Workplace Skills, Technology Adoption and Firm Productivity: A Review

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Review of Workplace Skills, Technology Adoption and Firm Productivity

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Abstract

The way that skills contribute to productivity improvements in firms is still something of a "black box". There is general agreement that human capital (broadly defined) is important for growth. Less is known about the ways in which skills and knowledge contribute to a firm's pursuit of efficiency in production, the process of innovation and technology adoption, and to the take-up of market opportunities. This paper reviews literature on the types of skills utilised by firms, the mechanisms by which skills contribute to firm productivity, and how skills are acquired. It identifies potential policy implications relating to work based skills training.

JEL CLASSIFICATION

D21 - Firm Behaviour

D24 - Production; Capital and Total Factor Productivity; Capacity

J24 - Human Capital Formation; Occupational Choice; Labor Productivity

L19 - Market Structure, Firm Strategy, and Market Performance - Other

O30 - Technological Change - General

KEYWORDS

technological change, human capital; labour productivity; multi-factor productivity; firm productivity; workplace productivity; skills

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Executive Summary

Skills contribute in complex ways to a firm's productivity

There is general agreement that human capital (broadly defined) is important for economic growth. Less is known about the ways in which skills and knowledge contribute to a firm's pursuit of efficiency, innovation, and market opportunities. This paper explores the evidence about those ways. It does not cover the impacts of other firm inputs like R&D and access to capital.

What types of skills do firms need?

Three broad categories of skills are important in the search by firms for productivity improvements.

- Entrepreneurial ability is needed to identify and respond to market and innovation opportunities.
- Managerial capability is essential to provide the leadership and organisational skills required to oversee the effectiveness of production processes.
- The technical skills of employees support the effectiveness of production processes and the adoption of new technologies.

Skills contribute to increased firm productivity in three main ways

Increasing the skill level of an individual worker can influence the productivity of firms in three principal ways:

- Higher skill levels can increase a worker's own productivity, thereby improving the firm's productivity. A more productive worker will complete tasks more quickly, or with higher quality, or take more responsibility.
- The higher skill level of a worker can improve firm productivity by making better use of other inputs such as capital investments or R&D activities or new technologies.
- The worker's skill levels can affect the productivity of other workers in that firm through synergies in teams, or the productivity of other firms in an industry through knowledge spillovers in activities like R&D.

How are skills acquired?

The skills required by firms can be innate, developed in the formal education system, and extended on the job. Upskilling of the existing workforce can occur through work experience, on- and off-the-job training, and job turnover.

Entrepreneurs improve firm productivity by taking up innovations and developing market opportunities

Entrepreneurship performs a number of functions, including exploring market opportunities, risk taking, innovation, the re-allocation of resources, arbitrage, and market coordination. It typically takes two forms: breakthrough inventions by smaller entrepreneurs; and cumulative, incremental improvements by R&D in larger firms.

These forms are complementary, but require different skills. Smaller entrepreneurs need innate skills such as imagination and attitudes to risk, analytical abilities and knowledge that can be acquired, and sound judgment obtained through experience. The large firm's R&D activity needs researchers with a mastery of extant knowledge and analytical methods.

Regulatory policies influence entrepreneurial activity

Regulations affect the structure of payoffs that entrepreneurs face, and their impact on productivity. Pro-competitive policies allow entry by firms to explore new business opportunities, and assist resource re-allocation amongst firms. Policies affecting the costs of firms of entering or exiting, such as employment protection legislation, also influence firm dynamics. Access to finance supports firm start-ups and expansions.

Management capability is central to raising firm productivity

Managerial capability is central to removing inefficiencies and optimising firm performance. One aspect is managing production processes. Also important is the design of organisational structures that utilise technology and skill inputs effectively, and human resources management that ensure worker motivation and effort. Managers require a wide skill set, including the strategic ability to adapt to a changing environment, the organisational and supervision skills to run the business, people and communication skills, and an awareness of information management processes.

Management practices are also important

Human resource management practices can provide a coherent system of incentives that enhance the contribution of workers to firm productivity. These include individual incentive contracts, the screening of new hires for suitability, group incentive pay to encourage teamwork and effort, and the provision of training. Worker rotation increases flexibility and teamwork, while communication addresses worker concerns and locates productivity improvements.

Formal education only contributes some of the technical skills needed by firms

The skills firms seek are only partly formed within the formal education system. The earnings of individuals increase with their level of education. However, other behavioural traits and cognitive capacities, such as motivation, trustworthiness, and adaptability, seem to be equally important in explaining differences in earnings. Thus, the linkage with the education system is weaker where a significant sub-set of the skills required are formed inside the firm, or where the cognitive abilities sought are largely innate.

Skill-technology complementarities increase the relative demand for more skilled labour.

The adoption of new technologies increases the relative demand for skilled labour, by making skilled workers more productive and replacing the routine tasks of less skilled workers.

At the aggregate level, the increased supply of skilled labour allows firms to take up skill-complementary technologies, and can encourage further inventions. Even with substantial increases in the supply of skilled labour over the past two decades, the earnings premium for skills has remained high.

The entry and exit of firms allows skills and technology to be used more productively

Differences in the productivity of firms within an industry are both marked and persistent. Productivity increases as innovative firms enter, poorly run new businesses fail, and continuing firms adjust their mix of skills and technology. Resource re-allocation from less to more productive plants, and firm entry and exit, are important in aggregate multi factor productivity growth.

Plants with higher levels of firm productivity also have higher workplace skills. There is US evidence of different skill-technology matches amongst plants, giving rise to a growing dispersion of wages and productivity between plants within the same industry. This, in turn, is linked to different rates of technological adoption.

Firms adopting new technologies typically already have more skilled workforces

Technology adoption itself may not be the main driver of firm skill and productivity levels. Firms appear to have a more skilled workforce already in order to be able to adopt more advanced technology. The evidence suggests that workers are better paid because they are abler, rather than because they are utilising newer technologies.

Obtaining the full productivity gains from technical change requires changes in workplace organisation

Obtaining the full productivity gains from technical change, especially with the diffusion of computer based technologies (ICT), appears to require substantial changes in workplace organisation. These changes include flatter management structures, more team work, and performance-related pay. Thus, changes in workplace organisation complement technical change. Organisational change may account for a larger fraction of the productivity gains than does technological change alone.

Organisational changes facilitate adjustment in the skill mix. They increase the skill levels needed for data analysis and for worker autonomy and responsibility, and reduce the demand for less skilled labour for repetitive tasks.

…involving a range of adjustment and diffusion processes

Three broad groups of factors appear to be influencing the diffusion of ICT across industries and countries:

- The regulatory environment affects the ability of firms to take advantage of opportunities, in particular product market competition, and firm entry and exit.
- Firms differ in their ability to absorb ICT, arising from the firm's skill base and level of innovative activity, and the reorganisation of work practices.
- Large differences also persist in the costs of investing in ICT across OECD countries.

The time needed for investments in complementary learning and organisational change can lead to substantial lags between ICT capital investments and productivity growth.

Knowledge spillovers occur within and between firms

Increased individual skill levels can improve the productivity of co-workers and other firms through knowledge spillovers. The importance of these externality effects is hard to assess. Where people work, and who they work with, can contribute significantly to their productivity and wages. For instance, specialists working in teams benefit from the complementary skills of other team members.

Where there is a greater stock of shared knowledge in an industry, the individual firms will be more productive. Knowledge spillovers can arise through three specific mechanisms, namely sharing of inputs, matching, and learning. Thicker labour markets appear to be important in allowing better matches between firms and the skills required, as well as increased specialisation by workers.

There is some path dependence in decisions about technology adoption and skill investments

Nationally, firms may choose technologies conditional on the expected supply of skills in the workforce, while educational investment by individuals may be influenced by the expected availability of jobs.

