[a]	0.91 (1.73)	0.25 (0.87)	0.48	4.05[b]

Notes: The t-values are between brackets. The superscripts *a*, *b* and *c* indicate a significant coefficient at the 10%, 5% and 1% level respectively. *C* represents the constant term.

Table 7.2b shows the impact of the factor endowments of low-skilled, intermediate-skilled and highly-skilled labour on revealed comparative advantage, by estimating equation (7.8b) instead of equation (7.8a). It is immediately apparent that the $\bar{R}^2$ is higher for the labour-intensive and the technology-intensive categories of economic sectors. On the other hand, the $\bar{R}^2$ and the significance of the relative factor endowments for the two capital-intensive categories of sectors is lower.

In line with the hypotheses of Table 7.1b, the relative factor endowment of highly-skilled workers is significantly negatively, and significantly positively, related to the revealed comparative advantages of the labour-intensive and technology-intensive categories of sectors respectively. However, the relative factor endowment of low-skilled labour has, in contrast to what was expected, no significant impact on either the labour-intensive or the technology-intensive categories. Moreover, the results for the technology-intensive category of sectors are not exactly as expected, since estimating equation (7.8b) instead of (7.8a) reduces the effect of the relative factor endowment of technological knowledge to insignificance,[30] and increases the effect of the relative factor endowment of physical capital to a significant level.

Table 7.2b
Estimation results for four categories of economic sectors with different factor intensities, including skill levels (equation 7.8b)

Category	C	LSW_i	ISW_i	HSW_i	TEC_i	CAP_i	RCA_i	$\bar{R}^2$	F-stat
labour-intensive	0.64 (0.71)	0.21 (1.51)	−0.24 (−0.54)	−0.79 (−2.16)[a]	−1.19 (−2.35)[b]	0.87 (1.18)	0.30 (0.79)	0.68	5.61[b]
capital-intensive, low/med.-tech	0.03 (0.02)	−0.10 (−0.61)	−0.33 (−0.62)	−0.36 (−0.81)	−1.05 (−1.69)	1.67 (1.89)[a]	0.77 (1.59)	0.37	2.27
capital-intensive, high-tech	−1.49 (−1.53)	−0.13 (−0.88)	0.44 (0.84)	−0.04 (−0.11)	0.11 (0.19)	1.36 (1.78)	0.52 (1.36)	0.42	2.59
technology-intensive	−2.32 (−4.04)[c]	0.06 (0.69)	0.18 (0.63)	0.59 (2.53)[b]	0.57 (1.63)	1.13 (2.35)[b]	0.16 (0.65)	0.65	5.06[b]

Notes: See Table 7.2a

The results of Table 7.2a and 7.2b indicate that equation (7.8a) is to be preferred for the capital-intensive economic sectors, whereas equation (7.8b) is to be preferred for both the labour-intensive and technology-intensive sectors of industry. This implies that the human capital endowments of intermediate and highly-skilled labour do not have a significant impact on the trade performance of capital-intensive sectors. The estimations of Table 7.2a also imply that technological knowledge, partly embodied in R&D workers, does in general have the expected impact on the trade performance of the four categories of sectors. These results will be taken into account below, in testing at a more disaggregated level, by using equation (7.8a) for the capital-intensive sectors and equation (7.8b) for the labour-intensive and technology-intensive sectors. Tables 7.3a and 7.3b present the results of the respective estimations.[31]

30. Multicollinearity between human capital and technological knowledge is probably not the reason for this, since the correlation between *HSW* and *TEC* is insignificant (see Table C.2 in Appendix 7.C).

31. Once again, all resource-intensive sectors revealed very poor results, as expected.

Table 7.3a
Estimation results for the capital-intensive economic sectors, excluding skill levels (equation 7.8a)

Sector	*C*	LAB_i	TEC_i	CAP_i	RCA_i	$\bar{R}^2$	F-stat
Capital-intensive, low/medium-tech sectors							
paper and printing	1.41	0.36	-1.12	-0.80	2.64	0.50	4.24[b]
	(0.92)	(0.58)	(-1.22)	(-0.66)	(3.75)[c]		
rubber	-0.68	-0.61	-0.82	2.14	0.32	0.36	2.86[a]
	(-0.62)	(-1.37)	(-0.82)	(2.50)[b]	(0.65)		
plastic	0.25	-0.58	-1.74	1.67	0.28	0.44	3.52[b]
	(0.27)	(-1.56)	(-3.19)[c]	(2.35)[b]	(0.68)		
non-metallic minerals	0.06	-0.03	-1.72	1.66	-0.34	0.50	4.20[b]
	(0.07)	(-0.08)	(-3.11)[c]	(2.30)[b]	(-0.81)		
iron and steel basic metals	-1.99	-0.76	-0.99	3.70	-0.29	0.50	4.29[b]
	(-1.61)	(-1.50)	(-1.33)	(3.79)[c]	(-0.51)		
Capital-intensive, high-tech sectors							
industrial chemicals	-0.43	-0.21	1.07	-0.02	0.53	0.75	10.61[c]
	(-0.91)	(-1.11)	(3.56)[c]	(-0.04)	(2.94)[b]		
non-electrical machinery	-0.98	-0.22	0.58	0.90	0.03	0.27	2.21
	(-1.13)	(-0.61)	(1.06)	(1.40)	(0.08)		
electrical machinery	-1.47	-0.37	-0.27	2.06	-0.24	0.49	4.11[b]
	(-1.90)[c]	(-1.18)	(-0.54)	(3.60)[c]	(-0.81)		
transport equipment	-2.03	-0.52	-0.51	3.13	0.84	0.45	3.62[b]
	(-1.41)	(-0.88)	(-0.55)	(2.93)[b]	(1.51)		

Notes: Although the sector names are often equal to those used in Chapter 6, the industrial activities that are covered by these sectors need not to be exactly the same. See Appendix 7.A for the full description of the sectors. The t-values are between brackets. The superscripts *a*, *b* and *c* indicate a significant coefficient at the 10%, 5% and 1% level respectively. *C* represents the constant term.

All estimated equations presented in Table 7.3a are significant, except for the non-electrical machinery sector. The results for the capital-intensive economic sectors are in accordance with the hypotheses of Table 7.1a as far as the significant coefficients are concerned, although the estimation results of the paper and printing sector are not adequately explained by the relative factor endowments. For six of the nine capital-intensive economic sectors, the coefficient of relative factor endowment of physical capital is significantly positive, as expected. Also in accordance with the hypotheses of Table 7.1a, the coefficients for the low/medium-tech category are significantly negative for both the plastic and the non-metallic minerals sectors, while the coefficients for the high-tech category are significantly positive only for the industrial chemicals economic sector. However, the fact that most coefficients cannot be rejected against the null-hypothesis does not contradict the hypotheses of Table 7.1a.

Table 7.3b

Estimation results for the labour-intensive and technology-intensive economic sectors, including skill levels (equation 7.8b)

Sector	C	LSW_i	ISW_i	HSW_i	TEC_i	CAP_i	RCA_i	$\bar{R}^2$	F-stat
Labour-intensive sectors									
textile, apparel and	0.74	0.39	-0.43	-0.75	-1.59	0.88	0.17	0.81	10.36[c]
leather	(0.75)	(2.57)[b]	(-0.90)	(-1.87)[a]	(-2.86)[b]	(1.09)	(0.41)		
metal products	0.58	-0.11	0.24	-0.89	-0.58	0.77	0.46	0.37	2.28
	(0.63)	(-0.76)	(0.55)	(-2.39)[b]	(-1.12)	(1.03)	(1.17)		
other manufacturing	0.36	0.05	-0.28	-0.78	-0.70	0.97	0.53	0.12	1.29
	(0.28)	(0.27)	(-0.45)	(-1.50)	(-0.98)	(0.93)	(0.96)		
Technology-intensive sectors									
other chemicals	-0.50	-0.05	0.03	-0.18	1.09	0.02	0.29	0.74	7.01[c]
	(-1.03)	(-0.63)	(0.18)	(-0.94)	(3.70)[c]	(0.05)	(1.39)		
office machinery	-3.45	0.27	-0.00	1.35	1.23	0.91	0.16	0.35	2.15
	(-2.79)[b]	(1.42)	(-0.00)	(2.67)[b]	(1.63)	(0.88)	(0.30)		
radio and television	-4.58	0.04	0.52	0.70	-0.53	3.63	0.10	0.50	3.17[a]
equipment	(-3.22)[b]	(0.16)	(0.72)	(1.21)	(-0.62)	(3.06)[b]	(0.16)		
aircraft	1.94	-0.08	-0.47	0.11	0.77	-1.69	0.08	0.43	2.65
	(2.33)[b]	(-0.65)	(-1.12)	(0.32)	(1.51)	(-2.44)[b]	(0.23)		
professional goods	-2.16	0.07	0.62	0.63	1.12	0.18	0.22	0.78	8.60[c]
	(-3.99)[c]	(0.83)	(2.27)[a]	(2.84)[b]	(3.40)[c]	(0.40)	(0.94)		

Notes: See Table 7.3a

The results for the labour-intensive and technology-intensive economic sectors are presented in Table 7.3b. They reveal very strong results only for the textile, apparel and leather sector, the other chemicals sector and the sector of professional goods. Interpreting the results of the labour-intensive economic sectors, it can be concluded that the signs of the significant regression coefficients are in accordance with the hypotheses of Tables 7.1a and 7.1b. In particular, the regression of the textile, apparel and leather sector performs remarkably well, and in line with the hypotheses for the relative factor endowments of low-skilled labour, highly-skilled labour and technological knowledge. Moreover, the metal products sector reveals, as expected, a significant negative coefficient for the relative factor endowment of highly-skilled labour. On the other hand, the sector of other manufacturing shows a poor result, which may be because it is a heterogeneous residual sector.

In accordance with the hypotheses, the technology-intensive economic sectors reveal the importance of technological knowledge and highly-skilled labour in three out of five cases. The professional goods sector is the only economic sector for which an abundance of intermediate-skilled labour seems to matter. The significant results for the relative factor endowment of physical capital in the radio and television equipment sector and the aircraft sector are not in line with the hypotheses.[32] Moreover, relative abundance of low-skilled labour does not have the expected negative effect on revealed comparative advantage in the technology-intensive economic sectors.

7.6 Conclusions

The empirical results generally confirm the value of the HOV model (and the related neo-factor endowments model) for explaining net trade flows between industrialized countries. The empirical results suggest that it is worthwhile to consider country-specific relative factor endowments to explain sector-specific revealed comparative advantages, which are a measure of trade performance. Therefore the HOV model is an adequate framework for testing the relevance of country-specific human capital factors for the trade performance of sectors.

In line with the formulated hypotheses based on the four productivity effects of human capital in Chapter 5, the human capital endowments of highly-skilled labour and technological knowledge seem to have a significantly positive impact on the revealed comparative advantage of technology-intensive economic sectors, and a significantly negative impact on the revealed comparative advantage of labour-intensive sectors. Moreover, the factor endowment of highly-skilled labour seems to have at least as great an impact as the factor endowment of technological knowledge on the trade performance of technology-intensive economic sectors. However, in general the human capital endowment of intermediate-skilled labour has no significant impact in these sectors. For capital-intensive sectors the human capital endowments of intermediate-skilled and highly-skilled labour were not found to have a significant effect, whereas the relative factor endowment of physical capital was found, as expected, to have a significantly

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32. Specialization of countries in these relatively small 4-digit sectors may disturb the empirical analysis.

positive effect. On the other hand, technological knowledge has a significantly negative effect on the revealed comparative advantage of capital-intensive low/medium-tech economic sectors, which is according to expectations.

As stated in the introduction recent empirical research on international trade flows has cast considerable doubt on the explanatory power of the Heckscher-Ohlin-Vanek model. The relatively good empirical results in this chapter are, in our opinion, to a large extent due to the correct specification of the model, the method of double scaling, and the use of data for industrialized countries, which are probably more equal in their input-output coefficients than a mixed group of industrialized and developing countries.

Three further points should be noted with regard to the specification of the empirical model. First, the specification of the model follows directly from the theoretical exposition of the HOV model of Section 7.2. Therefore net trade flows between countries should be explained by country-specific factor endowments rather than by sector-specific factor inputs. Second, as has been argued in Section 7.1, the human capital factor endowments should be measured by the level of education of the workforce rather than by occupational categories. The fact that human capital was measured using occupational categories may account for the relatively poor results of human capital factor endowments in e.g. Leamer (1984). Third, the empirical results deny the proposition by Wood (1994a) that the international mobility of financial capital flows means that the factor endowment of physical capital should be excluded from the model. The empirical analysis of this chapter shows that the factor endowments of human capital and physical capital are important for the trade performance of economic sectors.

The suggested country-specificity of skilled labour, technological knowledge and physical capital may be due to different national educational systems, government technology policies and national capital investment climates respectively. Nevertheless, the results also indicate that country-specific relative factor endowments cannot explain more than about 40% to 80% of the variances in revealed comparative advantages at sector level. This may be due to measurement errors or some violations of the assumptions of the model. Moreover, the unexplained variance may plausibly be accounted for by sector-specific inputs that have been analysed in the previous chapter.

Appendix 7.A Classification of ISIC sectors

According to OECD (1987), economic sectors can be divided into five categories with different factor intensities, i.e., resource-intensive, labour-intensive, scale-intensive, differentiated goods, and science-based sectors. These categories of sectors are assumed to have different factor intensities, so that they can be used to develop hypotheses with regard to the relationship between relative factor endowments and revealed comparative advantages. However, the OECD (1987) admits that it is hard to distinguish the scale-intensive and differentiated goods sectors. Therefore both kinds of industry are classified in the capital-intensive sector. Moreover, in accordance with the neo-factor endowments theory, it is expected that technological knowledge will also matter. Therefore the OECD (1987) classification is combined with the classifications of OECD (1986) and Verspagen (1995), which distinguish between low-tech, medium-tech and high-tech sectors. Since data are available on only one capital-intensive low-tech sector (i.e. paper and printing, ISIC 3400), the classification will not distinguish between low-tech and medium-tech sectors. Moreover, both the science-based sectors distinguished by the OECD (1987) and the 'core-R&D' sectors distinguished by Verspagen (1995) are here called 'technology-intensive sectors'. The ISIC codes of the various economic sectors are as follows:

1. Resource-intensive sectors

1000	Agriculture, hunting, forestry and fishing
2000	Mining and quarrying
3100	Food, beverages and tobacco
3300	Wood and wood products, including furniture
3530	Petroleum refineries
3540	Miscellaneous products of petroleum and coal
3720	Non-ferrous metal basic industries

2. Labour-intensive sectors

3200	Textile, wearing apparel and leather industries
3810	Fabricated metal products, except machinery and equipment
3900	Other manufacturing industries

3. Capital-intensive, low/medium-tech sectors

3400	Paper and paper products, printing and publishing
3550	Rubber products
3560	Plastic products not classified elsewhere
3600	Non-metallic mineral products, except products of petroleum and coal
3710	Iron and steel basic industries

4. Capital-intensive, high-tech sectors

3510	Industrial chemicals
3820	Machinery except electrical, and excluding sector 3825
3830	Electrical machinery apparatus, appliances and supplies, excluding sector 3832

3840 Transport equipment, excluding sector 3845

5. Technology-intensive sectors

3520 Other chemical products
3825 Office, computing and accounting machinery
3832 Radio, television and communication equipment and apparatus
3845 Aircraft
3850 Professional, scientific, measuring, controlling equipment not classified elsewhere, photographic and optical goods

Appendix 7.B Data sources[33]

Net exports

The data for net exports per sector j of country i (T_{ji}) are drawn from the OECD's COMTAP database. Data are available for economic sectors at the two, three, and four-digit level of the International Standard Industrial Classification (ISIC, revision 2). As it is hard to find appropriate data on volumes of net trade, which is required by the HOV model, values of net trade are regarded as a proxy for the volumes. All net export values are expressed in terms of 1985 dollars (in thousands of dollars). Section 7.2 indicated the relevance of correcting the net exports per sector to allow for the country's trade imbalance. The share of the production of each good in total world production (compare Q_w/GDP_w of Section 7.2) would have to be known to correct for trade imbalances in the proper way. As no adequate data are available on this proportion, we have corrected for trade imbalances by adding, after double scaling, an overall trade balance variable to the independent factor endowment variables on the right-hand side of equation (7.7). The country's overall trade balance is the sum of its net sector exports from agriculture (ISIC 1000), mining (ISIC 2000) and manufacturing (ISIC 3000), minus the net exports of the category of sectors which the economic sector being considered belongs to (see Section 7.3).

Labour force

The labour force variable indicates the amount of labour available in a country. The Eurostat Labour Force Survey (1985) data are used for the various EC countries. These data are supplemented by the data from the *Year Book of Labour Statistics* (various issues) of the International Labour Office (ILO) for Canada, Japan and the United States. There are some minor differences in the definitions used in the two data sources, but these differences are not significant. The labour force is indicated as the 'economically active population' by the ILO.

Educational attainment

The human capital variables are distinguished by the educational attainment or "educational stock" of the population. A related indicator proposed by the OECD (*Employment Outlook*, 1989) is the distribution of the population over the levels of educational attainment, ranging from A (low) to E (high).[34] This distribution over levels of education is to a certain extent analogous to UNESCO's International Standard Classification for Education (ISCED). In particular, the ISCED levels 0/1 (pre-primary and primary education as highest achieved level) and 2 (lower secondary education as highest achieved level) correspond with the OECD definition of level A. Level A is defined as "completed less than upper secondary education" (OECD, 1989), which corresponds with "completed less than ISCED level 3." This level of education is called low-skilled in this paper. The 'highly-skilled' workers in the paper correspond to either

33. Unless stated otherwise, the reference year for the data used is 1985.

34. Level C is not part of the rank order A to E, it indicates only that a person has vocational skills at some level.

level D (higher non-university education) or level E (university education) in the OECD classification. A proxy for the share of intermediate-skilled workers in the labour force is the proportion of the population aged 25 to 64 years who completed an initial education beyond lower secondary education (ISCED level 2), but without achieving level D or E. This implies that workers with vocational education are counted as intermediate-skilled workers. As far as possible, data are drawn from the OECD's (1989) *Employment Outlook*. Additional data sources are the OECD's (1992b) *Education at a Glance*, UNESCO's (1992) *Statistical Yearbook* and Eurostat's (1991) *Labour Force Survey*.