The factors giving rise to low technology/skill matches are clearly important, and will influence the role for government. However, it is not clear what perpetuates low skill equilibriums over time, or hinders economies from transitioning out of them. There is evidence for the UK that persistent shortages of skilled labour may be influencing technology adoption and capital investments. However, the case for further increases in the supply of skilled workers depends on whether other factors are more critical.

A number of factors influence work-based training

A significant proportion of knowledge accumulation occurs on the job, including informal training. With ongoing technical change, continuous learning will be required to maintain the stock of skills in the existing workforce and offset skill obsolescence. Larger firms are more likely to provide on-the-job training, while higher labour turnover lowers employer incentives to invest in training. Those with few educational qualifications are likely to face more limited training opportunities in the workforce. Thus the provision of employer-funded work-based training tends to amplify the skill gap, rather than compensate for low levels of prior educational attainment.

There are failures in the supply of work-based training,

Imperfections in the market for work-based training seem likely. Contrary to the dominant view of human capital formation in the workplace, there is a good deal of evidence of extensive employer-funded general training, and of wage growth following training being much less than productivity growth. However, it is unclear how important these market imperfections are, and the extent to which they cause employers and workers to under-invest in work-based training.

... but the case for policy intervention is not clear-cut

Evidence of market failure is not a sufficient basis for government intervention. A comparative institutional analysis is warranted to assess the relative merits and effectiveness of the options. The design of any interventions depends on which types of market failure are more important. A number of co-financing arrangements are used in OECD member countries that allow employers and workers to generate more tailored training assistance packages and generate the types of skills needed by firms. They also permit various approaches to encouraging lifelong learning. Regulatory and/or institutional failure with particular interventions would also have to be taken into account.

Workplace Skills, Technology Adoption and Firm Productivity: A Review

1 Introduction

There has been ongoing evaluation of New Zealand's growth performance following the recent economic reforms. That performance has improved since the mid 1990s.[1] Growth in multi-factor productivity (MFP) is now more comparable with that of Australia. MFP growth has, however, been uneven across nine broad industry sectors through the 1990s – being better in primary industries, retail and wholesale trade, and personal and community services, but poorer in utilities, manufacturing, mining, and transport and communications. In addition, our capital to labour ratio is significantly lower than Australia's. The IMF (2002) has also identified differences in the rate of capital accumulation between Australia and New Zealand as being important in the divergence in growth rates between the two countries.

This paper explores some of the micro-foundations that help to explain these aggregate outcomes. It investigates how skills and knowledge generate productivity improvements within firms through the pursuit of efficiency, innovation and market opportunities. The analysis is organised around the firm, as it constitutes the basic production unit in the economy, and provides the link between capital, product and labour markets. The paper draws together the evidence on the role of skills and knowledge around three main themes: the different categories of skills involved, the mechanisms by which skills contribute to productivity improvements, and the acquisition of skills. The review indicates that substantial gaps exist in our understanding of how skills contribute to firm performance, which skills are important, and how important skills are relative to other firm inputs.

This role of skills within the firm is part of the wider linkages between human capital and economic growth. The skills and knowledge that influence firm productivity include the skills embodied in people through innate abilities, learned skills, accumulated formal and tacit knowledge. A skilled workforce can be obtained by recruiting suitably skilled workers, and/or by training employees on the job. Also included is the knowledge embedded in organisational and incentive arrangements. Less attention is given here to

[1] Black, Guy, and McLellan (2003) and Claus and Li (2003)) explore New Zealand's recent growth history.

the acquisition of disembodied knowledge through a firm's purchase of technologies and equipment.

The scope of the paper has been limited in three broad ways. First, the primary focus is on economic growth. Governments have concerns for fairness or equity, and the wellbeing of society has other dimensions, and so a wider range of goals will need to be taken into account in policy formulation processes.[2] Second, attention is restricted in the paper to the contribution of workplace skills to firm productivity. Other factors are excluded such as business R&D, the process for commercialising innovations from publicly funded R&D, and the cost of capital and New Zealand's financial institutions. Third, several aspects of the connection between workforce skills and aggregate growth are not covered in any depth. Given the paucity of New Zealand evidence, there is often a reliance on overseas findings. This requires that differences in firm size and economic geography be taken into account. It has also been assumed that increases in firm productivity are good for aggregate economic growth. A range of second round impacts, such as the effects on employment and on technology diffusion, would need to be included to formalise that connection.

The paper is structured in the following way. A framework for organising the review of literature is provided in Section 2. The review of evidence begins in Section 3 by considering the main attributes of the three broad categories of skills, and how each contributes to improvements in firm productivity. Section 4 sets out evidence on the linkages between skill levels and technology adoption, and their contribution to productivity. The evidence on knowledge spillovers that are occurring at the worker, firm and industry levels is considered in Section 5. In terms of skill acquisition, Section 6 focuses on work-based training, the scope for market failure in the demand for and supply of training, and whether government intervention might improve this outcome. Section 7 draws out the key themes in the paper, together with opportunities for further work.

2 Skills and firm productivity – an organising framework

This section provides an organising framework for sorting the evidence on how skills contribute to firm productivity. Three broad questions are explored: the broad types of skills required; the principal mechanisms by which skills contribute to technology adoption and increased firm productivity; and how skills are acquired over time.

2.1 Skills contributing to firm productivity

Three broad categories of skills seem to be important in firms for production, organisational design and technology adoption, although in reality these skills types probably exist along a continuum.[3] *Entrepreneurial ability* is needed to identify and respond to market shocks and to pursue market opportunities. These abilities combine a mixture of risk taking, innovation, resource re-allocation, arbitrage, and coordination. *Managerial capability* provides the leadership and organisational skills required to oversee the effectiveness of production processes. Managerial capabilities affect the decisions

[2] On the linkage from income to well being, see New Zealand Treasury (2001b).

[3] Paul David (2001) provides a more detailed categorisation of skills, abilities and knowledge.

about how to organise the set of production tasks, motivate workers, and, over time, to adapt the organisational structure. Employees' *technical skills* enable the various production tasks to be undertaken. Higher skill levels improve the effectiveness of production processes, and allow advantage to be taken of technological improvements.

2.2 Mechanisms by which skills contribute

The skill level of a worker can influence firm productivity in three main ways. Rising skills can affect a worker's own productivity in the given production tasks; there is the effect on firm productivity from the tasks that the worker performs with capital or technology; and the worker's skill levels can directly affect the productivity of other workers in that firm, or the productivity of other firms.

2.3.1 Skill level

Higher skill levels can increase a worker's own productivity, thereby improving the firm's productivity. For example, more productive workers will complete a production task in a shorter period of time, and/or with higher quality. They should make fewer mistakes, be able to recognise and solve problems in the tasks they undertake, and may need less supervision. They are also more likely to be adaptable to changes in production processes and organisational structures. Skills can be combined within the enterprise in various ways. Thus, firms have to make choices around the combinations of people who contribute generalist and specialist skills, or high and low skill levels, in order to maximise firm productivity.

Given bounded rationality, a more skilled worker may be able to "process" or "communicate" more information in a given amount of time, and hence contribute to better decision-making. Both the breadth and depth of skills may matter. For example, a worker with greater "depth" in a particular skill may perform tasks requiring that skill more quickly, while a worker with greater "breadth" of skills may be more adaptable in undertaking a range of production tasks within a firm. Firms allow combinations of skills to be drawn together and organised to take advantage of synergies between skills, and to balance the gains from skill specialisation and the need for coordination. While there can be gains from greater specialisation in labour inputs, these will be offset by the costs of coordination. As coordination costs rise, generalist skills will be preferred.

2.3.2 Interactions with other firm inputs

Higher worker skill levels can improve firm productivity by making better use of other inputs such as capital investments or R&D activities or new technologies, and in the assimilation of knowledge embodied in capital investments. It seems likely that capital complements skilled labour, but is a substitute for unskilled labour. Nevertheless, a certain level of basic levels of skills may be required by workers for the operation of more sophisticated technology.

The optimal organisational structure is one that allows synergies in the use of mixes of inputs to be captured. Obtaining the full productivity gains from technological change may require changes in workplace organisation. Gains may also be available to firms from information management systems to assimilate external knowledge, manage internal

knowledge, and apply that knowledge commercially. Both have implications for skill requirements.

2.3.3 Knowledge spillovers

The worker's skill levels can directly affect the productivity of other workers in that firm through synergies in teams, or the productivity of other firms through knowledge spillovers like R&D activities. These occur because of the unique economic characteristics of skills and knowledge. Knowledge is non-rival because it can be used simultaneously by many, and its use is only partly excludable through institutions like patents or employment contracts. Knowledge spillovers are thought to be an important element in the growth process. Within the firm, knowledge transfers can occur between workers in teams. "Co-worker" effects can be significant: who you work with matters in terms of the use of jointly held knowledge. Further, workers changing employers can be a source of knowledge transfer between firms. In this case, skills that are developed in one firm then become available for use at another firm.

Spillovers can also occur between firms or within localised regions, either through market exchanges or by direct interactions with other firms. These transfers between skilled workers across firms lower the cost of knowledge accumulation. For example, the rate of diffusion of information technologies will be influenced at the firm level by the costs of adoption, which will be affected by the industry's experience of implementing the technology. Shared knowledge or trust also reduces the costs of coordination. In addition, proximity of upstream or downstream firms can influence the level of specialisation within firms or locations, as in industry clusters or the proximity to suppliers or customers.

Spillovers can also arise from expectations about the behaviour of firms and workers in the choices of skill and technology mixes. Firms may make decisions about capital investments, and people may make decisions about skill investments on the basis of expectations about what they expect other parties will do. This possibility has given rise to concerns around coordination failures that affect the skill/technology mix adopted. The importance of path dependence increases where it takes much time and effort for a firm to change its resource and technology mix, or for workers to build up skills. An implication may be that the expected supply of more skilled workers can influence the adoption of a more technologically advanced trajectory.

2.3 Skill acquisition

For policy purposes, an understanding is required of how the skills and knowledge required in the workplace are formed. In general, worker skills are derived from innate ability, family background factors, and knowledge accumulated from formal education and learning in the workplace.[4] Learning in the workplace includes formal training activities, learning-by-doing, or informal knowledge transfer from other workers, or by workers changing jobs. This process of knowledge accumulation is important. It influences decisions on educational investment before and after employment, and how the returns

[4] Less attention is given here to knowledge accumulation up to the end of formal education, as it is not central to the discussion. The Journey project (Jacobsen et al (2002)) looks at child development processes. Nechyba (1999) looks the influence of family background factors. Given the cumulative effects of education, Heckman (1999, 2003) argues in general for earlier rather than later interventions to support skill acquisition.

from these investments accumulate over the working lifetime. With the likelihood of skill obsolescence given technical change, some approach to continuous learning is required.

In the knowledge accumulation process, the knowledge acquired in one period complements the skills available in next. Skills are more productive in environments where there is an existing high stock of knowledge. This can affect decisions about recruitment policies, the building up of firm-specific knowledge, information retrieval processes, or mentoring by more experienced and skilled workers, and will be influenced by the size of the firm.

In decentralised labour markets, the dominant model for thinking about firm-based human capital investments has been that of Becker (see Acemoglu and Pischke (1999)). Workers evaluate investments in education, based on earnings foregone and improvements in future earning streams, and may accept lower or no wages while skills are built up. Employers, faced with risks of labour turnover or poaching by other employers, will invest mainly in firm-specific knowledge (which by definition is not valued elsewhere), and require training wages to be paid to fund the acquisition of general skills (which are valued by other employers). The Becker model substantially relies on workers and employers to finance training, and assumes there is no case for government intervention. However, firms are observed to fund much generic training, and to pay wage increases after training that are less than the gains in productivity. This suggests that labour market imperfections exist, and that firms are adopting other strategies to encourage employee effort, manage information asymmetry and incentives, and respond to employee exit/mobility costs and job turnover.

2.4 Complementarities and productivity improvements

At some point, additional expenditure on education or training will lead to decreasing returns from those investments.[5] For firm productivity to improve beyond that point in response to additional investments in education or training, and overcome decreasing returns, increasing productivity is required from the use of skills with other production inputs (see Maré (2003)). These complementarity effects can occur in various ways, such as enabling the more effective use of new technologies. Here improvements in workforce skills increase overall returns by raising the productivity of other resources. Because of the particular economic characteristics of knowledge, Dowrick (2003) argues that "complementarity is probably more pervasive in the accumulation of skills than in the accumulation of objects." If the gains from these complementarities are strong enough, the effect of diminishing returns to further investments in training may be overcome.

Complementarities are likely to influence firm productivity in a number of ways. For example, skills can be combined with other inputs by the firm to increase returns, such as R&D activities or using new technologies, or in conjunction with organisational change. Combinations of skills may be brought together in teams, and the mix of skills can yield synergies that are productivity enhancing. Knowledge transfers (or spillovers) can occur between firms where the knowledge acquired by one firm (for instance in R&D activities) can benefit other firms in the industry or in the same location, and through employee movements between firms. Knowledge can accumulate via training or learning-by-doing,

[5] For the purpose of illustration only, Krueger and Lindahl (2001) suggest that relationship between education and GDP growth is often modelled as being linear, whereas it seems to them to peak at about 7.5 years of education, which is less than the average level of education for OECD countries.

where stocks of knowledge or skills acquired in one period complement the skills available for use in the firm in the next.

These complementarities need not be externalities. They may be able to be captured, at least in part, by various "Coasean institutions". If complementarities can be priced, for example, private and social benefits are equated. Over time, one would expect organisational approaches to be sought to take advantage of these complementarities, and so internalise these spillovers to some extent. Some may be internalised by individuals. Entrepreneurs, for instance, are thought to possess a range of complementary skills. They may also be internalised within firms – such as opportunities to internalise gains from R&D expenditures through patents. There may be scope for internalising firm-level spillovers through industry associations, joint ventures, clusters and vertical integration. Where these effects are unable to be internalised by private institutions, at reasonable cost, there may be a case government intervention.

3 Skills as determinants of firm productivity

A range of skills are utilised within the firm. Three broad categories of skills are considered here: entrepreneurship that identifies and responds to market and innovation opportunities; the managerial capabilities associated with overseeing production activities; and the technical skills required to undertake production processes. These roles, while being presented as distinct for the purposes of this discussion, in reality probably exist along a continuum. They may be undertaken by separate people, or combined in the one individual, especially in smaller firms. This section explores in more detail some of the attributes of each of these categories of skills, and the factors that influence their contribution to firm productivity.

Following Baumol (1993, p3), entrepreneurship is distinguished from management. The entrepreneur chooses the output and the technology, and is responsible for the marketing strategy. The manager, given these settings, chooses the labour and capital inputs, and the organisational structure and management practices, in order to produce and market that output. Entrepreneurship might be viewed as pushing out the production frontier, while the role of management is to remove inefficiencies and move the firm outwards towards its production frontier. As a result, both of these roles are clearly important in improving firm productivity. There is inevitably some fuzziness at the boundary of these activities in terms of the pursuit of market opportunities, utilisation of technology, choice of organisational structure, and development of an innovative culture.