The reference year for the educational data is 1987, except for Belgium (1986), Denmark (1988), France (1989), Ireland (1989), Greece (mean of 1981 and 1991) and the United States (1988). However, we do not expect that these differences between reference years will cause serious problems, since the educational attainment of an entire labour force does not generally change very much in the course of a few years.

Technological knowledge

The technology variable indicates the stock of technological knowledge embodied by R&D workers of a country, which can be approximated by the research and development intensity of a country. The R&D intensity is the R&D expenditures of both the government and the private sector, plus payments for imports of technological knowledge, divided by the gross domestic product. For Portugal the mean of the 1984 and 1986 R&D intensities was used. For Ireland the only figure available for imports of technological knowledge was for 1983. The fact that R&D expenditures instead of R&D stocks are used is, in our opinion, not a serious shortcoming since both R&D intensities and import intensities of technological knowledge are relatively constant over time at the national level. See the OECD's *Basic Science and Technology Statistics* and *Main Science and Technology Indicators*, from which the data are drawn.

Capital stock

The physical capital variable indicates the capital stock of a country. The capital stock measure equals the accumulated, depreciated sum of past gross domestic investments in producer durables, nonresidential construction and other construction. This capital stock measure is expressed in 1985 purchasing power parities, in millions of dollars. Data are drawn from Maddison (1991) and the OECD's *Penn World Table*, mark 5. The first source is only used for the Netherlands. Because there are no appropriate data available on the Portuguese capital stock, the Portuguese capital intensity (i.e. capital stock divided by employment) has been estimated using the GDP per worker and the R&D intensity.

Appendix 7.C Data of factor endowments and trade performance

Table 7.C.1 presents the relative factor endowments, which are calculated according to equation (7.5). The data sources used to calculate these relative factor endowments are mainly from the OECD and Eurostat, with 1985 as year of reference.[35]

The relative factor endowment of highly-skilled labour in West Germany is surprisingly low. This can be partly explained by the fact that vocationally skilled workers are considered as intermediate skilled workers (see Appendix 7.B). Moreover, due to double-scaling, countries with high income levels such as West Germany would have to have proportionally higher absolute factor endowments to reveal equal relative factor endowments as countries with low income levels. For this reason the relative factor endowments of highly-skilled labour in Greece and Ireland are very high. However, in the case of Ireland, the high relative factor endowments of highly-skilled labour and technological knowledge explain the high RCAs for the capital-intensive high-tech and the technology-intensive sectors (see Figure 7.C.1). Furthermore, the United States and Great Britain have very low relative factor endowments of physical capital, which is in line with the low capital per worker ratio in the *Penn World Table* relative to the income level in both countries.

Table 7.C.1
Relative factor endowments per country (1985)

country	LAB_i	LSW_i	ISW_i	HSW_i	TEC_i	CAP_i
Belgium (BEL)	1.05	1.80	0.56	0.55	1.03	1.34
Canada (CAN)	0.91	0.75	0.78	1.37	0.61	1.06
West Germany (DEU)	1.08	0.87	1.77	0.33	1.15	1.22
Denmark (DNK)	1.23	1.33	1.32	0.90	0.59	1.07
Spain (ESP)	1.41	2.52	0.83	0.43	0.34	1.12
France (FRA)	1.03	1.30	1.00	0.63	0.94	1.17
Great Britain (GBR)	1.24	1.87	0.80	0.86	0.97	0.79
Greece (GRC)	1.88	3.07	1.01	1.22	0.14	0.82
Ireland (IRL)	1.68	2.62	0.95	1.24	1.07	1.22
Italy (ITA)	1.02	1.91	0.58	0.22	0.49	0.97
Japan (JPN)	1.27	1.12	1.53	1.10	1.10	1.67
Netherlands (NLD)	0.99	1.34	0.80	0.68	0.99	1.21
Portugal (PRT)	2.78	6.18	0.60	0.48	0.23	1.00
United States (USA)	0.80	0.46	0.84	1.31	1.14	0.72

Sources: See Appendix 7.B. See Table 7.C.2 for the correlations between the relative factor endowments. The abbreviations of the countries in the sample are used again in Figures 7.C.1 and 7.C.2 below.

35. See Appendix 7.B for an extensive list of data sources.

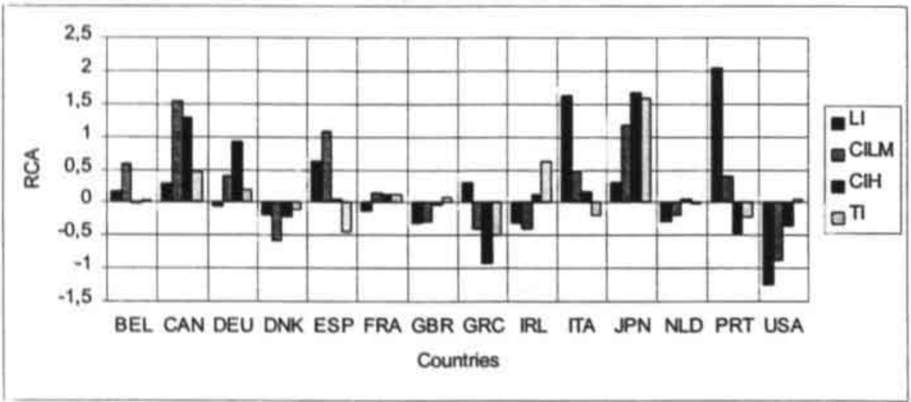
Table 7.C.2 presents the correlations between the relative factor endowments of Table 7.C.1. Although the shares of low skilled, intermediate skilled and highly-skilled workers are correlated, this correlation is strongly reduced due to the double scaling. From Table 7.C.2 it follows that only the correlations between LAB_i, LSW_i and TEC_i are significant, which may reduce the significance of these variables in the OLS estimation of Section 7.5.

Table 7.C.2
Correlations between the relative factor endowments

	LAB_i	LSW_i	ISW_i	HSW_i	TEC_i	CAP_i
LAB_i	1.00	0.96	-0.15	-0.08	-0.59	-0.10
LSW_i		1.00	-0.38	-0.25	-0.64	-0.17
ISW_i			1.00	0.09	0.34	0.42
HSW_i				1.00	0.14	-0.14
TEC_i					1.00	0.39
CAP_i						1.00

Note: Correlation coefficients are significant at 10% if they are larger than 0.46 or smaller than -0.46.

Figure 7.C.1
Revealed comparative advantages by four categories of economic sectors (1985)

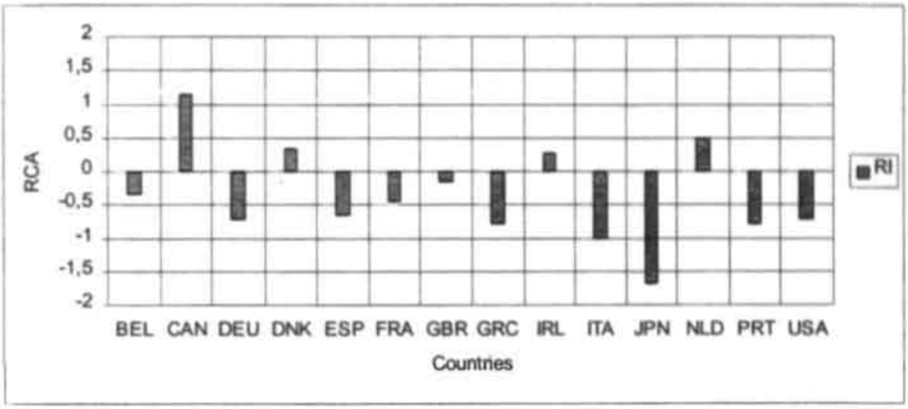


Sources: See appendix 7.B.
Notes: LI, CILM, CIH, TI stand for the labour-intensive, capital-intensive low/medium-tech, capital-intensive high-tech and technology-intensive categories of economic sectors respectively. See table 7.C.1 for the abbreviations of the country names. Note that the RCAs are not corrected for trade imbalances.

Figure 7.C.1 shows the revealed comparative advantages (RCAs) of the four categories of economic sectors for which the HOV model is tested.

Figure 7.C.2 presents the revealed comparative advantages of the resource-intensive category of sectors in the fourteen industrialized countries of our sample. The figure shows that only Canada, Denmark, Ireland and the Netherlands have a comparative advantage in the resource-intensive category of economic sectors. As would be expected, Japan has a strong comparative disadvantage in this category of economic sectors.

Figure 7.C.2
Revealed comparative advantages of the resource-intensive category of economic sectors (RI)



Sources: See Appendix 7.B.
Notes: See Table 7.C.1 for the abbreviations of the country names. Note that the RCAs are not corrected for trade imbalances.

Chapter 8

Country-specific and sector-specific determinants of Dutch trade performance[1]

8.1 Introduction

This chapter further analyses the impact of both country-specific and sector-specific factors on trade performance. Again the Heckscher-Ohlin-Vanek model is used as a starting point for the empirical analysis. As will be demonstrated, the results of an empirical analysis with a HOV model that uses sector-specific factor inputs should be interpreted carefully. In Chapter 7 the HOV model has been used to explain the trade performance of manufacturing sectors by country-specific factor endowments. Furthermore, in the Ricardian model of Chapter 6 sector-specific factor inputs explain the trade performance of manufacturing sectors. This chapter integrates both the country-specific and the sector-specific determinants of trade performance in a factor content analysis of Dutch trade. Instead of including only the manufacturing sectors as in the preceding chapters, the analysis covers all sectors in the Netherlands. Moreover, five production factors are distinguished, namely the human capital factors of low, intermediate and highly-skilled labour, and the physical capital factors of structures and producer durables.[2] The trade-revealed factor endowments and the sector-specific factor inputs of these production factors are calculated by taking account of their factor contents in net exports and domestic consumption.[3]

The method of calculating factor contents is largely based on the use of input-output (I-O) tables. The human capital content calculations in this chapter are based on Social Accounting Matrices (SAMs) of Statistics Netherlands, which contain detailed data on educational levels of labour inputs per industry (see Timmerman

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1. This chapter is partly based on Cörvers and Reininga (1996, 1998). Moreover, to avoid confusion note that the model used in this chapter is *not* related to the specific factors model.

2. Two factors of physical capital are included, since physical capital is less homogeneous than in the preceding chapters in which only the manufacturing sectors are included in the empirical analysis. For data reasons, a variable indicating technological knowledge could not be included in the analysis. Including this variable would probably not affect the conclusions of the chapter very much.

3. The sector classification used is listed in Appendix 8.A. Furthermore, Appendix 8.B discusses the construction of a matrix with the input-output requirements of 40 sectors, including the 17 manufacturing sectors, which is used for the calculation of the sector-specific factor inputs.

and Van de Ven, 1994). This data set is drawn from the Labour Accounts (LA) and is consistent with the input-output data of the National Accounts (NA). Also the latter accounts are constructed by Statistics Netherlands. The use of different accounts in the empirical analysis of this chapter illustrates one of the major advantages of SAMs as statistical tools: they make it possible to use statistical information from various sources.

The trade-revealed factor endowments of the above mentioned production factors are ranked according to their abundance within the Netherlands. This rank order can be compared to the rank order of the true factor endowments of these production factors in the Netherlands, which is a test of the HOV theorem for the Netherlands. The true factor endowments of the Netherlands represent the real availabilities of low, intermediate and highly-skilled labour and two components of physical capital, i.e. structures and producer durables, relative to those of 20 other industrialized countries. Furthermore, it will be shown that the impact of the sector-specific factor inputs on trade performance also reveals the abundances of the production factors only if all sectors of the Netherlands are included in the empirical analysis. Apart from considering the factor abundances at the country level, the relevance of the sector-specific factor inputs for the trade performance of the manufacturing sectors is analysed.

The remainder of the chapter is organized as follows. The next section discusses the background of factor content studies. Section 8.3 discusses the trade-revealed factor endowments and the true factor endowments for the five production factors mentioned above. The rank orders of true and trade-revealed factor endowments are compared in order to test the HOV theorem for the Netherlands. Section 8.4 discusses the input of sector-specific factors in the manufacturing sectors only, and carries out regression analyses to explain the trade performance of both manufacturing and non-manufacturing Dutch sectors by sector-specific factor inputs. Section 8.5 presents the conclusions.

8.2 Background of factor content studies

A major advantage of factor content analysis is that it requires less restrictive assumptions than an analysis based on the commodity version of the Heckscher-Ohlin theorem. The multidimensional case of the commodity version states that countries tend to export those goods which require relatively large inputs of their relatively abundant production factors and tend to import those goods which require relatively large inputs of the production factors in which they are relatively poor. This multidimensional case has been difficult to prove (Deardorff, 1982 and 1984) and does not generate clear or correct predictions about the trade flows of goods (Bowen and Sveikauskas, 1992). Moreover, in a factor content analysis, in contrast to an analysis based on the commodity version of the HOV theorem, the number of traded goods may be either equal to or larger than the number of production factors (as one would expect). Under this less restrictive assumption, the commodity composition of trade flows is not uniquely determined, whereas the factor services incorporated in the exports and imports are uniquely determined. In factor content analysis it is not even necessary to assume factor price equalization or identical and homothetic preferences (see e.g. Grossman and Helpman, 1992).[4]

As has been argued by for example Bowen et al. (1987) and Leamer (1992), a proper test of the HOV theorem necessarily involves the triad of trade, input-output requirements and factor endowments. The HOV theorem equates the factors embodied in a country's net exports, which are calculated by using factor input requirements, to the country's excess supplies of factor endowments. As mentioned in Chapter 7, some empirical studies conclude that the HOV theorem offers a good explanation of international trade flows, whereas other empirical studies cast considerable doubt on the explanatory power of the HOV theorem. Contrary to most other empirical studies, the study by Bowen et al. (1987) really tests the HOV theorem by separately measuring trade, input-output requirements and factor endowments. Bowen et al. find a poor performance of the HOV model and mentions two possible reasons for that. Firstly, countries may have different input-output requirements (i.e. technological differences). As the HOV theorem assumes identical input-output requirements between countries, this may seriously affect the results. However, input-output requirements are relatively similar for industrialized countries, between which the majority of world trade takes place (see OECD, 1987 and CPB, 1993). Secondly, measurement errors in either the factor contents or the factor endowments may seriously affect the outcomes of the empirical analysis (see also Bowen et al., 1987). Therefore the human and physical capital contents of net trade, production and consumption are carefully calculated in this chapter by using e.g. social accounting matrices and basic prices. This is described in Appendix 8.B (see also Deardorff, 1984, for a description of the technique).

Factor content analysis has been used as a valuable tool to obtain empirical evidence of the impact of human capital on trade performance in, e.g., Clifton and Marxsen (1984), Webster (1993), Maskus et al. (1994), Reininga (1994) and Webster and Gilroy (1995). However, only Webster (1993) and Reininga (1994) measure human capital by distinguishing educational categories of labour, which has to be preferred instead of measuring human capital by discounted sector-wage differentials (see Chapter 2) or by distinguishing occupational categories of labour (see Chapter 7). Moreover, factor content studies of Dutch trade give ambiguous results with regard to the relevance of human and physical capital for Dutch trade. Hamilton and Svensson (1984) and Bowen et al. (1987) calculate the factor content of trade flows for many countries, including the Netherlands. They apply the input-output requirements of Sweden and the United States, respectively, to the Netherlands. The former study shows that the capital content of Dutch exports is larger than the capital content of Dutch imports, for bilateral trade flows between the Netherlands and the main regions in the world during the period 1970 to 1980.[5]

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4. As mentioned in Chapter 7, most other assumptions of the HOV model can be relaxed without changing the implications of the model.

5. This does not hold for the trade of the Netherlands (and most other countries) with Latin America in the Hamilton and Svensson (1984) study.

Unfortunately this study does not distinguish between physical and human capital.[6] The study by Bowen et al. (1987) shows that, if trade flows are corrected for the Dutch trade balance deficit, the Netherlands imports the factor services of physical capital and exports the factor services of seven different occupational categories of labour in 1967.[7]

To clarify the theoretical framework of the factor content studies, the same initial analysis as in Chapter 7 is required. Net exports of country *i* equal the difference between production and consumption, $T_i = Q_i - C_i$, in which *T*, *Q* and *C* represent the *n*x1 vectors of net trade (i.e. exports minus imports), production and consumption, respectively,[8] and where *n* represents the number of goods that are internationally freely mobile. Pre-multiplying the last equation with the *mxn* input-output matrix *A*, in which *m* represents the number of production factors that are internationally perfectly immobile, leads to an equation in which factor services embodied in net exports are equal to the difference between the supply of factor services and the use of factor services, thus $AT_i = A(Q_i - C_i)$. Define F_i as the *m*x1 vector of factor services of net trade, which equals AT_i by definition. Subsequently, define V_i as the vector of factor endowments, which equals AQ_i by definition. Finally, due to the above assumptions, the factor content of consumption equals the share β_i that country *i* uses from the *m*x1 vector of total world factor endowments, V_w. Moreover, this share equals the share of national income, corrected for the trade balance B_i, in total world income. In other words, $\beta_i = (GDP_i - B_i)/GDP_w$. If the above definitions and results are substituted into equation (7.1), this leads to equation (8.1) for a particular production factor *k*.

$$F_{ki} = V_{ki} - \frac{(GDP_i - B_i)}{GDP_w} V_{kw} \tag{8.1}$$

This equation can be rewritten as follows:

$$\frac{F_{ki}/V_{kw}}{GDP_i/GDP_w} - \frac{B_i}{GDP_i} = \frac{V_{ki}/V_{kw}}{GDP_i/GDP_w} - 1 \tag{8.2}$$

The right-hand side of this equation reflects the *relative true factor endowments* of country *i*, which will be used in Section 8.3 to calculate the Dutch factor endowments of human and physical capital relative to twenty other industrialized countries. If the right-hand side is positive for a particular factor *k* in country *i*, then

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6. Hamilton and Svensson (1984) calculate the factor content by using the labour productivity level. They assume that the labour productivity level measures the sum of human and physical capital intensity.