Bowles et al (2001) identify a similar set of skills required within the firm. Skills may be "Walrasian" in that human capital is viewed as a factor in the production process in the neoclassical sense. The attributes required by the parties in moving to equilibrium are not considered. They may be "Coasean", reflecting the capabilities to generate and work within different organisational structures. "Schumperterian" skills relate to the abilities needed to seek out opportunities, adapt to change, and respond to markets in disequilibrium. However, Acemoglu (2002) considers that the Schumpeterian and Coasean ideas are similar, in that an important dimension of skills may be adaptability to working in different production environments.

3.1 Entrepreneurship

Entrepreneurial skills influence firm performance through the choice of final outputs. Their role is in recognising and pursuing unexploited market opportunities. Different measures of entrepreneurship have been used. Some of the literature on the subject associates entrepreneurship with small business activity and firm entry. For example, Audretsch and Thurik (2001) look at the link between entrepreneurial activity in a country, as measured by the self employment rate and the share of economic activity accounted for by small firms. Carree and Thurik (2003, p445) cite literature indicating that small enterprises serve as the engine of innovative activity in some industries. However, Baumol (2004) sees two types of entrepreneurship: breakthrough inventions undertaken disproportionately by smaller independent inventors and entrepreneurs; and cumulative, incremental improvements by larger firms with substantial R&D activities. It therefore appears more useful to think of entrepreneurship as a general activity, rather than the functions performed by particular people or firms.

Differing views exist about the set of key functions that entrepreneurs contribute. They involve varying combinations of the recognition of market opportunities, risk taking, R&D and innovation, the re-allocation of resources amongst firms, arbitrage, and market coordination. Formaini (2001) and Rima (2002) set out the development of understanding and treatment of the entrepreneur in economics. For Rima (2002), the entrepreneur is "someone who specializes in taking responsibility for and making judgment decisions that affect the location, form and use of goods, resources or institutions". Rigotti, Ryan, and Vaithianathan (2001) build a model of entrepreneurial innovation and risk aversion, with types of firms led by bulls and bears who interpret imprecise risk information in more optimistic or pessimistic ways. The model developed by Blanchflower and Oswald (1996) finds that the probability of self-employment rises with receipt of an inheritance or gift. They posit that entrepreneurs perceive business opportunities that are not seen by others, but are constrained in taking them up by limits on borrowing. Kirzner (1997) reviews the more general coordinating role of entrepreneurs in markets as moving the economy towards equilibrium.

Lazear (2002) views entrepreneurs as "jacks of all trades who may not excel in any one skill, but are competent in many". They differ in this regard from specialists. His model tested whether entrepreneurs (those who reported starting a business) had a broader skill base that was built up from more diverse studies and/or a wider range of work experiences. He used data on alumni from Stanford Graduate School of Business, and found that entrepreneurs are more likely to have held a number of prior roles, and taken a more dispersed set of courses. The "jack of all trades" label also applies to senior managers. A similar study by Charney and Libecap (2000) explores how entrepreneurship education contributes to the sales and employment growth of small firms. It also appears to contribute to the transfer of technologies from universities to the private sector. Bowles et al (2001) note that, while part of the skill set of entrepreneurs is amenable to development through training (such as analytical ability), other elements may be innate (such as imagination and attitudes to risk), while others (such as foresight, or soundness of judgment) may be honed through learning-by-doing.

Baumol (2004) contrasts the very different (but complementary) modes of operation of the smaller independent inventors responsible for a disproportionate share of breakthrough inventions, and of those larger firms involved in cumulative, incremental research. The skill sets utilised are very different, which is reflected in their educational backgrounds. Break-through inventions require originality and imagination, and tend to be provided by

those who have had little formal training. In contrast, the incremental advances in the large firm's R&D activity require researchers to be highly equipped in extant knowledge and analytical methods. While the teaching practices required for the mastery of current knowledge and practices are well known, Baumol notes that much less is known about the appropriate training for those generating breakthrough inventions.

Entrepreneurial activity is essential to the process of innovation and adaption to market opportunities. Their contribution to the productivity of firms is in finding new ways of carrying out economic activities, and developing new market opportunities. Schumpeter saw the entrepreneur as the main player in the process of competitive rivalry, through creative activities such as the opening of new markets, and the introduction of new goods or production processes. These confer monopoly power and profits for a time, and engender a process of creative/destruction. Baumol (1993) also sees this role as enhancing the dissemination of new technologies and knowledge through an industry, by looking for new or non-standard ways of doing things. While not all entrepreneurial activities are successful, in terms of firm dynamics they are responsible for firm entry, and a significant part of the resource re-allocation occurring within and between firms.

Baumol (1993) argues that entrepreneurs can act in productive or unproductive ways, depending on the structure of payoffs that they face, and that this is important for growth. They respond to the profit objective on the basis of the "rules of the game". Consequently, they can act in ways that improve efficiency and spur growth, or engage in rent-seeking. Three broad groups of regulatory policies affect the structure of payoffs: product market regulations; policies that affect the costs to the firm of entering or exiting the industry; and access to financial resources.

In terms of product market settings, the OECD (2003b, Chapter 3) argues for pro-competitive regulations to improve productivity performance and stimulate entrepreneurial activity. Increased product market competition provides more scope for risk takers to explore new business opportunities, and stimulates the process of creative destruction (firm entry/exit). Here innovation is the primary means whereby rivals maintain their market share. Competition also acts to constrain rent-seeking and eliminate slack in the use of inputs. Conversely, restrictive regulatory policies make catching up to technology leaders difficult. Cross-country OECD work has shown that over half of labour productivity gains come from within firm resource reallocation. The OECD notes that entry is important in industries where the technology is changing, as in the case of the uptake of ICT. Gains also come from low productivity firms closing down.[6]

Policies influencing the costs to the firm of entering or exiting the industry can also affect entrepreneurial activity. Such policies influence the scope for resource re-allocation. They include employment protection legislation (EPL) (see OECD (2003b), where there is some evidence that high hiring and firing costs weakens incentives to innovate and affects productivity performance. The adjustment costs associated with stricter EPL relative to the costs of internal retraining can also influence the adoption of new technologies. Other costs of firm entry/exiting are those associated with firm registration and bankruptcy, and the rules around mergers, takeovers, foreign direct investment (FDI). The OECD (2001, Chapter V) considers the effects of regulations around firm registration and bankruptcy. If administrative barriers prove to be excessive, complicated or protracted, entry can be

[6] Estimates of the effects of firm dynamics on labour productivity and MFP are given in S 4.2.

discouraged.[7] Black and Strahan (2004) provide a case study, looking at business formation following US banking deregulation.

Access to financial resources is also important to support firm creation and entrepreneurial activity. The OECD (2001, Chapter V) comments on the role of well developed and regulated financial markets, in relation to the availability of risk-capital for firms starting up. Lack of finance is viewed as potentially being an important impediment to the entry of innovative new firms. Kreft and Sobel (2003) examine the relationship between entrepreneurial activity and access to venture capital in US states. They explore which side of this relationship local government strategies should focus on, by investigating the direction of the causal relationship. They compare two measures of entrepreneurial activity (sole proprietorships and patent activity) with a measure of venture capital investment. Their results show a one-way causal effect flowing from entrepreneurship to venture capital investment, suggesting that higher entrepreneurial activity in a state causes an inflow of funds. There is a question of whether sufficient controls included for omitted variables to allow conclusions to be drawn at this level of aggregation.

The case study by Lerner (2004) looks at the rationale for, and effectiveness of, the government being involved in the practice of subsidising small high-tech firm start-ups. He explores the two assumptions underlying such interventions: that the private sector will provide insufficient capital to start-up firms, and that governments can identify profitable investments. He notes that such start-ups are inherently risky, and that the providers of financial resources face severe informational asymmetries. If venture capitalists often pick losers, can governments do better? Lerner then evaluates the rationale for government involvement, in terms of certifying these firms to venture capitalists, and generating technological spillovers. He then considers the challenges of designing interventions to achieve the aims and limit the risks involved.

Audretsch and Thurik (2001) look at the link between entrepreneurial activity in a country (as measured by the self employment rate and the share of economic activity accounted for by small firms) and growth performance. They find increases in entrepreneurial activity occurring where industry structure is moving to a greater role for smaller firms. They argue that high levels of uncertainty associated with technological change, deregulation and globalisation have shifted industry structure towards less concentration and decentralisation. They also argue that, because of the inherent features of knowledge such as uncertainty and knowledge spillovers, entrepreneurship becomes more important in a knowledge economy. Further, entrepreneurial firms become an important vehicle for the transmission of those spillovers. Their policy prescription emphasises approaches that enable the creation and commercialisation of knowledge, such as encouraging R&D, venture capital and firm start-ups.

The Global Enterpreneurship Monitor (Reynolds, Bygrave and Autio 2003) provides a periodic assessment of national entrepreneurial activity. GEM provides two measures of entrepreneurial activity. The Total Entrepreneurial Activity (TEA) index measures the proportion of start-up firms in their first 42 months of operation, on the basis of population telephone surveys. The Firm Entrepreneurial Activity (FEA) index provides a measure of entrepreneurial firms amongst existing firms, on the basis of a survey of experts. The latest GEM (2003) puts New Zealand in the top bracket for both indices, along with a number of other non-OECD countries. (There are some questions about the robustness

[7] The OECD (2001, Figure V.7) views New Zealand as having lower administrative barriers.

of subjective assessments used in the indices, and the comparability of this data across countries.)

3.2 Management capability

The role of managers is to choose production processes, to implement these effectively, and to remove inefficiencies. They also design and operate the organisational structures that enable the firm to operate effectively and utilise the complementarities existing between capital and skilled labour. This includes the application of human resources management (HRM) techniques which improve the productivity of workforce, by addressing agency issues and ensuring worker motivation and effort. This assessment of managerial capability is organised around two topics: the nature of the contribution that management systems make to firm productivity; and the evidence on managerial performance in New Zealand.

3.2.1 Models of management practices

Within the institutional economics literature, various approaches have been utilised to investigate the nature and scope of decision making activities within firms.[8] These utilise in some way the Coasean idea that institutions serve to facilitate exchanges, and operate to manage contractual constraints more than production tasks. A key feature is the management of information – both internal and external – in a changing environment. Three approaches are identified here to indicate something of the range of different, but overlapping, sets of management activities:

- *Hierarchies within firms:* Managers operating in hierarchical structures undertake a range of functions such as planning, decision making and supervising. Hierarchies provide the means for managing agents' limited capacity to acquire and process information in complex environments. They allow talented individuals to hold more senior positions and exert more influence. The size of the firm and the extent of senior managers' influence are limited by the difficulties inherent in supervision, co-ordinating and contracting.

- *Human resource management practices:* The focus here is on the effective management of employment relationships. The task facing managers is getting the best performance from their workforces using a range of human resource management practices that align workers' efforts with the aims of the firm. The objective is also to maximise worker input into the efficiency of production by eliciting worker ideas for improvement and assistance in problem solving.

- *Operating routines and dynamic capabilities:* The emphasis here is on the ability of the firm to adapt to changed circumstances through various knowledge acquisition processes. This knowledge is structured within the firm into the operating routines that guide "business as usual", and the dynamic capabilities by which firms systematically respond to change. Management has a key role in the development of these knowledge bases and routines. The formation of routines and capabilities economises on bounded rationality, but also creates the possibility of path dependence through retaining ineffective practices.

[8] A more detailed analysis would require greater use of management literature.

These models tend to incorporate a limited range of behavioural variables. Other behaviours may also be important for firm success. Bertrand and Schoar (2003) note that to date studies have tended not to include manager characteristics. They provide an initial assessment of how the behaviour and aims (ie, the "style") of individual managers affect corporate behaviour and firm policies. The use of matched manager-firm panel data enables the independent contribution of managers to be tracked over time as they move between firms. The data on CEO characteristics they include is limited to the position they came from, MBA graduation, and age. They find that these manager characteristics explain a significant proportion of variation in investment, financial and organisational practices.

Hierarchies within firms

The literature on hierarchies within firms points to the important roles of managers across a number of dimensions (see Holmstrom and Tirole (1989), Borland and Eichberger (1998), Radner (1992) and Rosen (1982)). These include managing information flows and decision making, contracting and supervision, incentive structures, internal labour markets, and providing an authority structure. One dimension is the management of information flows within pyramidal management structures. Hierarchies provide the means for managing agents' limited capacity to acquire and process information in complex environments. Processing wide-ranging information, such as customer or production requirements, must inevitably be decentralised. Higher tiers of management can access more aggregated information, but require it in a more distilled form. Bounded rationality requires that trade-offs be made between costly information collection and decision making where errors are also costly. The costs of coordinating information communications across management layers limit their number.

Hierarchies also allow talented individuals to move into more senior positions. Authority is matched to talent by market forces. The contribution of top managers is multiplicative, in that their influence filters down through the organisation. Conversely, their failures in their supervisory, coordination and arbitration functions also flow down the hierarchy. The contribution of senior manager to firm productivity is, therefore substantial. A related feature of hierarchies, given incomplete internal labour contracts, is that supervision of subordinates is required. The interests of owners, managers and workers need not be aligned. Supervision enables directions to be given across management layers. However, there are limits to how effectively supervision and incentives extend down the hierarchy, potentially yielding a loss of control as the firm increases in size. Thus, the size of the firm and the extent of senior managers' influence are limited by the difficulties of supervision, co-ordinating and contracting.

Hierarchies also create internal labour markets. These provide source of information about the productivity of worker. They allow career paths, where the accumulated knowledge of the employee and the awareness of their capabilities allows them to be assigned more responsibility. Hierarchies allow yardstick competition where in promotions the performance of agents can be compared. Given incomplete employment contracts and unobservable behaviour, incentive problems arise. These can be addressed in part through supervision, monitoring and incentive arrangements.

Human resource management practices

In a series of papers, Ichniowski, Shaw and Prennushi (1995, 1997), and Ichniowski and Shaw (2003) examine the effect of a range of human resource management (HRM)

practices on firm productivity. They argue that these practices are complementary, in that using one more intensely increases the benefits gained from the others. They suggest three main reasons for this: reducing the incentive problems under certain performance pay schemes; eliciting worker ideas; and supporting multi-tasking and problem solving.

These authors collected longitudinal data on measures of productivity for 26 steel plants in the US, and the associated work practices, and technology usage. The investigation of one specific production process limits the effects of other sources of firm heterogeneity on productivity findings (but raises questions about their generality). Work practices measured included work teams, flexible job assignments, employment security, training in multiple jobs, and incentive pay. They found that the adoption of clusters of these practices yielded substantially higher levels of productivity (in terms of steel throughput) than more traditional personnel practices, such as narrow work definitions, strict work rules, hourly pay and close supervision. In addition, they found that the adoption of individual practices in isolation had little or no influence on productivity. They tested models to identify the effects of HRM practices independently of the effects of any changes in management or wages that may have been occurring concurrently. They note that these HRM practices are adopted at all greenfield sites, but that transition costs can hinder their adoption at existing sites.