7. Another interesting factor content analysis of the Netherlands by Reininga (1994) will be discussed below.

8. In this chapter we refer to the terms production and (domestic) consumption instead of the empirically correct terms value added and domestic final use respectively, since the use of the former terms is common practice in factor content studies.

the country has a true abundance of this factor. This is similar to the implications of equation (7.5) in Chapter 7. The left-hand side of the equation reflects the *trade-revealed factor endowments* indicated by a country's net trade, and will be used for the factor content analysis of this chapter. If the left-hand side of equation (8.2) is positive, then country *i* has a revealed abundance of this factor. This implies that country *i* has a revealed comparative advantage in goods that make intensive use of factor *k*. The left-hand side of the equation is corrected for the trade balance, so that a country with for example a positive trade balance has both positive and negative trade-revealed factor endowments. The relationship between the true factor abundance and the trade-revealed factor abundance is a consequence of the HOV theorem, which implies that countries that have an abundance of a particular production factor *k* should have net exports of the factor services of factor *k*.

From the left-hand side of the equation, it follows that a country is more abundant in factor *k* than in factor *k'* if the following inequality holds.

$$\frac{F_{ki}}{V_{kw}} > \frac{F_{k'i}}{V_{k'w}} \tag{8.3}$$

Since $V_{ki} = (AC)_{ki} / \beta_i$ and $(AC)_{ki}$ represents the domestic consumption of factor *k*, which is renamed D_{ki} for convenience, inequality (8.3) can be rewritten to give the inequality that will be used in the empirical analysis of this chapter.

$$\frac{F_{ki}}{D_{ki}} > \frac{F_{k'i}}{D_{k'i}} \tag{8.4}$$

Inequality (8.4) implies that if the ratio of the factor content of net trade to the factor content of domestic consumption, for a production factor *k* such as highly-skilled workers, is larger than the same ratio for production factor *k'*, for example low-skilled workers, then highly-skilled workers are more abundant than low-skilled workers in country *i*. The rank order of the factor content ratios of net trade relative to consumption indicates the revealed factor abundances of the production factors within a country: the larger the ratio, the larger the revealed factor abundance.

In contrast to the two above mentioned empirical studies, Reininga (1994) uses Dutch input-output data. He finds that in 1990 the Dutch export/import ratio for the factor content of human capital hardly differs from the ratio for homogeneous labour, from which he concludes that the Dutch economy is not as human capital intensive as would be expected. Reininga (1994) also finds the unexpected result that Dutch exports are less intensive in physical capital than Dutch imports. However, his empirical analysis follows the same approach as Leontief's (1953), who compares the physical capital intensity of exports to the physical capital intensity of imports. On the contrary, equation (8.4) above shows that the factor intensity of net exports should be compared to the factor intensity of consumption to reveal factor abundance of physical capital.

It is relatively easy to show that the factor abundance condition of inequality (8.4) is only similar to that of Leontief (1953) if the important condition is satisfied that the net exports of the factor services of factor *k* are opposite in sign to the net exports of the factor services of factor k' (see also Leamer, 1980). Suppose that factor k is more abundant than factor k'. By definition F_{ki} equals $X_{ki} - M_{ki}$ and $F_{k'i}$ equals $X_{k'i} - M_{k'i}$, with X representing the factor (k or k') content of exports and M representing the factor (k or k') content of imports. Under the condition that F_{ki} and $F_{k'i}$ are opposite in sign, it follows that $X_{ki} - M_{ki} > 0$ and $X_{k'i} - M_{k'i} < 0$.[9] Thus, $X_{ki}/M_{ki} > 1$ and $X_{k'i}/M_{k'i} < 1$, and therefore $X_{ki}/M_{ki} > X_{k'i}/M_{k'i}$. This results in Leontief's factor abundance inequality (8.5).

$$\frac{X_{ki}}{X_{k'i}} > \frac{M_{ki}}{M_{k'i}} \tag{8.5}$$

Suppose that factor k represents physical capital and factor k' represents labour, as in Leontief's study. If the factor services of physical capital embodied in net exports are positive and the factor services of labour embodied in net exports are negative, then the above inequality, which is used by Leontief, implies that the capital per man embodied in exports exceeds the capital per man embodied in imports. Leontief finds that the physical capital intensity of exports is smaller than the physical capital intensity of imports for the United States in 1947, which is contrary to the expectations and is known as the *Leontief paradox*. However, if the assumption that the factor services of factor k embodied in net exports are opposite in sign to the factor services of factor k' embodied in net exports is not satisfied, the Leontief inequality (8.5) is not the proper test of the HOV theorem. Indeed, the condition that the factor services of physical capital and labour embodied in net exports are opposite in sign, is not satisfied for the 1947 US data in Leontief's study, nor for the 1990 Dutch data in the study by Reininga (1994).[10] In other words, for these studies it holds that even if physical capital is revealed to be abundant relative to labour according to inequality (8.4), the capital intensity of exports can be smaller than the capital intensity of imports. Leamer (1980) solves the Leontief paradox by rewriting inequality (8.4)[11] and showing that the physical capital intensity of net exports is larger than the physical capital intensity of consumption for the 1947 US data used in Leontief's empirical analysis. Since Reininga (1994) follows Leontief (1953), Reininga's conclusions with regard to the human and physical capital content of Dutch trade may be wrong for the same reason.[12]

9. Remember that factor k is more abundant than factor k'.

10. Reininga (1994) confirms the Leontief paradox for the Netherlands, which implies that the Netherlands imports capital-intensive goods and exports labour-intensive goods. This is analogous to the results for the United States in Leontief's study.

11. Inequality (8.4) can be easily rewritten by dividing both sides by $F_{k'i}$ and multiplying both sides by D_{ki}. Since the United States is a net exporter of both capital and labour services in 1947, inequality (8.4) is not changed by negative multiplication.

12. This also holds for the study by Hamilton and Svensson (1984).

8.3 True versus trade-revealed factor endowments

Factor content analysis of trade refers to measures of trade-revealed factor endowments, which is based on the left-hand side of equation (8.2). The right-hand side of equation (8.2) measures the true factor endowments. Both methods of measuring the factor endowments of a country are examined in this section. The factor content analysis includes the 40 sectors of the whole Dutch economy, including the 17 manufacturing sectors.[13] The true factor endowments of the Netherlands are calculated relative to 20 OECD countries. For this reason the true factor endowments are called the relative true factor endowments. Equation (8.2) indicates that the two definitions of factor abundances must correspond to each other. If the factor contents of trade flows are not in line with the relative true factor endowments then the HOV theorem must be rejected. By using data at the country level this section shows the abundant and scarce factor endowments of the Netherlands, and whether the HOV theorem is confirmed or rejected for the case of the Netherlands.

The data used for the two methods of measurement are different from each other, with regard to both sources and definitions.[14] Firstly, the relative factor endowments of low-skilled, intermediate-skilled and highly-skilled labour are calculated from the OECD data (1992, 1993) and refer to the level of educational attainment of the whole population between 15 and 64 years old. The factor content data are drawn from national statistics (see Appendix 8.B) and refer to the wage sum of the three skill categories of the working population.[15] Secondly, relative factor endowments of physical capital (producer durables and structures) are calculated from the Penn World Tables (mark 5.6) and refer to the stock of physical capital. On the contrary, factor content analysis uses depreciation flows drawn from Dutch national statistics.

True factor endowments

Table 8.1 presents the true factor endowments of low-skilled, intermediate-skilled and highly-skilled labour, producer durables and structures for the Netherlands relative to 20 OECD countries. The right-hand side of equation (8.2) indicates that

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13. See Appendix 8.A for the sector classification that is used in this chapter. This sector classification is based upon the SBI classification of Statistics Netherlands, which is compatible with the International Standard Industrial Classification of All Economic Activities (ISIC).

14. The reference year of the data used for the true factor endowments is 1990, whereas it is 1991 for the data used for the factor content ratios. This is not considered to be a problem, since factor endowments and trade patterns generally change only slightly over time.

15. Nevertheless, the definitions of the levels of educational qualifications are similar in the two data sources. Low-skilled labour refers to ISCED 0/1/2, intermediate-skilled labour refers to ISCED 3 and highly-skilled labour refers to ISCED 6/7. See OECD (1995) for the Dutch educational system in an international context.

the relative true factor endowments, $(V_k/V_{kw})/(GDP_k/GDP_{kw})$,[16] will be larger than one where there is factor abundance. Table 8.1 shows that only low-skilled labour is abundant in the Netherlands. A relative true factor endowment smaller than one indicates factor scarcity, so that we can conclude from Table 8.1 that intermediate-skilled labour, highly-skilled labour and structures are scarce in the Netherlands. Moreover, the endowment of producer durables is neither abundant nor scarce in the Netherlands, since the relative true factor endowment of producer durables equals one.

Table 8.1
True factor endowments of low, intermediate and highly-skilled labour, structures and producer durables for the Netherlands, relative to 20 other countries, 1990

relative true factor endowment	value	ranking
low-skilled	1.14	1
intermediate-skilled	0.83	3
highly-skilled	0.81	5
structures	0.82	4
producer durables	1.00	2

Sources and notes: See Table 8.C.1 in Appendix 8.C.

The rank order of the relative true factor endowments for the Netherlands is (from high to low): low-skilled labour, producer durables, intermediate-skilled labour, structures, highly-skilled labour. The differences between the last three relative true factor endowments are very small, whereas the relative true factor endowments of producer durables and in particular low-skilled labour are considerably larger.

Trade-revealed factor endowments

As indicated by equation (8.4), the larger the ratio between the factor content of net trade and the factor content of domestic consumption for a given production factor in a country, the larger the trade-revealed factor endowment of the production factor.[17] Although the factor content ratios do not indicate factor abundance or factor scarcity, they indicate the rank order of production factors with regard to their

16. National income is measured by Gross Domestic Product (1990 international prices).

17. The trade-revealed factor endowments of the Netherlands are based on net trade, which equals the exports to the rest of the world minus the imports from the rest of the world. However, the true factor endowments presented above are calculated relative to 20 other OECD countries instead of all countries of the rest of the world. This is not considered as a problem, since 83% of Dutch imports originated from OECD-countries and 89% of Dutch exports went to OECD-countries in 1990 (CBS, 1990).

factor abundance within a country.[18] The ranking of the Dutch factor content ratios is presented for low, intermediate and highly-skilled labour and for two types of physical capital. For a more comprehensive analysis, the three skill levels of labour are also disaggregated to the seven levels of educational qualifications that are typical for the Netherlands.

Table 8.2 shows the factor content ratios of net exports relative to domestic consumption of all sectors of the Dutch economy. The factor ratios show that the rank order from the most abundant to the least abundant production factor in the Netherlands is as follows: producer durables, low-skilled labour, intermediate-skilled labour, structures, highly-skilled labour.[19] Note that producer durables has by far the largest factor content ratio and low-skilled labour has the largest factor content ratio of the labour content ratios.

Table 8.2
Dutch factor contents (millions of guilders) of net exports (*F*) and domestic consumption (*D*), for three skill levels, all sectors, 1991

Production factor (*k*)	F_k	D_k	F_k/D_k	ranking
low-skilled	13,149	50,440	0.261	2
intermediate-skilled	15,166	79,379	0.191	3
highly-skilled	6,828	56,402	0.121	5
structures	2,696	18,820	0.143	4
producer durables	8,322	20,803	0.400	1

Table 8.3 presents the shares of low, intermediate and highly-skilled labour in the total factor content of both net exports and domestic consumption. The table shows the low share of low-skilled labour in Dutch net exports and the relative significance of highly-skilled labour in Dutch domestic consumption. Moreover, the share of the factor content of intermediate-skilled labour in the total labour content of net exports is the same as the share of intermediate-skilled labour in the total labour content of domestic consumption.

18. In this chapter the trade-revealed factor endowments only have a ranking according to their factor abundance, whereas a relative true factor endowment larger than one indicates factor abundance and a relative true factor endowment smaller than one indicates factor scarcity.

19. Remind that the absolute abundance cannot be determined by the ranking of the factor content ratios.

Table 8.3
Dutch factor content shares of low, intermediate and highly-skilled labour in the total labour content of net exports (F) and domestic consumption (D), all sectors, 1991

Skill category	F	D
low-skilled	0.37	0.27
intermediate-skilled	0.43	0.43
highly-skilled	0.19	0.30
total	1.00	1.00

Table 8.4 shows results similar to those in Table 8.2, except that the three human capital factors have been disaggregated into seven educational categories of labour. The ratios are high for producer durables, primary education (BO), junior secondary vocational education (VBO) and junior general secondary education (MAVO), and low for higher vocational education (HBO) and university education (WO). The table shows moderate factor content ratios for senior general secondary education and pre-university education (HAVO/VWO), for senior secondary vocational education (MBO) and for the structures component of physical capital.

Table 8.4
Dutch factor contents (millions of guilders) of net exports (F) and domestic consumption (D), for seven educational categories, all sectors, 1991

Production factor (k)	F_k	D_k	F_k/D_k	ranking
low-skilled				
BO	4,091	14,332	0.285	2
MAVO	2,208	10,648	0.207	4
VBO	6,850	25,461	0.269	3
intermediate-skilled				
HAVO/VWO	1,570	8,336	0.188	6
MBO	13,596	71,042	0.191	5
highly-skilled				
HBO	4,654	35,787	0.130	8
WO	2,175	20,614	0.106	9
physical capital				
structures	2,696	18,820	0.143	7
producer durables	8,322	20,803	0.400	1

Note: BO = primary education, MAVO = junior general secondary education, VBO = junior secondary vocational education, HAVO = senior general secondary education, VWO = pre-university education, MBO = senior secondary vocational education, HBO = higher vocational education, WO = university education.

With regard to the ranking of the ratios of the factor services of net exports to domestic consumption, the disaggregated educational categories of labour perfectly fit in the classification of low, intermediate and highly-skilled labour. This illustrates that a more disaggregated analysis does not provide additional information and that the classification of low, intermediate and highly-skilled labour is well chosen.

Comparison of true and trade-revealed factor endowments

The next step of the analysis is to compare the rank order of the relative true factor endowments, which is shown in Table 8.1, to the rank order of the trade-revealed factor endowments, which is shown in Table 8.2. Comparing these rank orders shows that both rank orders are identical, except that the rankings of producer durables and low-skilled labour are switched. Moreover, the relative true factor endowment of producer durables in Table 8.1 does not indicate a true factor abundance, since it equals one, whereas producer durables has the largest trade-revealed factor abundance. To test the correlation between the rank order of the relative true factor endowments on the one hand, and the rank order of the trade-revealed factor endowments on the other, the Spearman's rank correlation coefficient is calculated. This rank correlation coefficient equals 0.9 and is significant at the 5% level (one-tail test).[20] Therefore the null hypothesis of no correlation between these rank orders is rejected at the 5% significance level, against the alternative that the correlation between the relative true factor endowments and trade-revealed factor endowments is positive. It follows that the HOV theorem is confirmed for the case of the Netherlands.

Since producer durables is the most abundant trade-revealed factor endowment in the factor content analysis of Table 8.2, and the relative true factor endowment of producer durables is considerably larger than the relative true factor endowments of intermediate-skilled labour, highly-skilled labour and structures in Table 8.1, we conclude that the Netherlands is abundant in producer durables. From the results of both measurement methods of factor abundance it may be concluded that low-skilled labour is also abundantly available. Furthermore, from Tables 8.1 to 8.3 it follows that the trade performance of the Netherlands, measured by exports minus imports, is dependent on the country-specific scarcity of intermediate-skilled labour, highly-skilled labour and structures. With regard to the human capital endowments, this implies that the Netherlands has a comparative advantage in goods that make intensive use of low-skilled labour, and a comparative disadvantage in goods that make intensive use of intermediate and highly-skilled labour.

20. See James and Elmslie (1996) for a similar analysis to test the HOV model in the G7-countries (Canada, France, West-Germany, Italy, Japan, UK and US). Five of the seven countries have a significant correlation of the two rank orders at the 10% level. Only in France and Italy the correlations are found to be inconsistent with the HOV model.

8.4 Using the HOV model with sector-specific factor inputs

This section illustrates the significance of sector-specific factors for trade performance in two ways. Firstly, the factor content analysis of the last section is repeated by including the factor content of net exports and domestic consumption of the manufacturing sectors only. Secondly, two regression analyses based on the HOV model are carried out to explain how the trade performance of Dutch sectors is related to the input of sector-specific factors.

Factor content analysis for the manufacturing sectors

Table 8.5 shows the factor content calculations of net exports and domestic consumption for the 17 manufacturing sectors of the Netherlands (see Appendix 8.A). Contrary to the factor content ratios of the entire economy, the factor content ratios of the manufacturing sectors are larger than one. This implies that the manufacturing sectors of the Netherlands are more involved in export activities than the average Dutch sector. Moreover, the ranking of the factor content ratios for the manufacturing sectors is very different from the ranking of the factor content ratios when all sectors of the Dutch economy are included. Highly-skilled labour takes the first instead of the last position, which is now taken by low-skilled labour. The rankings of the other three factors shift one position. Although highly-skilled labour is relatively scarce in the Netherlands, the manufacturing sectors make intensive use of highly-skilled labour for the production of export goods relative to the production of goods that are consumed domestically. Highly-skilled labour clearly is an important factor input for the trade performance of the manufacturing sectors.