They see the gains from clusters of HRM practices as evidence of the importance of complementarities that exist amongst these practices. These complementarities are reflected in the high correlations amongst the effects of these variables on firm productivity. That is, individual practices may be more effective when they operate in concert with other practices. In this way they address the full range of personnel management practices that influence workers' contribution to the productivity of the plant. Together, these "high involvement" practices provide a coherent incentive system. Free riding by individual workers is overcome through both individual incentive contracts, the screening of new hires to assess suitability for teamwork, and also group incentive pay to encourage a culture of teamwork and effort. Appraisals of subjective dimensions of performance were included to recognise worker behaviours where subjective assessment is required, like dependability or problem solving initiative. Other HRM variables included were pledges of employment security which helped the adoption of change, rotation of workers across tasks which increased flexibility and teamwork, communication to address concerns and find productivity improvements, and off-the-job skills training. Labour relations were measured in terms of unionisation of the production line and the grievance filing rate.

More extensive attention has been given to incentives in remuneration structures, for instance by Freeman (2000), Prendergast (1999, 2002), Lazear (2000) and Feldstein (2003). Freeman (2000) notes that studies show a positive relationship between incentive pay and productivity, though with more variable results. Conyon and Freeman (2002) review UK evidence on shared compensation schemes. One question about these studies is whether, following the Ichniowski et al studies, the omission of other HRM variables will bias upwards the estimated contribution of incentive pay schemes.

Operating routines and dynamic capabilities

The emphasis here is on management's role in enabling the firm to adapt to change. It is a more dynamic perspective on how the changing technological or market environment shapes the way the organisation operates. Peter Gorringe (1993), building on the work of Nelson and Winter (1982), considers the role of firm capabilities and competencies that

have been built up over time through various knowledge acquisition processes (such as on-the-job learning, interaction with customers and problem solving). It is often tacit, and specific to the particular processes operating within the firm. This knowledge is structured within the firm into the operating routines by which firms respond, which in turn contributes to the firm's capabilities and culture. Management has a key role in the development of these knowledge bases and operating routines. These routines have strengths and weaknesses. The formation of routines and capabilities economises on bounded rationality, but also creates the possibility of path dependence around getting stuck in ineffective practices. Competition leads to the selection of routines that are effective, and the modification or demise of routines that are not.

Teece and Pisano (1998) develop the notion of dynamic capabilities by which firms systematically respond to change. Zollo and Winter (2002) view dynamic capabilities as the processes by which operating routines are modified. Their definition is that a dynamic capability is "a learned and stable pattern of collective activity through which the organisation systematically generates and modifies its operating routines in pursuit of improved effectiveness". Teece and Pisano see dynamic capabilities as key to maintaining competitive advantage in a changing environment. They see them as incorporating strategic management, but also as the ability to systematically adapt and re-configure internal technical, organisational and managerial processes. Thus, a firm's learning ability strongly influences its competitive advantage. Managers have a role not only in addressing agency and incentive problems within the firm, but also in maintaining its knowledge assets and problem solving competencies that enable it to anticipate and respond. Since building competencies takes time, and these can be slow to adapt, a degree of path dependence is inevitable. Hence, when significant technological changes require substantially different routines to be implemented effectively, this appears more likely to occur through firm entry.

In one application of this perspective on capabilities, Lane and Lubatkin (1998) find that a firm's absorptive capacity – its ability to locate, assimilate and utilise new external knowledge – is important. With rapid technical change, firms are unable to generate all the knowledge required to adapt, and must utilise external sources to build their own capabilities. Through "learning alliances" with other firms they can accelerate the development of internal capabilities. Lane and Lubatkin explore the effects on learning of the characteristics of the "teacher firm" in terms of their knowledge base, the similarity of the two firm's organisational arrangements, and the information being offered. They test their model with data on R&D alliances between pharmaceutical (the "students") and biotechnology companies (the "teachers").

Knowledge management (KM) policies also appear to improve innovation and productivity outcomes. The suggestion is that in the so-called knowledge economy, practices for acquiring processing and applying knowledge become more important. Kremp and Mairesse (2004) utilise a French data set on manufacturing firms to explore the effects of relatively well defined KM policies. The KM policies investigated include a culture of knowledge sharing, practices to motivate staff to remain in the firm, forging external alliances and partnerships for knowledge sharing, and implementing written KM rules. The data indicates that larger firms, and those more connected with technology intensive industries, are more likely to have introduced KM practices. Those firms undertaking R&D and adopting new management methods had also adopted these practices. The joint adoption by firms of two or more KM practices suggests that they are viewed as complementary. KM usage is found to be positively associated with firm innovation and

productivity, after controlling for firm size, industry and R&D effort. (With cross-section analysis, establishing causation is more difficult with limited controls for other factors.)

3.2.2 New Zealand evidence

The Ministry of Economic Development's *Firm Foundations* (Knuckey, Johnston, Campbell-Hunt, Carlaw, Corbett and Massey 2002) provides evidence on the state of business practices in New Zealand. This includes insights on aspects of management capability, such as employee relations. *Firm Foundations* (Knuckey *et al* 2002) reports data on the implementation by firms of six business practices (such as leadership and planning, quality and supplier focus, and innovation and technology) that appear from management literature to be associated with higher firm performance. Business practices influence how firms operate to achieve outcomes (such as quality and service, timeliness, flexibility, innovation and human resource management practices) and create competitive advantage. Leading and lagging firms are distinguished on the basis of being in the top or bottom 20% of firm scores of both business practices and outcomes.[9] Several papers by Fabling and Grimes (2003, 2004) explore the *Firm Foundations* data to determine how adoption of specific business practices is aligned with the data obtained on business results (using self-assessments of profitability, productivity and return on investment relative to competitors, and trends in sales and market share). They find that only three of the business practices have a significant effect on any of the business results, and only innovation and technology affects more than two.

Management capability: The Ministry of Economic Development (2003) has undertaken a review of the evidence on the level of management capability in New Zealand. There is evidence for the early 1990's of managers utilising older styles of supervision and control, and being slow to adapt to the changed environment following industry deregulation. There is also evidence (especially from *Firm Foundations* and its predecessors) that few firms have adopted a strategic approach to innovation, although there appears to be some improvement. Enhanced managerial capabilities are also thought to be important when firms seek to expand beyond the small domestic market into export markets. This can occur at an early stage of their development when their organisational structure is becoming more specialised and formalised. More generally, the *Firm Foundations* study found that the largest differences between leading and lagging firms, in terms of the indicators of leadership and planning, were associated with having a vision statement, promoting company values to employees and incorporating stakeholder requirements. The econometric work of Fabling and Grimes (2003) found little evidence of an association between formal planning processes and the indices of business results, except for formal goal setting.

Technology and innovation: Innovation occurs in response to a number of inter-related search, experimentation and development activities. These include product and service innovation, process and organisational change, and the purchase of new technologies. The *Firm Foundations* study found large differences between leading and lagging firms in terms of carrying out formal R&D, and purchasing new technologies. For instance, only one in five firms regularly or continuously undertook R&D. Fabling and Grimes (2003, 2004) found that the implementation by firms of innovation related practices involved

[9] The *Firm Foundations* study also compared NZ business practices with those used in Sweden. It applied the same methodology to manufacturing firms in both countries with 10 FTEs or more. Across most business indicators, Swedish manufacturers outperformed their NZ counterparts. NZ firms seemed to perform relatively well on information and benchmarking, but less well on employee practices, quality and supplier focus, and formal planning. There also seems to be a long "tail" of under-performing NZ firms.

having up-to-date core equipment, continuous in-house R&D, and making investments in marketing new products were significant for six of the seven business result indices. However, less than 20% of the firms surveyed innovated along more than one of these dimensions. Few firms adopted all three innovative practices, and these are mostly found in the services sector. Manufacturers were relatively less innovative in terms of core equipment.

Information and benchmarking: The *Firm Foundations* study investigated the use of internal and external information. It noted a heavier emphasis on financial or quality measures, compared to innovation and HR. The study found that the major distinguishing feature of leading firms was the emphasis on external benchmarking of performance with competitors.

Employee practices: Managerial capability contributes to good employment relations. It influences the ability of firms to re-organise working relationships in order to improve productivity and respond to changing market conditions. The importance of particular forms of worker participation and incentive alignment in enhancing productivity is emphasised by Ichniowski and Shaw (2003). *Firm Foundations* found measures such as having employee performance review and performance pay systems, providing training, and providing job rotations distinguished the leading firms. Here Fabling and Grimes (2003) found a positive association between performance pay and two business practices (namely, relative productivity and net cashflow). Of the other employee practices, only formal goal setting was linked to improved outcomes.

3.3 Technical skills

More skilled workers can improve the output of the firm in various ways, such as undertaking tasks more quickly and with fewer mistakes, performing more complex or responsible tasks, and implementing new technologies. Much of the evidence on the value to firms of skills is from the estimated relationship between an individual's education and their earnings. However, other cognitive capacities and behavioural traits also seem to be influencing earnings outcomes, such as motivation, trustworthiness, and adaptability. Work experience is also rewarded. Thus, firms seek skills and abilities which are only in part formed within the formal education/training system. Nevertheless, the evidence reported here and later points to a positive relationship between higher skill levels and both earnings and firm productivity.

The starting point for analysing the contribution of skills is to use level of education as a proxy for skill. The strength of this approach is that it allows a focus on the knowledge accumulation process over the working life, including the level of education, work experience and on-the-job training. It also provides a direct link back to major policy instruments – the funding of education and industry training. However, this approach has several limitations. A major concern is over the strength of the signalling effect, where credentials reflect underlying innate ability rather than productivity improvements from further education. Without controls for ability effects, the estimates of the benefits of education will be biased upwards. Wages may also not be a satisfactory proxy for productivity. Reasons for this include wages following training not reflecting productivity gains, wages reflecting labour demand/supply interactions, the payment of efficiency wages and the exclusion of knowledge spillovers.[10]

[10] Johnston (2004) provides a discussion of the wider benefits of education.

New Zealand evidence on the returns from education and qualifications have been provided by Sylvia Dixon (1996) and Sholeh Maani (1999). Sylvia Dixon uses Household Economic Survey data for two yearly intervals from 1984 to 1994 to explore changes in the distribution of earnings over time. She finds, when pooling this data, that workers with no qualifications have earnings 16% below those who have school qualifications, while having university qualifications yielded 31% higher earnings. The introduction of industry and occupational dummies reduced the earnings advantage from having a university qualification to 19%, suggesting that some of the variation in earnings is due to job characteristics or unmeasured variables correlated with industry or occupational groups. Sholeh Maani used 1996 Census data to analyse private and public returns to higher education, and compares these with returns in earlier census years. Relative to no school qualifications, the private rates of return from attaining School Certificate or higher qualifications are significant, and rose from 1981 to 1996 with few exceptions. It should be noted that these models do not control for innate ability.

Earning equations can also separate out the effects of work experience. The OECD (1998, p60) provides cross-country estimates of literacy, educational attainment and experience effects. These estimates show that the earnings effects of experience are significant, and that the effects of additional years since formal education have effects of a similar order to years of schooling. Sylvia Dixon (2000) has assessed the effect on returns of reduced work experience for women in contributing to the gender wage gap. It is not clear what mix of skills is being rewarded beyond initial qualifications, such as on-the-job upgrading of technical skills, or acquiring firm specific information, or developing a wider range of capabilities. The gains from work experience may be affected by firm size, with smaller firm having more limited internal labour markets. Similarly, firm turnover could accelerate the obsolescence of firm specific skills, and may encourage the development of generalist skills to manage the risks involved (see Haltiwanger (2002)).

More disaggregated estimations are able to show variations in earnings along a number of dimensions, such as returns in relation to subjects taken (see (New Zealand Treasury 2001a)). Hanushek and Kimko (2000) report that average students scores on maths and science are strongly related to growth. Gemmell (1997) reports that the only group of graduates with positive growth effects are scientists and engineers. Paul Ryan (2001) summarises the empirical evidence on the earnings and employment effects of general education compared with vocational training. Blundell (1999, p7) reports significant returns to vocational training consistently found, especially for higher vocational qualifications. Hyslop, Mare and Timmins (2003) provide further New Zealand evidence on links between changes in qualifications and the patterns of employment and income growth across industries, using Census data from 1986 to 2001.

Bowles et al (2001) note that much of the variation in earnings is unexplained by an individual's years of schooling, labour market experience, and parental characteristics. Human capital is multi-dimensional, and other behavioural traits appear to be influencing employment and earnings outcomes. They note in passing that employer surveys have ranked characteristics like attitude, motivation and communication more highly than technical skills. More senior management may need to be able to adjust to shocks and opportunities to capture rents, which may be assisted by a degree of self-directedness). Since employment contracts are typically incomplete, and monitoring is costly, employers may seek behaviours that reflect trustworthiness, motivation and low discount rates that reduce the problems of managing such contracts. Seemingly irrelevant personal characteristics (like appearance and tidiness of home) may be valued because they are correlated with behaviours sought by employers such as conformity with appropriate

behaviour and self-control. Family backgrounds and the school environment can also be important, as they help to develop capacities like punctuality, dependability, industriousness that both teachers and employers reward.

A related argument has been made that skills affect the responsiveness to technical change, for instance in aiding organisational change. For instance, Aghion and Howitt (2002) have argued that technological change is not skill-biased in the sense that it raises the demand for technical production skills, but rather that it raises the rewards to adaptability. During the introduction of new technologies, unobserved skills like higher ability, reliability, "trainability" appear to be in increased demand. They point to the rise in the within education and age group wage inequality occurring before the rise in between group inequality. Their argument is that this reflects the progressive diffusion of general purpose technologies within industries. Caroli (2001) has argued in a somewhat similar manner that a skilled workforce is crucial for the adoption of high tech equipment and production of high quality goods. She argues, in the context of technological and organisational change, that more general education and training is required that increase adaptability, problem solving learning and inter-personal skills at intermediate levels in the occupational distribution. The implication is that technical change requires a different set of skills, and not just higher skills.

Evidence of the importance of intermediate level skills comes from the detailed case studies undertaken by the UK's National Institute for Economic and Social Research (NIESR). These mainly compared matched manufacturing plants and service sector firms in the UK and European countries. Keep and Mayhew (2002) summarise this evidence as pointing to large differences in shop floor, supervisory and managerial skill levels that largely account for differences in firm productivity levels and product market strategies (with UK firms producing low value added standardised products). Higher European rates of innovation and technology adoption were attributed to the higher level of intermediate skills held by supervisory staff. The later UK-Germany-US comparisons painted a somewhat different picture. These have qualified the view that superior vocational skills are the main difference in productivity levels, with the US putting more stress on state investment in higher education compared with European employer-funded vocational training. The larger US domestic markets has also allowed economies of scale in manufacturing. Broadberry (2003) and Broadberry and Ghosal (2003) also document the relative productivity performance of Britain, the US and Germany, and assess the role of human capital and organisation in the provision of market services. Blundell et al (1999b) see the NIESR evidence as "suggesting strong links between employment of graduates, including professional scientists and engineers, and the adoption and use of high-level technologies in the firm, and between the extent of investment in worker training and the speed and successful adaptation of new technology."

4 Skill-technology complementarities

Improvements in workforce skills can increase firm productivity by raising the productivity of other firm inputs. The focus of this section is the way skilled labour complements capital investments, particularly in supporting the introduction and effective use of new technologies, the implementation of R&D findings, and the assimilation of external knowledge. Various measures of skills are used. These include the proportions of production and non-production workers, education level, or the proportions of graduates. These proxies have limitations in measuring skill levels, but are required by the availability

of data. Consequently, only broad inferences on the types of skills required for innovation can be drawn from these studies.