Table 8.5
Dutch factor contents (millions of guilders) of net exports (F) and domestic consumption (D), manufacturing sectors, 1991

Production factor (k)	F_k	D_k	F_k/D_k	ranking
low-skilled	7,089	5,976	1.186	5
intermediate-skilled	8,664	7,045	1.230	4
highly-skilled	4,563	2,977	1.532	1
structures	1,423	1,093	1.301	3
producer durables	3,992	2,876	1.388	2

Table 8.6 shows the factor content shares of low, intermediate and highly-skilled labour in the total labour content of net exports and domestic consumption for the manufacturing sectors. The factor content shares of net exports relative to domestic consumption reflect the factor content ratios for the manufacturing sectors in Table 8.5. Therefore the factor content share of highly-skilled labour in net exports is larger than its factor content share in domestic consumption. Conversely, the factor

content shares of low and intermediate-skilled labour in the net exports in the manufacturing sectors are lower than the shares in the factor content of domestic consumption. This is opposite to the factor content shares of low, intermediate and highly-skilled labour in net exports relative to domestic consumption of the total economy (see Table 8.3 of the previous section).

Table 8.6
Dutch factor content shares of low, intermediate and highly-skilled in total labour content of net exports (*F*) and domestic consumption (*D*), manufacturing sectors, 1991

Skill category	*F*	*D*
low-skilled	0.35	0.37
intermediate-skilled	0.43	0.44
highly-skilled	0.22	0.19
total	1.00	1.00

The above analysis of the manufacturing sectors shows that highly-skilled labour and producer durables are intensively used in net exports relative to domestic consumption. Thus highly-skilled labour and producer durables are important factor inputs for the trade performance of the Dutch manufacturing sectors. However, the analysis also shows that judging factor abundances by calculating the factor contents of net exports and domestic consumption in the manufacturing sectors can lead to completely wrong conclusions. In other words, the factor contents of net exports and domestic consumption of the manufacturing sectors give information on the contribution of sector-specific factor inputs to trade performance rather than on the abundance of trade-revealed country-specific factor endowments.

Explaining trade performance by sector-specific factor inputs

Many empirical studies that use the Heckscher-Ohlin framework explain net trade by sector-specific factor inputs, e.g. capital intensities of physical and human capital, instead of country-specific factor endowments (see Chapter 7). Moreover, in Chapter 7 it has been proved that the net trade of manufacturing sectors is dependent on country-specific factor endowments rather than on sector-specific factor inputs. For the Netherlands an analysis with sector-specific inputs as explanatory variables for trade performance is carried out by Fortune (1976), Koekkoek et al. (1978) and Hulsman-Vejsová and Koekkoek (1980). These studies carry out a cross-section regression analysis of Dutch manufacturing sectors to reveal the comparative advantages of the Dutch industry. The results of these and other studies on Dutch comparative advantage, reviewed by Koekkoek and Mennes (1984), often point to different and sometimes even opposite conclusions with respect to the revealed comparative advantage of the Dutch manufacturing sectors.[21] As is defined before, a country has a revealed comparative advantage in the production of a good (represented by a sector), if the country has an abundance of the production factor that is used intensively for the production of that good. Based on their review of studies Koekkoek and Mennes (1984) conclude that, among other things, the Dutch manufacturing sectors have a revealed comparative advantage in skill-intensive products, whereas the physical-capital intensity does not contribute to the revealed comparative advantage of the Dutch manufacturing sectors.

Table 8.7 presents the results of the regression analyses that regress the vector of net exports T_{Bi} (see Section 7.2), which is adjusted for trade imbalance, on the input-output requirements of matrix A. Bowen and Sveikauskas (1992) refer to three issues that are relevant when estimating cross-section regressions. Firstly, the reliability of the estimated coefficients as indicators of revealed factor abundance improves if net exports per sector are corrected for the trade imbalance. This correction has been made for each of the 40 sectors by subtracting a weighted share of the trade balance surplus of the Netherlands from the net exports of each sector. The weighted shares equal the weights of domestic consumption of the sector in total domestic consumption (see also Section 7.2). The signs of most of the estimated coefficients in the regression analyses of Table 8.7 do not change as a result of adjusting net exports in this way. Secondly, it is not clear in advance whether or not the constant term should be included in the regression analysis. Following Bowen and Sveikauskas (1992) we include a constant term. This term measures the level of net trade (imports) when there is no domestic production, in which case the factor inputs are zero. Therefore the sign of the constant term is expected to be negative. Thirdly, according to Bowen and Sveikauskas many sources of heteroscedasticity may exist. A general test for the assumption of homoscedasticity of the error terms is the White test. In case of the usual ordinary least squares (OLS) regression of the above mentioned specification this test does not indicate heteroscedasticity.[22] By conducting the Park test and the Goldfeld-Quandt test (see e.g. Gujarati, 1988) for each of the explanatory variables, it is found that the heteroscedasticity of the error terms is significantly dependent on the physical capital measure of producer durables. Since other sources of heteroscedasticity may also exist, we follow Bowen and Sveikauskas and use a covariance matrix that is heteroscedasticity consistent

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21. For clarification purposes Koekkoek and Mennes refer to the differences in these studies with respect to the explanations of the structure of international trade, the aims of the studies, the measurements of relevant concepts, the use of the sets of explanatory variables, and finally the definition of revealed comparative advantage. Even Koekkoek and Mennes themselves draw conclusions about the revealed comparative advantage of the manufacturing sectors in the Netherlands without saying what they exactly mean by revealed comparative advantage.

22. The White heteroscedasticity test is also a general test for model misspecification. Therefore the non-significant result for the White test indicates that the omission of land input and other natural resources as explanatory variables does not seriously hamper the results of Table 8.7. See White (1980) for both the White test and the White covariance matrix.

(White covariance matrix). In general this improves the significance of the estimated coefficients in our regression analyses.

The first column of Table 8.7 presents the results of the regression analysis with sector-specific factor inputs as the explanatory variables for the trade performance of the manufacturing sectors. Analogous to the analysis of the rank order of factor abundances for the manufacturing sectors that has been carried out above, the signs of the estimated coefficients should not be interpreted as an indication of factor abundance or scarcity. The estimated coefficients merely indicate that the use of producer durables and the use of highly-skilled labour are significantly and positively related to trade performance, whereas the use of low and intermediate-skilled labour is significantly and negatively related to trade performance. In other words, manufacturing sectors in the Netherlands that make intensive use of producer durables and highly-skilled labour instead of low-skilled labour, are expected to have large positive net trade flows. These findings confirm the results of the factor content analysis for the sample of manufacturing sectors in Tables 8.5 and 8.6. It is also in accordance with the results of Table 8.5 that the physical capital variable measuring structures is not significant for the manufacturing sectors, whereas the finding that the constant term is significantly negative is according to the above mentioned expectation. Moreover, the estimated equation is significant at the 1% level, whereas 75% of the variance of net exports is explained by the sector-specific factor inputs.

Table 8.7

Estimated indicators of trade-revealed factor endowments: net exports per sector adjusted for trade imbalance regressed on the sectoral input-output requirements, 1991

	manufacturing sectors	all sectors
constant	-2,185	-206
	(2.17[a])	(0.17)
low-skilled labour	-146,187	8,707
	(3.07[b])	(1.69[a])
intermediate-skilled labour	-159,634	-38,244
	(2.15[a])	(2.60[b])
highly-skilled labour	209,606	-14,506
	(2.83[b])	(2.23[b])
structures	270,652	-80,422
	(0.47)	(4.98[c])
producer durables	706,595	180,755
	(3.07[b])	(4.07[c])
$\bar{R}^2$	0.75	0.24
F-stat.	10.66[c]	3.40[b]
observations	17	40

Notes: The absolute t-values are between brackets. The t-values are calculated by using a heteroscedasticity consistent covariance matrix. The superscripts *a*, *b* and *c* indicate a significant coefficient at the 10%, 5% and 1% level respectively.

Bowen and Sveikauskas (1992) show that if the vector of net exports T_{Bi} is regressed on the input-output requirements (given by matrix A), the signs of the estimated coefficients indicate the revealed factor abundances of the respective production factors. In Chapter 7 it has been noted that such a regression analysis is not theoretically correct. However, provided that all sectors of a country's economy are included in the regression analysis, this theoretical concern seems to be of little empirical importance. This implies that the positive and negative signs of the estimated coefficients can be used as reliable indicators of revealed factor abundance and scarcity respectively if all sectors are included in the regression analysis. This finding of Bowen and Sveikauskas validates the use of sector-specific factor inputs to explain sectoral trade performance in the empirical studies on Dutch trade performance and in the empirical studies mentioned in Chapter 7, although these studies failed to correct properly for trade imbalances. Another point of interest is that many of these studies only include a selection of sectors in the cross-section regression analysis. This may lead to wrong conclusions, as will be shown below.

An important advantage of the cross-section regression analysis is that a positive (negative) sign of the estimated coefficients in the regression analysis reflects a trade-revealed factor abundance (scarcity) of the production factor (Bowen and Sveikauskas, 1992), while the factor content ratios that are found in the analysis at the country level in the previous section only indicate the rank order of factor abundances. To reveal the factor abundances and scarcities of each production factor the adjusted net exports are regressed on the input-output requirements of low, intermediate and highly-skilled labour, and structures and producer durables. These input-output requirements represent the sector-specific factor inputs, which are regarded as the determinants of trade performance in many empirical studies that test one or another variant of the Heckscher-Ohlin model.

The last column of Table 8.7 shows the results of including all sectors in the regression analysis. The table shows that all estimated coefficients of the factor inputs are significant.[23] Moreover, the estimated equation is significant at the 5% level with an adjusted R-square of 0.24. The positive signs of the estimated coefficients of low-skilled labour and producer durables in the regression equation for all sectors reveal that the low-skilled labour and producer durables are abundant in the Netherlands. On the contrary, the negative coefficients for intermediate-skilled labour, highly-skilled labour and structures indicate that these factors are scarce. These results of factor abundance and scarcity perfectly match with the conclusions that have been drawn in the previous section. This again confirms the value of the HOV model for analysing factor abundances.

Now it can be seen what happens if the signs of the regression analysis with the 17 manufacturing sectors only are interpreted as indicators of factor abundance. In

23. Cörvers and Reininga (1996) show that these results are not dependent on including the resource-intensive non-manufacturing sectors such as agriculture, fisheries, mining and quarrying, as is often stated (see e.g. Branson and Monoyios, 1977). Moreover, note that the constant term is negative as expected, although it is not statistically significant.

that case the conclusions on factor abundance are wrong and in some cases even opposite to the conclusions on factor abundance stated when all sectors are included in the regression analysis. This can be explained by the fact that the signs of the estimated coefficients of low-skilled labour, highly-skilled labour and structures are opposite to the signs of the estimated coefficients of these factors in the regression analysis when all sectors are included. Four out of five estimated coefficients of sector-specific inputs in the manufacturing sectors are significant, which indicates their relevance for the trade performance of the manufacturing sectors.

Finally, the estimated coefficients of the regression analysis for all sectors show that the sectors with larger input-output requirements of low-skilled labour and producer durables have on average larger net exports. On the contrary, sectors with larger input-output requirements of intermediate and highly-skilled labour have on average smaller net exports. If the factor abundances of the human and physical capital endowments in the Netherlands change, the net exports of all sectors change. For example, a further rise of the factor abundance of low-skilled labour, and a simultaneous fall of the factor endowment of highly-skilled labour, increase the net exports of sectors that make intensive use of low-skilled labour, whereas they decrease the net exports of the sectors that make intensive use of highly-skilled labour.[24]

However, the regression analysis for the manufacturing sectors only shows that net exports are large for the manufacturing sectors that have large input-output requirements of highly-skilled labour and small input-output requirements of low-skilled labour.[25] A rise of the factor abundance of low-skilled labour with a simultaneous fall of the factor abundance of highly-skilled labour in the Netherlands, may have a positive impact on the net exports of some manufacturing sectors, and a negative impact on the net exports of other manufacturing sectors. As stated before, whether there is a positive or a negative impact on the net exports of a particular manufacturing sector, depends on the input-output requirements of this sector relative to the input-output requirements of all other sectors of the economy. For example, textile, wearing apparel and leather, and fabricated metal products are low-skill manufacturing sectors (see Chapter 6 and 7). These sectors will improve their trade performance when the relative factor endowment of low-skilled labour increases and the factor endowment of highly-skilled labour decreases. Conversely, the trade performance of high-skill intensive or technology-intensive manufacturing sectors such as chemicals, precision and optical instruments, and electrical machinery will deteriorate in that case.

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24. This is an implication of the so-called *Rybczynski theorem* of the HOV model. According to this theorem, in a world with two factors and two sectors, and with each sector producing one good that is sold against a constant price, an increase in the supply of a factor will lead to an increase in the output of the sector that uses that factor intensively and a decrease in the output of the other sector (see e.g. Leamer, 1984).

25. This only holds within the sample of the 17 manufacturing sectors.

8.5 Conclusions

In this chapter the HOV theorem is tested by measuring both true and trade-revealed factor endowments. Since the rank orders of factor abundance according to both methods of measurement are very similar, the HOV theorem is confirmed. It has also been illustrated that comparing the factor intensities of exports versus the factor intensities of imports is not the correct method to test the HOV theorem, since the factor intensity of net exports should be compared to the factor intensity of consumption to reveal factor abundance. The analysis of the Dutch factor endowments has shown that the Netherlands has factor abundances in producer durables and low-skilled labour, whereas it has factor scarcities in intermediate-skilled labour, highly-skilled labour and structures. This implies that the Netherlands has a revealed comparative advantage in goods that are intensive in the use of producer durables and low-skilled labour, and a comparative disadvantage in goods that are intensive in the use of intermediate-skilled labour, highly-skilled labour and structures. A further disaggregation of the trade-revealed factor endowments according to the educational types of labour that are typical for the Netherlands does not change these results, which confirms that the distinction between low, intermediate and highly-skilled labour is well chosen.

The factor content ratios for the Dutch manufacturing sectors are very different from the factor content ratios for the whole economy in the Netherlands, which highlights the relevance of including all sectors when drawing conclusions on trade-revealed factor abundances of human and physical capital. Moreover, also regressing a measure of trade performance on sector-specific factor inputs must include all sectors to draw correct conclusions on factor abundance. In other words, conclusions with regard to factor abundance based on an empirical analysis of the trade performance and factor inputs of the manufacturing industries only (as in e.g. Koekkoek and Mennes, 1984, for the Netherlands), may be misleading.[26] This chapter has shown that in the case of the Netherlands such a partial analysis of the economy can lead to wrong conclusions on factor abundance when using the HOV model.

However, the partial analysis of the manufacturing sectors by means of the HOV model indicates the contribution of sector-specific factor inputs to the trade performance of these sectors. The analysis reveals that in particular highly-skilled labour and producer durables are important factor inputs for the trade performance of the manufacturing sectors in the Netherlands, whereas the inputs of low and intermediate-skilled labour are negatively related to the trade performance of manufacturing sectors. For all sectors, including the manufacturing sectors, a further rise of the factor abundances of low-skilled labour and producer durables, and a simultaneous fall of the factor endowments of intermediate and highly-skilled labour,

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26. Note that in Chapter 7 relative true factor endowments of 14 industrialized countries are used to explain the cross-country trade performance of a particular manufacturing sector in these countries, which is very different from the cross-section analysis in this chapter. Nevertheless, both chapters use the HOV model.

increase the net exports of sectors that make intensive use of low-skilled labour and producer durables, whereas they decrease the net exports of the sectors that make intensive use of intermediate and highly-skilled labour.

Appendix 8.A Classification of sectors

The analysis in the chapter uses a classification of 40 sectors. This sector classification is listed below.

Agriculture and fisheries
1. Agriculture, horticulture and forestry
2. Fishing

Mining and quarrying
3. Extraction of crude petroleum
4. Other mining and quarrying

Manufacturing
5. Food and beverages
6. Tobacco
7. Textile
8. Wearing apparel
9. Leather
10. Wood and furniture
11. Paper and paper products
12. Publishing and printing
13. Petroleum refineries
14. Chemicals
15. Construction materials
16. Basic metals
17. Fabricated metal products
18. Machinery and equipment
19. Electrical machinery and apparatus
20. Transport equipment
21. Precision and optical instruments

Utilities and construction
22. Electricity, gas and water supply
23. Construction

Trade, hotels, repair of consumer goods
24. Wholesale, retail trade en repair
25. Hotels and restaurants

Transport, storage and communication
26. Water and air transport
27. Other transport activities
28. Communication

Commercial services
29. Banking
30. Insurance
31. Real estate activities
32. Other business activities

Other services
33. Public administration and social security

34. Defence
35. Education
36. Social work
37. Health
38. Cultural, sporting en recreational activities
39. Other services
40. Personnel in paid employment

Appendix 8.B Methodology of data generation[27]

This appendix first briefly discusses the methodology behind the input-output (I-O) tables, social accounting matrices (SAMs) and supply and use tables from which the data are drawn. It also discusses how we have dealt with two well-known methodological problems of I-O tables, i.e. the homogeneity of I-O tables and the production technology of imports, to make the I-O framework suitable for calculating the factor content of production, exports and imports. Next, the valuation of I-O tables will be briefly touched upon. Finally, the construction of a consistent set of labour and capital data will be discussed.

Input-output tables

I-O tables are widely used in national accounting.[28] They have proved to be a suitable framework for utilizing production statistics from different sources. However the intra-industry structure of I-O tables does not match the structure of the basic data. Although a firm knows the type of products purchased and produced, it usually does not know in what category statisticians classify the firms with which it does business. Consequently, since 1968 the System of National Accounts (SNA) has advocated the use of 'supply and use' tables as a balancing device (United Nations, 1968). The use table shows commodity usage by using industry and final demand category. The supply table gives a corresponding picture of the supply of commodities, distinguishing between the supplying industries. Since 1987 Statistics Netherlands has employed supply and use tables to arrive at accurate estimates of total production (GDP). However, Statistics Netherlands continues to construct I-O tables because they are still very much valued as an analytical tool. In contrast to the practice before 1987, these I-O tables are now derived indirectly from the supply and use tables (see e.g. Konijn, 1994).

Social accounting matrices

SAMs offer a very convenient expedient to combine the description of the production process in supply and use tables with detailed information on other aspects of the economic process. This is confirmed in Chapter 20 of the 1993 System of National Accounts (SNA), on SAMs: ".. A SAM is defined here as the presentation of SNA accounts in a matrix which elaborates the linkages between a supply and use table and institutional sector accounts.." (UN, 1993, p. 461). Because a SAM may be considered as an extension of an I-O table incorporating the distribution and use of income, the analytical applications of SAMs and I-O tables are largely the same. Basically, both SAMs and I-O tables are based on the assumption of a linear relation between an endogenous (target) variable, e.g. (aggregate) output and employment, and the exogenous part of the SAM, e.g.

27. This appendix is almost literally taken from Cörvers and Reininga (1996).

28. Den Bakker (1993) describes the extensive use of the I-O table by Statistics Netherlands until 1987.

government spending and exports. In contrast to I-O analysis, however, the SAM model is 'closed' with respect to income distribution and income use.

As stated before, the Dutch SAMs contain supply and use tables instead of an I-O table to describe the production process. Inverting this SAM for our analytical purposes implicitly leads to the mechanical construction of an industry-by-industry I-O table (see below) based on the 'assumption of fixed industry sales structures' (Konijn, 1994, pp. 110-111). According to this assumption, each industry has its own specific sales structure irrespective of its product mix. In other words, it is assumed that all products of a specific industry are sold in exactly the same proportion to other industries, households, governments, and other countries. As this assumption is rather implausible, using the SAM would lead to a distorted mapping of final demand to the use of production factors. Consequently, we have used an industry-by-industry I-O table for our analysis. This table is derived by Statistics Netherlands from supply and use tables, using additional information on commodity flows between industries. The SAM provides detailed additional data on the educational levels of the labour used by industry. These data are consistent with the data from the industry-by-industry I-O table. This chapter therefore utilizes one of the major advantages of SAMs as a statistical tool: the balancing of statistical information from various sources.

The homogeneity of the I-O table

An I-O table reflects the output of commodities on the one hand, and the intermediate goods, labour, and capital used to produce these commodities on the other hand. In many cases a firm, and therefore an industry defined as a group of firms engaged primarily in the same activity, does not produce only a single product. In addition to its primary, characteristic product, it may produce one or more secondary, non-characteristic products.[29] If firms are categorized in the various industries in the I-O table solely on the basis of their primary products, without taking specific account of the problem of secondary products, the result is an 'industry-by-industry table'. In a 'commodity-by-commodity' table the secondary products are separated from primary products whenever possible, and reallocated to other industries to obtain a more or less homogeneous table.[30]

However, there are as yet no labour market data consistent with the categorization of productive activities in the commodity-by-commodity table. As a consequence, the test has to be conducted using the less appropriate 60x60

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29. Two cases can be distinguished (see Konijn, 1994, pp. 60-64): 1. Subsidiary products: the products are technically unrelated, so that it is in principle possible to attribute inputs to the various products; 2. By-products and joint products: the primary and secondary product(s) are produced simultaneously, and joint inputs cannot be attributed to the various products. Where one product can be considered to be the primary product, the others are considered by-products. Where this is not possible all are considered joint products.

30. Statistics Netherlands has compiled such a commodity-by-commodity table for 1991 (Konijn and De Boer, 1993).

industry-by-industry table. This table had to be aggregated to a corresponding 40x40 table to make it possible to use the detailed labour data in the SAM.

Production technology of imports

Because no data are available on the production techniques actually used in the producing countries, the analysis discussed here has to be based on a number of assumptions with regard to the production technology of imports. In line with one of the postulates of the Heckscher-Ohlin theory, we follow the 'equal technology' assumption, i.e., that the production technology of competitive imports is assumed to be equal to the production technology in competing industries in the importing country.[31]

Valuation of I-O tables

According to SNA'93, I-O tables can be valued in (i) basic prices, (ii) producer prices, and (iii) purchasers' prices. It is important in testing the Heckscher-Ohlin theory to use basic prices as only this valuation excludes the distorting effect of government taxes and subsidies on products. Valuations in basic prices can be considered to reflect relative abundances of production factors more accurately than other valuation methods. For our analysis we used the 1991 I-O table for the Netherlands valued in basic prices.

Remarks on the labour data used

The Department of Labour Statistics of Statistics Netherlands is responsible for collecting and analysing labour market data. This department has constructed valuable employment data, splitting total employment data in full-time equivalents for the various industries into 7 different subtotals based on the levels of education of the employees: (i) primary education (BO), (ii) junior general secondary education (MAVO), (iii) junior secondary vocational education (VBO), (iv) senior general secondary education and pre-university education (HAVO/VWO), (v) senior secondary vocational education (MBO), (vi) higher vocational education (HBO), and (vii) university education (WO).

However, primarily because of some minor classification differences, the employment data do not fully match the data used in the National Accounts Department. A balancing process was therefore required, using a Social Accounting framework. This resulted in a consistent set of National Accounts and labour market data for 40 industries. Moreover, the Social Accounting Matrix supplies corresponding details on the wages for total employment in full-time equivalents per industry and for the seven educational categories. Thus the labour data offers ample opportunities to derive proxies for the human capital used in producing goods and services in the Netherlands. Three well-known methods to assess the volume of human capital inputs are: (i) valuation based on years of initial education, (ii) valuation based on wages paid per educational level and per industry, and (iii)

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31. As has been argued before, most trade takes places between industrialized countries, which are expected to have relatively similar input-output coefficients.

valuation based on the average wage per educational level of the total economy. The latter avoids the possible effect of industry-specific elements but, as Reininga (1994) has shown, the choice of valuation method does not influence the outcome of the factor content calculations for the Netherlands. In our analysis we have adopted valuation method (ii), since this method values human capital in monetary units (just like physical capital, see below) and at the most disaggregated level.

Remarks on the capital data used

The capital input is assumed to be equal to depreciation costs. However, in the Netherlands no depreciation data detailed at the level of our 40x40 I-O table are available. In line with standard Leontief I-O theory regarding the constancy of I-O coefficients, the available data on depreciation for 23 industries are disaggregated on the basis of output data to the 40 industries of the I-O table. Two types of physical capital are distinguished: producer durables, including machinery and (transport) equipment, and structures, which covers residential construction, non-residential construction and other construction.

Appendix 8.C Data of relative true factor endowments

Table 8.C.1 shows the relative true factor endowments of 21 OECD countries, including the Netherlands. Relative to the other OECD countries, the Netherlands takes an intermediate position in the rank orders of all relative true factor endowments mentioned in Table 8.1, except for the low ranking of the structures component of physical capital.

Table 8.C.1

Relative true factor endowments of low (LSW), intermediate (ISW) and highly-skilled (HSW) labour, producer durables (PRO) and structures (STR) per country, 1990

LSW		ISW		HSW		PRO		STR	
1. TUR	7.71	1. AUT	1.61	1. CAN	1.48	1. SWI	1.52	1.SWI	2.04
2. PRT	4.54	2. JPN	1.49	2. AUS	1.30	2. SWE	1.40	2. FIN	1.41
3. ESP	2.40	3. DEU	1.45	3. USA	1.24	3. DEU	1.31	3. DEU	1.41
4. IRL	2.02	4. NOR	1.30	4. JPN	1.18	4. JPN	1.24	4. CAN	1.25
5. ITA	1.90	5. GBR	1.29	5. NEZ	1.15	5. FIN	1.15	5. NOR	1.23
6. BEL	1.46	6. SWI	1.29	6. NOR	1.08	6. AUS	1.09	6. ESP	1.21
7. NEZ	1.40	7. DNK	1.21	7. SWE	1.03	7. FRA	1.08	7. DNK	1.13
8. FRA	1.31	8. SWE	1.09	8. DNK	0.91	8. GBR	1.02	8. JPN	1.12
9. DNK	1.27	9. FIN	1.08	9. TUR	0.88	9. DNK	1.02	9. SWE	1.11
10.FIN	1.19	10.NEZ	0.91	10.IRL	0.84	10.NEZ	1.01	10.ITA	1.05
11.AUS	1.18	11.USA	0.90	11.FIN	0.83	**11.NLD**	**1.00**	11.AUS	0.99
12.NLD	**1.14**	12.TUR	0.90	**12.NLD**	**0.81**	12.ITA	0.99	12.AUT	0.99
13.JPN	1.08	**13.NLD**	**0.83**	13.BEL	0.80	13.AUT	0.98	13.FRA	0.93
14.GBR	1.06	14.FRA	0.81	14.SWI	0.77	14.NOR	0.94	14.BEL	0.92
15.AUT	1.00	15.CAN	0.74	15.GBR	0.76	15.BEL	0.90	15.NEZ	0.92
16.SWE	0.94	16.IRL	0.70	16.DEU	0.73	16.USA	0.88	16.USA	0.90
17.DEU	0.60	17.AUS	0.58	17.FRA	0.63	17.IRL	0.88	17.PRT	0.85
18.NOR	0.58	18.BEL	0.53	18.ESP	0.48	18.TUR	0.70	**18.NLD**	**0.82**
19.CAN	0.57	19.ITA	0.50	19.AUT	0.33	19.CAN	0.69	19.IRL	0.79
20.SWI	0.47	20.ESP	0.32	20.PRT	0.30	20.ESP	0.64	20.TUR	0.69
21.USA	0.38	21.PRT	0.13	21.ITA	0.25	21.PRT	0.57	21.GBR	0.56

Sources: Penn World Table (Mark 5.6); Education at a Glance (OECD, 1992b, 1993).

Notes: German figures refer to the former Federal Republic of Germany; German levels of educational attainment are from 1989; Japanese levels of educational attainment are from 1987.

Abbreviations of the countries:
AUS = Australia; AUT = Austria; BEL = Belgium; CAN = Canada; DEU = Germany; DNK = Denmark; ESP = Spain; FIN = Finland; FRA = France; GBR = Great Britain; IRL = Ireland; ITA = Italy; JPN = Japan; NEZ = New Zealand; NLD = Netherlands; NOR = Norway; PRT = Portugal; SWE = Sweden; SWI = Switzerland; TUR = Turkey; USA = United States

Chapter 9

Summary and conclusions

This thesis analyses the contribution of human capital factors to international competitiveness and trade performance. It is argued that international competitiveness should by measured by productivity, whereas trade performance should be measured by an indicator of revealed comparative advantage. Productivity has been chosen as the indicator of international competitiveness for two reasons. Firstly, human capital theory explicitly refers to the relationship between human capital investments and labour productivity. Secondly, productivity is the prime long run determinant of the nation's income level per capita and the nation's standard of living. Here human capital investments are regarded as an important *source* of international competitiveness, because they are supposed to increase the productivity of workers. The trade performance of the countries' sectors of industry, represented by indicators of revealed comparative advantage, refers to the *results* of the process of international competition.

The central aim of the thesis is to establish the mechanisms along which human capital can affect international competitiveness as well as trade performance. Chapters 2, 3, 4 and 5 of the thesis present a theoretical exposition of how human capital affects productivity as a measure of international competitiveness. Therefore these chapters distinguish different forms of human capital as well as different productivity effects of human capital. Chapters 6, 7 and 8 present empirical investigations into the effects of human capital on productivity and trade flows, particularly focusing on the manufacturing sectors of industrialized countries. Figure 1.1 of Chapter 1 summarizes the general framework of the chapters of the thesis. Below these chapters will be recapitulated. Next, the lessons learned from the thesis and the possible directions for further research will be reviewed.

Summary

Chapter 2 shows that human capital theory explicitly considers investments in education as accumulated stock of human capital. This stock of human capital is used, analogous to physical capital, as a factor of production. The productivity enhancing effects of human capital can hardly be denied due to the empirical evidence in favour of human capital theory, although screening theory considers the workers' innate abilities as the most important determinants of productivity differences between workers. It has been argued that human capital theory and screening theory are complementary in understanding how investing in workers' education influences their productivity. Since ability differences of workers across different countries are probably of minor importance to explain sectoral productivity differences between countries, the choice of human capital theory instead of screening theory in the international context of the thesis can be justified. Furthermore, when measuring the effects of human capital on productivity, human capital should be measured by skills instead of the capital value of workers, since the capital value of workers is dependent on the current as well as future wages of the workers. Contrary to measuring human capital by the workers' current and future wages, the measurement of human capital by workers' acquired skills are not dependent on the supply and demand elasticities of the labour and the goods market. Therefore the human capital stock of a sector or a country can usefully be represented by the skill structure of the work force.

Chapter 3 shows that human capital is not just a stock of skills directly used as a factor of production, but it plays an important role in economic growth due to its relationship with technological change. Human capital not only represents the stock of workers' skills, but also represents the stock of embodied technological knowledge applied for the innovation and diffusion of new products and production processes. Technological knowledge is also embodied in materials like machines, books or blueprints. Technological change refers to the change in the state of technological knowledge. Contrary to technological change, technical change refers to the change in the use of factor inputs, given the level of technological knowledge. Due to nonrivalry and incomplete appropriability of technological knowledge, spillovers in knowledge from one to another firm can occur. A particular firm can generate technological knowledge by research and development (R&D) activities or different forms of learning. The resulting knowledge is an externality for the other firms. The human capital stock accelerates technological change and in turn economic growth in two ways. Firstly, specialized highly-skilled workers are required to perform research and development activities. Research and development is a driving force behind economic growth since it increases the level of technological knowledge. Secondly, technological diffusion of both new products and production processes goes faster with a higher educated work force. An improvement of the average level of educational attainment of the work force indirectly stimulates economic growth by facilitating the use of knowledge that is generated by research and development or learning in other firms.

Chapter 4 presents a theoretical background of the ways in which different forms of initial schooling and continuing training improve the match between the acquired skills of the worker and the skills required by the worker's job. This part of the thesis is reflected by the circle of Figure 1.1. Vocational initial schooling directly increases the productivity of workers, provided that there is a good match between the acquired and required skills at the start of the job. The higher the level of general initial schooling of workers, the better these workers are suited to adapt to changes in the circumstances, like the tasks of a job, the technology in use, the economic and political environment, etc. As a result the trainability of workers increases due to general initial schooling. Therefore general initial schooling may raise the productivity of workers indirectly, by enlarging the rate of return on investments in continuing training. Different forms of continuing training can be distinguished, formal versus informal, on-the-job, including learning-by-doing, versus off-the-job, general versus specific. Due to investing in various forms of initial schooling and continuing training by both employers and employees the mismatch between acquired and required skills disappears in the long run. Experienced workers may even have reached the productivity maximum associated with the job. In other words, their acquired skills are almost similar to the skills required by the job in the long run, except for the risk of underinvestment in training and skill obsolescence. The analysis in this chapter shows that the larger the general training components in a particular form of training, the larger the probability that underinvestment in training occurs. Moreover, solving the informational asymmetries on the training market, i.e. improving the transparency of the skills acquired by continuing training, may also increase underinvestment in training. Furthermore, skill obsolescence can cause a mismatch between the acquired skills of workers and the required skills of their jobs, which may result in a productivity loss. For example, if workers (at any age) are faced with techn(olog)ical change and the resulting economic depreciation of their skills, they have to participate in training courses to adapt to the new skill requirements. Therefore underinvestment in skills may occur as a result of underinvestment in training and skill obsolescence. On the other hand, workers may compete for a job by investing in initial schooling before they offer themselves on the labour market. This may lead to overinvestment in initial schooling, although the overeducation of workers is less wasteful if it is a substitute for continuing training in firms. Thus overinvestment in skills may occur as a result of matching relatively highly-educated workers to low-productivity jobs.

Chapter 5 presents a theoretical framework to understand the effects of human capital on productivity. The human capital stock is represented by the skill structure of workers with low, intermediate and high skills. Four productivity effects of human capital have been distinguished: worker, allocative, diffusion and research. Workers with a higher skill level because of investments in human capital are assumed to be more efficient in working with the resources at hand, i.e. these workers produce more physical output. This is called the *worker effect*. Moreover, the *allocative effect* points to the greater (allocative) efficiency of better skilled workers in allocating all input factors to the production process between the alternative uses. Next, to introduce new technologies, thus achieving productivity growth, firms require skilled workers. This is called the *diffusion effect* of human capital. Finally, since R&D expenditures are a key factor to developing new technologies and thereby establishing productivity growth, human capital is considered to be of crucial importance for achieving productivity growth. This is called the *research effect* of human capital. The worker and allocative effect refer to the relevance of human capital in a static environment, i.e. without technological change. They are therefore called *static effects*. The research and diffusion effect refer to the relevance of human capital in a dynamic environment, i.e. when production technology changes. They are therefore called *dynamic effects*. Furthermore, it has been argued that the static effects underpin the relevance of human capital for the *productivity level*, whereas the dynamic effects underpin the relevance of human capital for *productivity growth*. The empirical results from both case studies and econometric studies fit very well into the above theoretical framework. However, most empirical studies do not distinguish between the productivity effects of human capital as such and do not show the effects on sectoral labour productivity of intermediate skills and high skills separately. Most case studies are too restricted to draw general conclusions on the relative magnitude of the four productivity effects. Furthermore, econometric studies on the worker effect and the allocative effect are not yet convincing, whereas the diffusion effect seems to be relevant where there is technological change. In general the empirical evidence on the research effect of human capital on productivity growth is not yet convincing, although there is convincing empirical evidence that research and development activities, in which human capital is an important input factor, contribute to productivity growth.

Chapter 6 shows that there is empirical evidence for the proposition that relative sectoral labour productivity determines trade flows, which is in line with Ricardian theory of international trade. Therefore investments in human capital, which increase labour productivity, can be important for increasing the international competitiveness of manufacturing sectors within the EU Member States, which is indicated by the lower line of research in Figure 1.1. One of the sources for different labour productivities between sectors of industry is human capital. The human capital stock of the work force in a sector is represented by the employment shares of low, intermediate and highly-skilled workers. To distinguish between low-skill, medium-skill and high-skill manufacturing sectors, the sectors are ranked according to the 1988 cross-country average employment share of highly-skilled workers. The following high-skill sectors were selected from the 15 manufacturing sectors: chemicals, electrical machinery, professional goods and non-electrical machinery. In addition, it is possible to identify four medium-skill sectors: petroleum, transport equipment, paper and printing and basic metals. The remaining sectors are termed 'low-skill' sectors. Other variables than human capital included in the analysis are the physical capital intensity and the average firm size per sector. The chapter mainly focuses on the question whether the factor input of human capital at sector level matters for the average productivity level of manufacturing sectors. Least squares estimations for thirteen manufacturing sectors of the sample countries shows that the effects of intermediate and highly-skilled labour on sectoral labour productivity, which reflect the worker and allocative effect, are significantly positive for all categories of sectors, except for the effect of highly-skilled labour in the category of high-skill sectors. In general the estimated effects are larger than the employment shares of intermediate and highly-skilled labour, except for highly-skilled labour in the high-skill sectors. As a matter of fact, in some manufacturing sectors, particular those of Great Britain and Spain, the combined worker and allocative effect of intermediate-skilled labour is much larger than the employment shares of intermediate-skilled workers. This means that in these sectors both productivity and profits can be increased by further raising the employment shares of intermediate and highly-skilled labour. In that case underinvestment in human capital is likely. From a static point of view overinvestment in human capital is indicated if the estimated effects are relatively small, as for intermediate-skilled labour in the manufacturing sectors of Denmark and Germany and highly-skilled labour in the high-skill sectors. However, once the positive dynamic effects of human capital on productivity growth are also included in the analysis, overinvestment in human capital may not be evident anymore. Least squares estimations to explain sectoral productivity growth revealed the diffusion effect of both intermediate and highly-skilled labour in various sectors. A strong diffusion effect of highly-skilled labour has been found in the high-skill sectors in particular. Therefore the diffusion effect of intermediate-skilled and highly-skilled labour on productivity growth questions the conclusion that there is overinvestment of intermediate and highly-skilled labour in some manufacturing sectors. Moreover, the diffusion effect of intermediate-skilled labour provides additional evidence for the conclusion based on the static analysis that the employment share of intermediate-skilled workers in some manufacturing sectors is too small.

Finally, some evidence has been found to support a research effect of highly-skilled R&D workers in the low-skill category of sectors. This implies that only in these sectors human capital is found to contribute to the development of new technologies and thereby the establishment of productivity growth.

Chapter 7 conducts the theoretical and empirical analysis along the upper line of research of the general framework of Figure 1.1. This upper line of research indicates that differences in human capital endowments across countries determine the sectoral trade performance. The country-specific human capital endowments reflect the national skill structure and are represented by the factor endowments of low-skilled, intermediate-skilled and highly-skilled workers and the technological knowledge incorporated in highly-specialized R&D workers. The model used in the chapter is the Heckscher-Ohlin-Vanek (HOV) model. The HOV theorem says that countries with relatively large stocks of a particular factor endowment will export the services of this factor endowment. Also the factor endowment of physical capital is included in the analysis. In line with the hypotheses formulated in the chapter, which are based on the four productivity effects of human capital mentioned before, the human capital endowments of highly-skilled labour and technological knowledge have a significantly positive impact on the trade performance of technology-intensive economic sectors, and a significantly negative impact on the trade performance of labour-intensive sectors. However, in the capital-intensive sectors the effects of the human capital endowments of intermediate skilled and highly-skilled labour are not significant. Moreover, in accordance with the hypotheses technological knowledge has a significantly negative effect on the trade performance of capital-intensive low/medium-tech economic sectors, whereas physical capital has a significantly positive effect on the trade performance of almost all capital-intensive sectors. These empirical results generally confirm the value of the HOV model for explaining net trade flows between industrialized countries. Therefore the HOV model is an adequate framework for explaining sectoral trade performance by country-specific human capital factors.

Chapter 8 uses the Heckscher-Ohlin-Vanek model to further analyse the impact of both country-specific and sector-specific factors on trade performance. This chapter integrates the analyses of the preceding two chapters by incorporating both the country-specific and the sector-specific determinants of trade performance in a factor content analysis of Dutch trade. Five production factors are distinguished, namely the human capital factors of low, intermediate and highly-skilled labour, and the physical capital factors of structures (i.e. residential, non-residential and other construction) and producer durables (i.e. machinery and equipment). The trade-revealed factor endowments and the sector-specific factor inputs of these production factors are calculated by taking account of their factor contents in net exports and domestic consumption. The true factor endowments of the Netherlands represent the real availabilities of each production factor relative to the real availabilities of 20 other industrialized countries. The HOV theorem is confirmed for the case of the Netherlands, since the rank orders of the factor abundances of the five production factors distinguished are very similar according to both methods of measurement, i.e. according to the trade-revealed factor endowments on the one hand and the true factor endowments on the other. This chapter also illustrates that comparing the factor intensities of exports versus the factor intensities of imports is not the correct method to test the HOV theorem as the factor intensity of net exports should be compared to the factor intensity of consumption to reveal factor abundance. Furthermore, the analysis of the Dutch factor endowments shows that the Netherlands has factor abundances in producer durables and low-skilled labour, whereas it has factor scarcities in intermediate-skilled labour, highly-skilled labour and structures. This implies that the Netherlands has a revealed comparative advantage in goods that are intensive in the use of producer durables and low-skilled labour, and a comparative disadvantage in goods that are intensive in the use of intermediate-skilled labour, highly-skilled labour and structures. A further disaggregation of the trade-revealed factor endowments according to the educational types of labour that are typical for the Netherlands does not change these results, which confirms that the distinction between low, intermediate and highly-skilled labour is well chosen. The results of a partial empirical analysis with a HOV model that uses sector-specific factor inputs should be interpreted carefully, since the factor content ratios of net exports and domestic consumption of the Dutch manufacturing sectors are very different from the sectors of the whole economy, and regressing a measure of trade performance on sector-specific factor inputs must include all sectors to draw correct conclusions on factor abundance. However, it can be concluded from the partial analysis of the manufacturing sectors by means of the HOV model that in particular highly-skilled labour and producer durables are important factor inputs for the trade performance of the manufacturing sectors in the Netherlands, whereas the inputs of low and intermediate-skilled labour are negatively related to the trade performance of manufacturing sectors.

Lessons learned: evaluation

Various questions related to the central aim of the thesis have been discussed either implicitly or explicitly, namely what is human capital, how should the stock of human capital be measured, what is its relationship with (technological) knowledge, which human capital factors can be distinguished, how is human capital accumulated by workers and firms, why do investments in human capital increase productivity, how can the effects of human capital on productivity and trade be measured, how large is the impact of different human capital factors on productivity and trade, what is the relevance of country-specific and sector-specific human capital factors for trade performance? The answers on these questions reflect the lessons learned from the thesis, and are included in the summary above. Below, the answers are given by describing how the general framework of Figure 1.1 has been elaborated in the thesis.

The human capital stock of firms, sectors or countries can be usefully represented by the skill structure of the work force and the technological knowledge embodied in the work force to analyse the impact of human capital on productivity and trade. Low, intermediate and high skills can be acquired by different forms of investments in initial schooling and continuing training, whereas technological knowledge is generated by learning and research and development activities. By means of initial schooling of students, the national educational system supplies workers who have attained low, intermediate or high skill levels, whereas the firms demand for workers with these skill levels. The workers' acquired skills must be matched to the skills required by the jobs that are available in the firms, as is illustrated by the circle in Figure 1.1. The mismatch is the difference between the real productivity level and the maximum productivity level that can be achieved in the job. Due to the continuing training of workers the mismatch between the workers' acquired skills and the skills required by the jobs in the firms disappears in the long run, except for underinvestment in training and skill obsolescence. The demand for workers by firms results in the sectoral employment shares of low, intermediate and highly-skilled workers, whereas the supply of workers results in the national factor endowments of low, intermediate and highly-skilled workers.

With respect to the *demand side* in Figure 1.1, the empirical evidence of the thesis points out that the sectoral employment shares of intermediate and highly-skilled labour have significantly positive effects on the sectoral productivity level of most manufacturing sectors. These effects are called the worker and the allocative effect. The empirical evidence also shows that both the sectoral employment shares of highly-skilled labour and the technological knowledge embodied in R&D workers at sector level have significantly positive effects on the productivity growth in many manufacturing sectors. These effects are called the diffusion and the research effect. Moreover, it has been empirically shown that the average sectoral productivity level is an important determinant of the trade performance of manufacturing sectors. Therefore the sector-specific human capital inputs of workers' skills and technological knowledge have a positive impact on both productivity and trade performance of the manufacturing sectors.

With respect to the *supply side* in Figure 1.1, the countries' factor endowments of low-skilled labour, intermediate-skilled labour, highly-skilled labour and technological knowledge have a significant effect on the sectoral trade performance of the manufacturing sectors. The effects can be either positive or negative. The factor endowments of highly-skilled labour and technological knowledge generally have a significantly positive effect on the trade performance of technology-intensive sectors, whereas these factor endowments in general have a significantly negative effect on the trade performance of the labour-intensive sectors. In general the effects on trade performance are less strong for the factor endowments of low and intermediate-skilled labour in the labour-intensive and technology-intensive sectors, and for all the human capital endowments in the capital-intensive sectors.[1]

The above findings show that both country-specific factor inputs and sector-specific factor inputs determine the trade performance of manufacturing sectors. The suggested country-specificity of skilled labour, technological knowledge and physical capital may be due to different national educational systems, government technology policies and different national capital investment climates respectively. The HOV model used to explain sectoral trade performance does not allow differing input-output combinations between similar sectors across countries. Nor does the model allow economies of scale and product differentiation. Models assuming economies of scale and product differentiation are best suited to explain the amount of trade between countries, whereas

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1. An exception is the significantly negative effect that has been found for the impact of the factor endowment of technological knowledge on the trade performance of the sectors that are both capital-intensive and low or medium technology-intensive.

the HOV model has the potential to explain the direction of net trade flows. The sector-specifity of factor inputs is based on differences between similar sectors across countries in the use of low, intermediate and highly-skilled labour as well as technological knowledge. The human capital model of the thesis shows the relevance of these sector-specific human capital inputs for productivity. Moreover, sector-specific differences in physical capital intensity and economies of scale determine productivity. By referring to the Ricardian model of trade, which explains trade performance by relative productivity levels of similar sectors across countries, sector-specific human capital inputs can be regarded as determinants of trade performance. In the Ricardian model of trade different input-output combinations between similar sectors across countries and economies of scale are not excluded as possible explanations of trade performance, which is contrary to the HOV model. Finally, in this thesis the HOV model is applied to integrate the use of both country-specific and sector-specific factor inputs of trade performance in one analysis. It turns out that the results of an analysis with sector-specific factor inputs in the HOV model should be interpreted carefully. Moreover, this analysis with the HOV model shows that the trade performance of the Dutch manufacturing sectors is positively related to the factor input of highly-skilled labour, whereas it is negatively related to the factor inputs of low and intermediate-skilled labour.

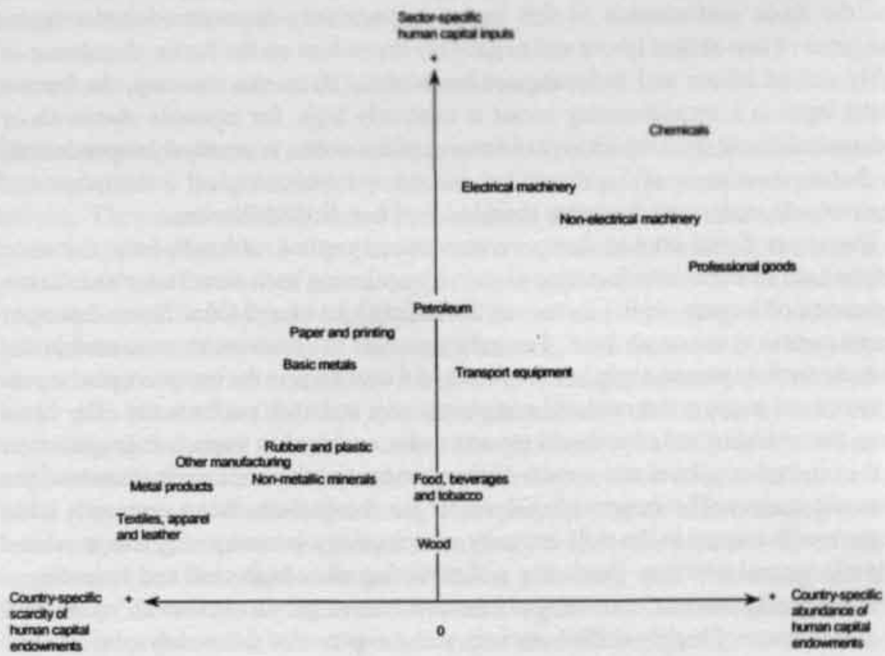
Figure 9.1 illustrates the empirical results concerning the impact of human capital on international competitiveness and trade performance for the manufacturing sectors distinguished in the thesis. The figure is based on the results of the empirical analyses in Chapters 6, 7 and 8.[2] The main result taken from Chapter 8 is that the sector-specific factors which contribute to the trade performance of manufacturing sectors, may be different from the factors that are abundantly available in a country. Thus sector-specific and country-specific human capital factors have to be distinguished from each other. The impact of the sector-specific human capital inputs on trade performance is reflected by, on the one hand, the employment shares of intermediate-skilled and in particular highly-skilled labour, and, on the other hand, the magnitude of the four productivity effects of intermediate and highly-skilled labour and technological knowledge embodied in R&D workers.[3] The larger both the employment shares and the productivity effects, the larger the positive impact of sector-specific human capital inputs on trade performance. This is indicated by the vertical axis of Figure 9.1. The impact of the country-specific human capital endowments on trade performance is

2. Note that the sector classifications of Chapters 6 and 7 are not completely similar. Some three and four-digit sectors of Chapter 7 are disaggregated from the sectors distinguished in Chapter 6 (see appendices A of both chapters). Since the sector classification of Chapter 6 is used in Figure 9.1, the impact of the country-specific human capital endowments on the trade performance of the more disaggregated sectors of Chapter 7 is taken into account in the position of the sectors in Figure 9.1.

3. Of course, the human capital input of a sector, represented by the employment shares of intermediate and highly-skilled workers, and the magnitude of the productivity effects are related. For example, small productivity effects of human capital in a sector lead to a relatively small demand for intermediate and highly-skilled workers by the firms in the sector.

reflected by the factor endowments of intermediate and in particular highly-skilled labour as well as the factor endowment of technological knowledge. As is explained above, the factor abundances of country-specific human capital endowments can have either a positive or a negative impact on the trade performance of the manufacturing sectors. The larger the positive impact of country-specific human capital on trade performance, the more the manufacturing sector is placed to the right on the horizontal axis in the figure. If the impact is negative for a particular manufacturing sector, this implies that the scarcity of the country-specific human capital endowment in question has a positive effect on the trade performance of the manufacturing sector. The larger the negative impact, the more the manufacturing sector is placed to the left on the horizontal axis in the figure.

Figure 9.1
The impact of sector-specific and country-specific human capital on the trade performance of manufacturing sectors



The vertical axis of the figure shows that sector-specific human capital has a positive impact on productivity, which is an indicator of international competitiveness, and thereby trade performance in all manufacturing sectors. Looking at the vertical axis of the figure, three categories of manufacturing sectors can be distinguished, namely high-skill sectors, i.e. chemicals, electrical machinery, non-electrical machinery and professional goods, medium-skill sectors, i.e. petroleum, paper and printing, basic metals and transport equipment and low-skill sectors, i.e. the remaining sectors. Looking at the horizontal axis, the trade performance of the resource-intensive manufacturing sectors petroleum, food, beverages and tobacco and wood are not dependent on the factor abundance or scarcity of country-specific human capital.

On the horizontal axis it can also be seen that the factor abundance of country-specific human capital has a negative impact on the trade performance of the sectors paper and printing, basic metals, rubber and plastic and non-metallic minerals. This impact is even larger for textiles, apparel and leather, metal products and other manufacturing. Moreover, the horizontal axis shows that the impact of the factor abundance of country-specific human capital is rather small for the manufacturing sectors of electrical machinery and transport equipment. This impact is largest, in ascending order, for non-electrical machinery, chemicals and professional goods.

Finally, the figure shows that a line can be drawn from the bottom left-hand sectors to the top right-hand sectors. Of course, not all sectors fit exactly on this line. The linear relationship in the figure illustrates that the more a manufacturing sector is intensive in the use of human capital, the larger the impact of the factor abundance of human capital on the trade performance of a manufacturing sector. If the human capital input in a manufacturing sector is relatively low, for example textiles, apparel and leather, then the trade performance of this sector is positively dependent on the factor abundance of low-skilled labour and negatively dependent on the factor abundance of highly-skilled labour and technological knowledge. If, on the contrary, the human capital input in a manufacturing sector is relatively high, for example chemicals or professional goods, then the trade performance of this sector is positively dependent on the factor abundance of highly-skilled labour and technological knowledge and negatively dependent on the factor abundance of low-skilled labour.

The above figure implies that governments can explain, at least partly, the trade performance of their manufacturing sectors by analysing both their factor abundance or scarcity of human capital factors at the national level and their factor inputs of human capital at the sector level. For policy makers the framework presented in the thesis shows *how* human capital endowments of a country and the human capital inputs at sector level improve international competitiveness and trade performance. The thesis shows that changing the educational structure of a country has important implications for the productivity level and growth of the country and the trade performance of the economic sectors. The empirical analyses of the thesis show that a country's trade structure with respect to the skill-intensity or technology-intensity of goods is related to its educational structure. Producing and exporting more high-skill and technology-intensive goods and less low-skill and labour-intensive goods requires an increase of the endowment of highly-skilled workers at the expense of the endowment of low-skilled workers. Policy makers of a country who have targeted their industrial policy on upgrading the product and export mix of their country, should without any doubt include the change of the educational structure as one of the necessary conditions in the industrial policy. This implies that investments in initial schooling and continuing training of the current and future work force should be an important part of a country's industrial policy.

Simultaneously upgrading the product and export mix and investing in human capital by raising the endowment of highly-skilled workers and reducing the endowment of low-skilled workers, will lead to a higher average productivity and income level in a country. The increase of the average productivity and income level is a country's final pay-off of human capital investments in workers' initial schooling and continuing training. Furthermore, these human capital investments do not only upgrade the product and export mix and improve the corresponding average productivity and income level at country level. Due to the positive productivity effects of human capital, investments in workers' initial schooling and continuing training at sector level also raise the sectoral export performance. For policy makers it is important to realize that employing more intermediate and highly-skilled workers does not immediately have to lead to a higher average productivity level, since these workers may contribute to productivity growth in the long run by stimulating and facilitating technological change. The thesis has shown that employing too many intermediate and highly-skilled workers at sector level may indicate overinvestment in human capital from a short term perspective, yet these workers may contribute to long term productivity growth and thus have advantageous effects on trade performance in the long run. Employing too few intermediate and highly-skilled workers at sector level may indicate underinvestment in human capital, which has a negative impact on the sectoral productivity level and thus on export performance. In that case technological progress may be turned down in the long run.

Lessons not-learned: directions for further research

The theoretical framework and the models used in this thesis to analyse the impact of human capital on international competitiveness and trade performance have some limitations. They can be further developed in many different directions. Below some limitations and directions for further research are mentioned. Firstly, in the empirical part of the thesis the stock of human capital is only represented by low-skilled labour, intermediate-skilled labour, highly-skilled labour and technological knowledge. Investments in various forms of continuing training, both formal and on-the-job, are not included as separate explanatory variables in the empirical analysis. The workers in the data set used in Chapter 6 may have attained their skill levels by both initial schooling and formal training courses. The productivity effects of the workers' acquired skills are assumed to represent the productivity effects of investments in both initial schooling and continuing training. However, for a better understanding of how human capital increases productivity it is necessary to know the productivity effects of investments in the various forms of initial schooling and continuing training separately.[4] Secondly, in the thesis it has been argued that human capital should be measured by the skill levels of workers rather than the occupations in which these workers are employed. However, in most international studies on human capital and trade performance the factor inputs of occupational categories of workers represent the human capital stock of the work force. Combining both skill levels and occupation-specific skills in one analysis is necessary to improve the measurement of the human

4. See Godfrey (1997; ed.) for some empirical studies on the relationship between training investments and international competitiveness. Furthermore, international harmonized data on workers' educational attainment and training courses attended, combined with workers' occupational background are recently becoming available (from e.g. Eurostat and OECD).

capital stock embodied in the work force and to analyse the relationship between skills acquired by initial schooling and the occupation-specific skills acquired by one or another form of continuing training.[5] Complementing educational data by training and occupational data of labour may increase our understanding of the match between the workers' acquired skills and the skills required by the jobs. Thirdly, more empirical research is needed on the four productivity effects of human capital. Due to data restrictions it was not possible to distinguish between the worker and the allocative effect. We would better understand what human capital does to productivity if these effects are measured separately. Although the diffusion and the research effect of human capital on productivity growth are distinguished in the thesis, the empirical analysis on these effects covers only a relatively short period of time because of data restrictions. Therefore the empirical analysis should be replicated, taking into account a longer period of time. Moreover, the evidence on the four productivity effects of this thesis could be enriched by empirical analyses on these productivity effects at the firm level. In particular the role of human capital in performing research and development activities at the firm level and in technological spill-overs between firms is an interesting topic for further research. Fourthly, it has been shown that the HOV model is a useful model to analyse the impact of human capital on trade performance. The HOV model is also suitable for the departure of more advanced analyses with less restrictive assumptions. Useful extensions of the HOV model may be the incorporation of human capital factors that are either mobile or immobile across sectors within a country,[6] and the incorporation of international productivity differences between countries (see e.g. Trefler, 1993, 1995). Fifthly, it may be useful to introduce human capital factors as endogenous variables in a general equilibrium model of international trade.[7] In this way, decisions to invest in initial schooling and continuing training can be better understood, which may be useful for considering various policy actions to improve international competitiveness.

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5. See Webster (1993) for incorporating both educational and occupational categories of workers to measure the skill content in a factor content analysis of trade.

6. See e.g. the Ricardo-Viner model mentioned by Leamer (1992).

7. See e.g. Findlay and Kierzowski (1983) and Chen (1995) for incorporating endogenous labour and skill variables in a model.

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Samenvatting (Summary in Dutch)

De uitgaven aan onderwijs en training hebben intuïtief op een of andere wijze gevolgen voor de internationale concurrentiekracht van een land. Dit is gebaseerd op de gedachte dat investeringen in mensen, waarmee menselijk kapitaal wordt opgebouwd, de arbeidsproductiviteit verhogen. Nationale regeringen houden de internationale concurrentiekracht van hun land nauwlettend in het oog, zoals onder meer blijkt uit de grote interesse voor het jaarlijks uitgebrachte World Competitiveness Report. Het belangrijkste doel van dit proefschrift is om de mechanismen vast te stellen via welke de productiefactor menselijk kapitaal ('human capital') de internationale concurrentiekracht en de handelsprestaties van een land beïnvloedt.

In dit proefschrift wordt de internationale concurrentiekracht door de productiviteit gemeten, terwijl de handelsprestaties gemeten worden door het waargenomen comparatieve voordeel ('revealed comparative advantage'). Productiviteit is om twee redenen gekozen als indicator van de internationale concurrentiepositie. Ten eerste, de theorie van het menselijke kapitaal ('human capital' theorie) verwijst expliciet naar de relatie tussen investeringen in menselijk kapitaal en arbeidsproductiviteit. Ten tweede, productiviteit is de belangrijkste lange termijn determinant voor het nationale inkomen per hoofd van de bevolking en de nationale welvaart. In het proefschrift worden investeringen in menselijk kapitaal beschouwd als een belangrijke *bron* van internationale concurrentiekracht, omdat ze de arbeidsproductiviteit kunnen verhogen. De handelsprestaties van industriële sectoren, gemeten door een indicator van het waargenomen comparatieve voordeel, hebben betrekking op de *resultaten* van de internationale concurrentieslag.

Diverse vragen die verband houden met het doel van het proefschrift worden impliciet of expliciet besproken, namelijk wat is menselijk kapitaal, hoe moet het worden gemeten, wat is de relatie tussen menselijk kapitaal en (technologische) kennis, welke vormen van menselijk kapitaal kunnen worden onderscheiden, hoe wordt menselijk kapitaal opgebouwd door arbeidskrachten en ondernemingen, waarom vergroten investeringen in menselijk kapitaal de productiviteit, hoe groot is de invloed van diverse vormen van menselijk kapitaal op de productiviteit en de handel, wat is de relevantie van het landenspecifieke en sectorspecifieke menselijk kapitaal voor de productiviteit en de handelsprestaties? De antwoorden op deze vragen geven de lessen weer die kunnen worden getrokken uit het proefschrift, en zijn opgenomen in de onderstaande samenvatting.

Figuur 1.1 in hoofdstuk 1 geeft het algemene raamwerk van het proefschrift weer en geeft daarmee ook een korte weergave van de samenhang tussen de diverse hoofdstukken van het proefschrift. De hoofdstukken 2, 3, 4 en 5 bevatten een theoretische beschouwing over hoe menselijk kapitaal de productiviteit, als maatstaf voor de internationale concurrentiepositie, beïnvloedt. In deze hoofdstukken worden verschillende vormen van investeringen in menselijk kapitaal onderscheiden en vier productiviteitseffecten van menselijk kapitaal behandeld. De hoofdstukken 6, 7 en 8 bevatten een weergave van het empirische onderzoek naar de effecten van menselijk kapitaal op de productiviteit en de handelsstromen van industriële sectoren in geïndustrialiseerde landen.

Hoofdstuk 2 laat zien dat volgens de human capital theorie het menselijk kapitaal is opgebouwd uit de investeringen in onderwijs en training die in het verleden zijn gedaan. Dit kapitaal van arbeidskrachten wordt als productiefactor gebruikt, analoog aan fysiek kapitaal zoals machines. De productiviteitsverhogende effecten van menselijk kapitaal kunnen nauwelijks worden ontkend vanwege het empirische bewijs ten gunste van de human capital theorie. Niettemin zijn in de zogenaamde screening theorie de aangeboren kwaliteiten van arbeidskrachten de belangrijkste verklarende factor van productiviteitsverschillen tussen arbeidskrachten. Beide theorieën vullen elkaar goed aan om te begrijpen hoe investeringen in onderwijs en training de productiviteit beïnvloeden. Het is echter niet aannemelijk dat aangeboren kwaliteiten in de internationale context van dit proefschrift relevant zijn en de sectorale productiviteitsverschillen tussen landen zouden kunnen verklaren. Op grond hiervan kan de keuze in dit proefschrift voor de human capital theorie in plaats van de screening theorie worden gerechtvaardigd. Daarbij dient het menselijk kapitaal te worden gemeten door de verworven vaardigheden van arbeidskrachten in plaats van de som van de huidige en toekomstige verdisconteerde lonen van arbeidskrachten. De accumulatie van de huidige en toekomstige verdisconteerde lonen is in tegenstelling tot de verworven vaardigheden van arbeidskrachten afhankelijk van de aanbod- en vraagelasticiteiten op de arbeids- en de goederenmarkt. Om deze reden is het beter om het menselijk kapitaal van arbeidskrachten weer te geven door de verdeling van verworven vaardigheden over het totale arbeidspotentieel.

Hoofdstuk 3 laat zien dat menselijk kapitaal niet alleen is opgebouwd uit de vaardigheden van arbeidskrachten, maar ook uit de geïncorporeerde technologische kennis die gebruikt wordt voor de innovatie en diffusie van nieuwe producten en productieprocessen. Technologische kennis is ook geïncorporeerd in materiële zaken als machines, boeken en ontwerpen. Technologische verandering verwijst naar de verandering in de stand van de technologische kennis. In tegenstelling tot technologische verandering, verwijst technische verandering naar een wijziging in het gebruik van inputfactoren, gegeven de stand van de technologische kennis. Door non-rivaliteit en niet volledige exclusiviteit van technologische kennis kan van deze kennis door andere economische sectoren gebruik worden gemaakt ('spillovers'). Een bepaalde onderneming kan technologische kennis genereren door research en development (R&D) of door diverse vormen van leren uit ervaring. De kennis die resulteert is een externaliteit voor andere ondernemingen. Menselijk kapitaal versnelt de technologische verandering en als gevolg daarvan de economische groei op twee manieren. Ten eerste, gespecialiseerde hooggeschoolde arbeidskrachten zijn nodig om research en development activiteiten uit te voeren. R&D is een drijvende kracht achter de economische groei omdat R&D de stand van de technologische kennis verhoogt. Ten tweede, technologische diffusie van zowel nieuwe producten als nieuwe productieprocessen gaat sneller met een beter geschoolde beroepsbevolking. Een verbetering van het gemiddelde opleidingsniveau van de beroepsbevolking stimuleert indirect de economische groei door het snellere en betere gebruik van kennis die gegenereerd is met de eigen research en development activiteiten of met de leerervaringen van andere ondernemingen.

Hoofdstuk 4 schetst een theoretische achtergrond van de manieren waarop verschillende vormen van initiële scholing en training de aansluiting verbeteren tussen de verworven vaardigheden van arbeidskrachten en de vaardigheden die in hun baan worden vereist. Dit gedeelte van het proefschrift wordt weergegeven in de cirkel van figuur 1.1. Initiële beroepsscholing verhoogt onmiddellijk de productiviteit van arbeidskrachten, onder de voorwaarde dat er een goede aansluiting is tussen de verworven en de vereiste vaardigheden in een nieuwe baan. Hoe hoger het algemene scholingsniveau van arbeidskrachten, des te beter deze arbeidskrachten toegerust zijn om zich aan te passen aan veranderingen in bijvoorbeeld de te vervullen taken in een baan, de gebruikte technologie, de concurrentie en de marktvorm, etc. Derhalve stijgt de trainbaarheid van arbeidskrachten als ze algemene initiële scholing hebben genoten. Door algemene initiële scholing stijgt de productiviteit van arbeidskrachten indirect, omdat het rendement van eventuele vervolgtrainingen wordt vergroot. Verschillende vormen van training kunnen worden onderscheiden, namelijk formele versus informele training, on-the-job, waaronder learning-by-doing, versus off-the-job training, algemene versus specifieke training. Doordat werkgevers en werknemers investeren in verschillende vormen van initiële scholing en vervolgtraining kan een gebrek aan aansluiting tussen verworven en vereiste vaardigheden (de 'mismatch') op de lange termijn verdwijnen. Ervaren arbeidskrachten kunnen zelfs het productiviteitsmaximum bereiken dat bij een baan hoort. Met andere woorden, hun verworven vaardigheden zullen op de lange termijn bijna gelijk zijn aan de vereiste vaardigheden in hun baan, indien hierbij geen sprake is onderinvestering in training en veroudering van vaardigheden.

De analyse in hoofdstuk 4 toont aan dat de kans op onderinvestering in training stijgt als het aandeel van de algemene trainingscomponenten in een bepaalde training groter is. Bovendien zal het verkleinen van de informatie-asymmetrieën op de trainingsmarkt, dat wil zeggen het verbeteren van de transparantie van de verworven vaardigheden door een training, de kans op onderinvesteringen in training vergroten. Daarnaast kan veroudering van vaardigheden een mismatch veroorzaken, hetgeen leidt tot productiviteitsverlies. Bijvoorbeeld, als arbeidskrachten geconfronteerd worden met techn(olog)ische verandering en als gevolg daarvan met de economische afschrijving van hun vaardigheden, dan zullen ze moeten deelnemen aan trainingen om zich aan te passen aan de nieuwe vaardigheidseisen. Daarom kunnen onderinvesteringen in vaardigheden optreden als gevolg van onderinvesteringen in training en veroudering van vaardigheden. Aan de andere kant kunnen potentiële arbeidskrachten met elkaar concurreren voor een bepaalde baan door extra te investeren in initiële scholing voordat ze zich op de arbeidsmarkt aanbieden. Dit kan leiden tot overinvesteringen in initiële scholing, hoewel deze overinvesteringen minder verspillend zijn als ze dienen als substituut voor investeringen in vervolgtrainingen. Overinvesteringen in vaardigheden kunnen resulteren uit de mismatch tussen relatief hooggeschoolde arbeidskrachten met banen die een laag productiviteitsmaximum hebben.

Hoofdstuk 5 bevat een theoretisch raamwerk dat dient om de effecten van menselijk kapitaal op de productiviteit te begrijpen. Het menselijk kapitaal kan worden weergegeven door de verdeling van het arbeidspotentieel in laaggeschoolde, middelbaar geschoolde en hooggeschoolde arbeidskrachten. Vier productiviteitseffecten van menselijk kapitaal kunnen worden onderscheiden: het arbeidseffect, het allocatie-effect, het diffusie-effect en het researcheffect. Arbeidskrachten met een hoog opleidingsniveau worden verondersteld efficiënter om te gaan met de beschikbare middelen, hetgeen wil zeggen dat deze arbeidskrachten een grotere fysieke productie genereren. Dit wordt het *arbeidseffect* genoemd. Daarnaast verwijst het *allocatie-effect* naar de grotere (allocatieve) efficiëntie van beter opgeleide arbeidskrachten bij de allocatie van alle inputfactoren over de alternatieve productiemogelijkheden. Bovendien hebben ondernemingen geschoolde arbeidskrachten nodig bij de introductie van nieuwe technologieën. Dit wordt het *diffusie-effect* van menselijk kapitaal genoemd. Ten slotte kan menselijk kapitaal als cruciale factor worden beschouwd om productiviteitsgroei te bewerkstelligen, vanwege zijn rol in R&D activiteiten die leiden tot de ontwikkeling van nieuwe technologieën en daarmee productiviteitsgroei. Dit wordt het *researcheffect* van menselijk kapitaal genoemd. Het arbeids- en allocatie-effect geven het belang aan van menselijk kapitaal in een statische omgeving, dat wil zeggen zonder technologische verandering. Ze worden daarom de *statische effecten* genoemd. Het research- en diffusie-effect geven de relevantie aan van menselijk kapitaal in een dynamische omgeving, wanneer de productietechnologie verandert. Daarom worden ze *dynamische effecten* genoemd. Er is betoogd dat de statische effecten het belang van menselijk kapitaal voor het *productiviteitsniveau* onderbouwen, terwijl de dynamische effecten het belang van menselijk kapitaal voor de *productiviteitsgroei* onderbouwen.

De empirische resultaten van zowel case studies als econometrische studies passen heel goed in het gepresenteerde theoretische raamwerk van hoofdstuk 5. De meeste empirische studies onderscheiden echter niet de hier genoemde productiviteitseffecten en laten niet deze effecten van kwalificaties op middelbaar en hoger niveau afzonderlijk zien. De meeste case studies zijn te beperkt om algemene conclusies te trekken over de relatieve grootte van de vier productiviteitseffecten. Bovendien zijn de resultaten uit de econometrische studies niet overtuigend wat betreft het arbeids- en allocatie-effect. Daarentegen lijkt het diffusie-effect vooral belangrijk te zijn bij technologische veranderingen. Voor het researcheffect geldt dat de empirische resultaten van menselijk kapitaal op de productiviteitsgroei in het algemeen niet overtuigend zijn, hoewel er voldoende bewijs is dat R&D activiteiten, waarbij menselijk kapitaal een belangrijke factorinput is, bijdragen aan de productiviteitsgroei.

Hoofdstuk 6 geeft antwoord op de vraag of de factorinput van menselijk kapitaal op sectorniveau van invloed is op de gemiddelde productiviteit van een sector. Bovendien laat het hoofdstuk zien dat er empirische bevestiging is voor de hypothese dat de relatieve sectorale arbeidsproductiviteit de handelsstromen beïnvloedt, hetgeen in overeenstemming is met de *Ricardiaanse handelstheorie*. Daarom zijn investeringen in menselijk kapitaal, welke de arbeidsproductiviteit verhogen, belangrijk om de internationale concurrentiekracht van industriële sectoren binnen de lidstaten van de Europese Unie te verhogen. Dit wordt weergegeven door de onderste onderzoekslijn in het algemene raamwerk van figuur 1.1. Eén van de verklarende factoren voor de verschillende arbeidsproductiviteiten tussen industriële sectoren is menselijk kapitaal. Het menselijk kapitaal van het arbeidspotentieel in een sector wordt weergegeven door de werkgelegenheidsaandelen van laag-, middelbaar en hooggeschoolde werknemers. Deze variabelen zijn naast de fysieke kapitaalintensiteit en de gemiddelde ondernemingsgrootte van een sector van belang bij het verklaren van de sectorale arbeidsproductiviteit.

De schattingen op basis van het *human capital* model van hoofdstuk 6 laten zien dat de effecten van middelbaar en hooggeschoolde arbeidskrachten op de sectorale arbeidsproductiviteit doorgaans significant positief zijn, behalve voor de hooggeschoolden in sectoren met een hoge intensiteit van menselijk kapitaal. De positieve significante effecten duiden op een positief arbeids- en allocatie-effect van middelbaar en hooggeschoolden. Daar waar de arbeids- en allocatie-effecten van middelbaar en hooggeschoolden aanzienlijk groter zijn dan de respectievelijke sectorale werkgelegenheidsaandelen, is er mogelijk sprake is van *onder*investering in menselijk kapitaal. Dit geldt met name voor de industriële sectoren in Groot-Brittannië en Spanje. De productiviteit en de winst kunnen hier worden verhoogd door de werkgelegenheidsaandelen van middelbaar en hooggeschoolden te vergroten. Vanuit statisch oogpunt geldt dat er sprake is van *over*investering in menselijk kapitaal als de geschatte arbeids- en allocatie-effecten klein zijn ten opzichte van de werkgelegenheidsaandelen in de betreffende sectoren. Dit is het geval voor middelbaar geschoolden in Denemarken en Duitsland, en voor de hooggeschoolden in de sectoren met een hoge menselijke kapitaalintensiteit. Indien echter de positieve dynamische effecten van menselijk kapitaal op de productiviteitsgroei worden meegenomen, dan is de vaststelling van overinvestering in menselijk kapitaal niet meer evident. Schattingen van de effecten van menselijk kapitaal op de productiviteitsgroei, laten het diffusie-effect van middelbaar en hooggeschoolden voor diverse sectoren zien. Het geschatte diffusie-effect is groot voor hooggeschoolden in sectoren met een hoge menselijk kapitaalintensiteit. Opvallend is dat deze sectoren de enige zijn waarvoor de geschatte arbeids- en allocatie-effecten niet significant zijn. Het geschatte diffusie-effect voor middelbaar geschoolde arbeid geeft aan dat het werkgelegenheidsaandeel van middelbaar geschoolden voor sommige industriële sectoren niet alleen te klein is vanuit statisch oogpunt maar ook vanuit dynamisch oogpunt. Ten slotte is er ook enige empirische bevestiging gevonden voor het research-effect van hooggeschoolde R&D arbeidskrachten in de sectoren met een lage menselijke kapitaalintensiteit. Alleen voor deze sectoren is vastgesteld dat menselijk kapitaal bijdraagt aan de ontwikkeling van nieuwe technologieën en daarmee productiviteitsgroei.

Hoofdstuk 7 bevat een theoretische en empirische analyse volgens de bovenste onderzoekslijn in het algemene raamwerk van figuur 1.1. Deze onderzoekslijn laat zien dat verschillen in de beschikbaarheden van menselijk kapitaal tussen landen de sectorale handelsprestaties bepalen. De landenspecifieke beschikbaarheden van menselijk kapitaal geven de nationale verdeling van vaardigheden weer en worden vertegenwoordigd door de factorbeschikbaarheden van laag-, middelbaar en hooggeschoolden en door de factorbeschikbaarheid van technologische kennis die in sterk specialistische R&D arbeidskrachten aanwezig is. Ook de factorbeschikbaarheid van fysiek kapitaal is in de analyse opgenomen.

Het gebruikte model in hoofdstuk 7 is het *Heckscher-Ohlin-Vanek (HOV)* model. Het HOV theorema stelt dat landen met relatief grote beschikbaarheden van een bepaalde factor de verrichtingen die door deze factor zijn geproduceerd zullen exporteren. In overstemming met de hypotheses die in het hoofdstuk zijn geformuleerd, op basis van de eerder genoemde vier productiviteitseffecten van menselijk kapitaal, hebben de factorbeschikbaarheden van hooggeschoolden en technologische kennis een significant positief effect op de handelsprestaties van technologie-intensieve sectoren, en een significant negatief effect op de handelsprestaties van arbeidsintensieve sectoren. De factorbeschikbaarheden van middelbaar en hooggeschoolden zijn niet significant voor de kapitaalintensieve sectoren. Daarentegen heeft de factorbeschikbaarheid van technologische kennis een significant negatief effect op de handelsprestaties van kapitaalintensieve sectoren met een lage of gemiddelde technologie-intensiteit, en heeft de factorbeschikbaarheid van fysiek kapitaal een significant positief effect op de handelsprestaties van kapitaalintensieve sectoren. De empirische resultaten bevestigen in het algemeen de waarde van het HOV model om de netto handel tussen geïndustrialiseerde landen te verklaren. Daarom is het HOV model een geschikt raamwerk om de sectorale handelsprestaties te verklaren met landenspecifieke factorbeschikbaarheden van menselijk kapitaal.

Hoofdstuk 8 laat het gebruik van het HOV model zien om de invloed van zowel landenspecifieke als sectorspecifieke determinanten van handelsprestaties te analyseren. Het hoofdstuk integreert de analyses van de voorgaande twee hoofdstukken door zowel landenspecifieke als sectorspecifieke determinanten van handelsprestaties op te nemen in een factorinhoudsanalyse van de Nederlandse handel. Vijf productiefactoren worden onderscheiden, namelijk de menselijke kapitaalfactoren van laag-, middelbaar en hooggeschoolden en de fysieke kapitaalfactoren gebouwen (residentieel, niet-residentieel en overige) en duurzame productiegoederen (machines en outillage). De waargenomen factorbeschikbaarheden uit de Nederlandse handel en de sectorspecifieke factorinputs zijn berekend uit de factorinhoud van de binnenlandse consumptie en de netto export. De werkelijke factorbeschikbaarheden van Nederland worden gerelateerd aan de werkelijke factorbeschikbaarheden van 20 andere geïndustrialiseerde landen. Het HOV theorema wordt bevestigd voor Nederland, omdat de twee rangordes van de factorbeschikbaarheden naar de mate van overvloedigheid grote overeenkomst vertonen. Het hoofdstuk laat ook zien dat het vergelijken van de factorintensiteiten van de export ten opzichte van de import, niet de juiste methode is. Volgens de correcte methode waarin de factorintensiteit van de netto export wordt vergeleken met de factorintensiteit van de binnenlandse consumptie, heeft Nederland een overvloed aan duurzame productiegoederen en laaggeschoolden, en een schaarste aan middelbaar geschoolden, hooggeschoolden en gebouwen. Dit betekent dat Nederland een zichtbaar comparatief voordeel heeft in de productie van goederen waarbij intensief gebruik wordt gemaakt van duurzame productiegoederen en laaggeschoolden, en een comparatief nadeel in de productie van goederen waarbij intensief gebruikt wordt gemaakt middelbaar geschoolden, hooggeschoolden en gebouwen.

Een verdere disaggregatie van de factorbeschikbaarheden uit de handel naar de voor Nederland gebruikelijke onderwijstypes in plaats van laag-, middelbaar en hooggeschoolden verandert de resultaten niet. Dit illustreert dat de indeling naar laag, middelbaar en hooggeschoolden voldoet.

De resultaten in hoofdstuk 8 veranderen niet bij een verdere disaggregatie van de waargenomen factorbeschikbaarheden naar de voor Nederland gebruikelijke onderwijstypes in plaats van laag-, middelbaar en hooggeschoolden. De resultaten van een partiële empirische analyse met een HOV model dat sectorspecifieke factorinputs als verklarende variabelen gebruikt, moeten met grote voorzichtigheid worden geïnterpreteerd, omdat de factorinhoud ratio's van netto export en binnenlandse consumptie van de Nederlandse industriële sectoren sterk afwijken van de ratio's voor de gehele economie. Een regressieanalyse voor de handelsprestaties met als verklarende variabelen de sectorspecifieke factorinputs moet alle sectoren van de economie bevatten om betrouwbare resultaten betreffende de overvloedigheid en schaarste van factorbeschikbaarheden te genereren. Wat betreft de handelsprestaties van alleen de industriële sectoren in Nederland, levert de partiële empirische analyse op dat de inzet van hooggeschoolden en duurzame productiegoederen positief samenhangen met de handelsprestaties, terwijl de inzet van laaggeschoolden, middelbaar geschoolden en gebouwen een negatieve samenhang vertonen.

Hoofdstuk 9 geeft een samenvatting van het proefschrift en geeft antwoord op de eerder gestelde vragen aan de hand van het algemene raamwerk van figuur 1.1. De bevindingen in het proefschrift laten zien dat zowel landenspecifieke als sectorspecifieke factorinputs de handelsprestaties van industriële sectoren bepalen. Het landenspecifieke karakter van geschoolde arbeid, technologische kennis en fysiek kapitaal kan het gevolg zijn van verschillende nationale onderwijssystemen, van verschillen in technologiebeleid tussen nationale overheden en van verschillen in het nationale investeringsklimaat tussen landen. Het HOV model dat wordt gebruikt om sectorale handelsprestaties te verklaren, laat geen verschillen in input-output combinaties toe tussen dezelfde sectoren van landen. Ook laat het HOV model geen schaalvoordelen of productdifferentiatie toe. Modellen die dit wel toelaten zijn geschikt om de handelsvolumes tussen landen te verklaren, in plaats van de netto export zoals in het HOV model.

Het sectorspecifieke karakter van factorinputs is gebaseerd op verschillen tussen dezelfde sectoren van landen wat betreft de inzet van laaggeschoolden, middelbaar geschoolden, hooggeschoolden en technologische kennis. Het human capital model van het proefschrift laat de relevantie voor de productiviteit zien van sectorspecifieke factorinputs van menselijk kapitaal. Daarnaast bepalen sectorspecifieke verschillen in de kapitaalintensiteit en schaalvoordelen de productiviteit. In het Ricardiaanse handelsmodel, dat handelsprestaties verklaart door relatieve productiviteitsniveaus van dezelfde sectoren tussen landen onderling, kunnen sectorspecifieke factorinputs van menselijk kapitaal als verklarende variabelen worden beschouwd van de handelsprestaties. In het Ricardiaanse handelsmodel worden, in tegenstelling tot het HOV model, verschillende input-output combinaties tussen dezelfde sectoren van landen en schaalvoordelen niet uitgesloten als mogelijke determinanten van de handelsprestaties. Ten slotte, in het proefschrift wordt het HOV model gebruikt om zowel landenspecifieke als sectorspecifieke factorinputs te gebruiken als verklarende variabelen voor de handelsprestaties. Het blijkt dat er voorzichtig moet worden omgegaan met de resultaten van een analyse met sectorspecifieke verklarende variabelen in het HOV model.

Het theoretische raamwerk en de geschatte modellen van dit proefschrift kennen enkele beperkingen, die tevens richting kunnen geven aan vervolgonderzoek. Ten eerste is het voor een beter begrip over hoe investeringen in menselijk kapitaal de productiviteit beïnvloeden, noodzakelijk om de afzonderlijke productiviteitseffecten van de verschillende vormen van investeringen in initiële scholing en vervolgtrainingen te kennen. Ten tweede is het mogelijk om niet alleen gegevens over de gevolgde opleiding van arbeidskrachten te gebruiken bij het schatten van de productiviteitseffecten, maar ook gegevens over de beroepsspecifieke vaardigheden van arbeidskrachten. Hierdoor kan een completer beeld van de productiviteitseffecten van menselijk kapitaal ontstaan, en kan mogelijk een beter zicht worden verkregen op de aansluiting tussen de door arbeidskrachten verworven vaardigheden en de in hun banen vereiste vaardigheden. Ten derde is het wenselijk om meer onderzoek te doen naar de vier genoemde productiviteitseffecten van menselijk kapitaal. In het proefschrift konden het arbeids- en het allocatie-effect niet onderscheiden worden, terwijl de schattingen van het diffusie- en het researcheffect op een relatief korte periode zijn gebaseerd. Ten vierde is het mogelijk om de empirische analyses met het HOV model te baseren op meer realistische veronderstellingen. In het proefschrift worden bijvoorbeeld verondersteld volledige mobiliteit van productiefactoren tussen sectoren in een land en gelijke productiviteitsratio's tussen landen. Ten vijfde is het interessant om investeringen in menselijk kapitaal te endogeniseren in een algemeen evenwichtsmodel, zodat er een beter inzicht kan worden verkregen over hoe initiële scholing en vervolgtrainingen de productiviteit en de internationale concurrentiekracht beïnvloeden.

Curriculum vitae

Frank Cörvers was born May 3, 1966 in Heerlen, the Netherlands. He went to highschool at the Albert Schweitzer College in Geleen, where he finished VWO-B in 1984. He then started to study physics at the Catholic University of Nijmegen. In 1985 he switched to economics at the Maastricht University, where he graduated on the relationship between corporatism and economic performance in 1991. Subsequently he worked as a lecturer at the economics faculty of the Maastricht University. In 1992 he started the PhD project on human capital and international trade at the Research Centre for Education and the Labour Market (ROA) in Maastricht. In 1996 he became researcher at ROA. Since 1998 he is employed at Statistics Netherlands in Heerlen. He currently works as Task Group Manager of the Income Information System, sector Income and Wealth.

Frank Cörvers werd geboren op 3 mei 1966 in Heerlen, Nederland. Hij doorliep de middelbare school op het Albert Schweitzer College in Geleen, waar hij in 1984 het VWO-B diploma behaalde. Daarna begon hij aan de studie natuurkunde aan de Katholieke Universiteit Nijmegen. In 1985 ging hij economie studeren aan de Universiteit Maastricht, waar hij in 1991 afstudeerde op de relatie tussen corporatisme en economische prestaties. Daarna werkte hij als docent aan de economische faculteit van de Universiteit Maastricht. In 1992 begon hij aan het promotieproject over menselijk kapitaal en internationale handel aan het Researchcentrum voor Onderwijs en Arbeidsmarkt (ROA) in Maastricht. In 1996 werd hij onderzoeker bij het ROA. Sinds 1998 is hij verbonden aan het Centraal Bureau voor de Statistiek in Heerlen. Momenteel is hij werkzaam als taakgroepchef van het Inkomens Informatie Systeem van de sector Inkomen en Vermogen.

ROA Dissertation Series

1. Lex Borghans (1993), *Educational Choice and Labour Market Information*, Maastricht: Research Centre for Education and the Labour Market (ROA).
2. Frank Cörvers (1999), *The Impact of Human Capital on International Competitiveness and Trade Performance of Manufacturing Sectors*, Maastricht: Research Centre for Education and the Labour Market (ROA).

The central aim of the thesis is to establish the mechanisms along which human capital can affect international competitiveness as well as trade performance. Various questions related to this aim have been discussed either implicitly or explicitly, namely what is human capital, how should the stock of human capital be measured, what is its relationship with (technological) knowledge, which human capital factors can be distinguished, how is human capital accumulated by workers and firms, why do investments in human capital increase productivity, how can the effects of human capital on productivity and trade be measured, how large is the impact of different human capital factors on productivity and trade, what is the relevance of country-specific and sector-specific human capital factors for trade performance? The answers on these questions reflect the lessons learned from the thesis.

Chapters 2, 3, 4 and 5 of the thesis present a theoretical exposition of how human capital affects productivity as a measure of international competitiveness. Therefore these chapters distinguish different forms of human capital as well as different productivity effects of human capital. Chapters 6, 7 and 8 present empirical investigations into the effects of human capital on productivity and trade flows, particularly focusing on the manufacturing sectors of industrialized countries.

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