Section 4.1 begins with some of the stylised facts about technical change, and the effects on the demand for and supply of more skilled labour. Sections 4.2 and 4.3 look at firm level evidence from the perspective of firm dynamics. This describes the dispersion and persistence of firm productivity, and the relationship between skill levels and technology adoption. Section 4.4 then explores firm level evidence on the role of work re-organisation in accessing the productivity gains from technology adoption. Section 4.5 points to more recent evidence on the effect of the diffusion of information and communication technologies (ICT) on productivity performance, first at an aggregate and then at an industry level.

4.1 Skill biased technical change

There is general agreement that new technologies have increased the relative demand for skilled labour, in what has been described as skill biased technical change (SBTC). Two broad explanations have been provided as to how technology is having this effect. One is that the introduction of technology has increased the productivity of skilled labour. It has enabled tasks to be undertaken by existing skilled workers with a higher level of productivity. Alternatively, it may be the case that new technologies mainly replace labour intensive tasks, thereby altering the structure of employment. Here new technologies may require certain tasks to be carried out by high skilled rather than low skilled workers. There is a need to distinguish between worker productivity and workforce composition effects. Both these effects appear to be present. They may well yield aggregate evidence of skill-technology complementarities, though they have very different employment effects.

Earlier evidence suggested that the adoption of new technologies, often involving ICT, has required a more skilled workforce or higher levels of formal education. Productivity effects received less attention. For instance, Machin and van Reenen (1998) compare technical change (as measured by R&D intensity) and skill structure (as measured by the proportions of production and non-production workers) across 7 OECD countries. They find a positive association between R&D intensity and higher levels of skills in all 7 countries over time, and conclude that the relative demand for skilled workers has increased with technical change. Further, they observe that this upgrading has occurred within rather than between industries, and has occurred in the same industries in the 7 countries. Haskel and Heden (1999) provide similar evidence for the UK on how computerisation (as well as R&D) has increased the demand for skilled relative to manual workers. Using firm and industry panel data containing information on computerisation and skills, they too find that most skill upgrading is occurring within continuing establishments, and involves a movement away from manual workers irrespective of their education level. Chennels and van Reenen (1999) review the econometric evidence on the association between measures of technology and skills, and the wages and employment of less skilled workers. They note that there is considerable evidence of the skill levels and skilled/unskilled wage margins being positively correlated with R&D investment and use of advanced technology. The evidence on total employment is more mixed, with there being a positive association with measures of technology diffusion, and a negative association with measures of R&D.

Autor, Katz, and Krueger (1998) document the widening education-wage differential in the US over the past 5 decades, and its relationship to technological change as measured by

computerisation. This widening differential is attributed to strong and persistent growth in the demand for skills, in spite of a continuing growth in the supply of college graduates. They note that most of this skill upgrading is occurring within industries, which supports a skill-biased technical change rationale. These and similar findings suggest that physical capital and new technologies are complements with more skilled workers. They also find that skill upgrading has been higher in a range of industries with more a more intensive use of computers. They model changes in workforce skills as a function of changes in industry capital intensity and industry-level investment in computer equipment.

Another aspect of this story is the interaction, at an aggregate level, between technical change and the supply of skilled workers. Acemoglu (2002) explores the connections between SBTC, the demand for and supply of skills, and the widening earnings inequality in recent decades. He argues that technical change has affected the demand for skills, and, in turn, the type of technologies adopted has been influenced by the availability of skills. Overall, in recent decades the skill bias has accelerated. One piece of evidence for this is that US skill premiums have continued or increased during the '80s and '90s, in spite of sharp increases in the supply of educated workers. Acemoglu (1998, 2002) also argues that technology development and adoption is driven by profit incentives. As a result, the availability of skills induces the development of skill biased technologies: "When there are more skilled workers, the market for skill complementary technologies will be larger." Acemoglu (1998, p1056). That is, technology is skill biased by design, and not by nature. He considers that the alternative arguments, that technological change is exogenous to labour supply and driven by advances in science, Government funded R&D, or non-profit behaviour by entrepreneurs, cannot account for the concurrent growth in the demand for and supply of skills since the 1970s.

Thus, the impact on technology of an increase in the supply of skills, initiated by rising skill premia, is determined by two competing forces. First, there is a substitution effect between skill types, as increasing skilled labour becomes available. Second, there is the directed technology effect which, in response to skill availability, causes the demand for skills to increase. Whether the final premium for skills is above or below the starting point will depend on the size of these two effects. It is possible, even with an increase in the supply of skills, for earnings inequality to grow, as has happened in the US over the past two decades.

Card and DiNardo (2002) review the evidence in favour of the SBTC hypothesis (which they take to be an increase in the relative demand for higher skilled workers). They focus on economy wide trends in wage inequality. The main problem they see with the SBTC hypothesis is that wage inequality stabilised in the 1990's, in spite of continuing advances in and diffusion of computer technologies. This suggests that some of the acceleration in skill premia in the late '80s and early '90s may have been an episodic effect. They conclude that the SBTC has limitations in explaining the changes that are occurring in the US wage structure, and that other institutional factors such as changes in the real minimum wage also seem to be having an effect.

More recently, Autor, Levy and Murnane (2003) have explored micro-evidence on how computerisation alters the demand for skills, and the tasks that computers are best suited to doing. This provides a more detailed understanding of the nature of SBTC. They use detailed US data on occupation characteristics, and how they have changed over time, in order to identify shifts in job task composition. These are then matched with industry or occupational worker characteristics. They find that over the past three decades computer capital has been substituted for workers following routine or repetitive manual and

cognitive tasks, and complemented workers undertaking non-routine problem solving and communication tasks. As computer prices have fallen, both substitution and complementarity effects have been occurring. These changes in job content are occurring within a range of industries, occupations, and education groups. Thus, computerisation is associated with a reduced demand for labour input into routine tasks and an increased labour input into non-routine cognitive tasks. Task shifts have been occurring at all educational levels. Nevertheless, the net effect is an increased demand for better qualified workers (graduates) who have an advantage in undertaking analytical non-routine tasks.

4.2 Firm dynamics and productivity change

Another line of evidence on the sources of firm productivity improvements, given new technology and skill levels, comes from studies of firm dynamics. These provide a more detailed description of what is going on at the firm level, and allow a clearer separation of the contribution to productivity of worker and firm characteristics. For our purposes, this evidence highlights the considerable heterogeneity in productivity levels that exists across firms in an industry, the effects on aggregate productivity growth of resource reallocation across plants, and the influence of skill levels on firm productivity.

Several authors (Bartlesman and Doms (2000), Haltiwanger, Lane and Spletzer (2000)), summarise the evidence on productivity differentials between firms within an industry:

- The amount of productivity dispersion is very large. Some firms are much more productive than others.
- Highly productive firms today are more than likely to be highly productive tomorrow, although there are some changes in the productivity distribution over time.

Dunne, Foster, Haltiwanger and Troske (2002), again utilising establishment level data, summarise the changes that have been occurring in productivity and wage dispersion:

- The between plant component of wage dispersion is an important part of total wage dispersion, and is occurring within industries.
- The between plant measures of wage and productivity dispersion have increased substantially over the past few decades.
- A significant fraction of rising wage dispersion, and to a lesser extent productivity, is accounted for by changes in the distribution of computer investment across plants.

Foster, Haltiwanger and Krizan (1998) provide a summary of recent (mainly US) research on the resource reallocation occurring amongst manufacturing plants over time:

- There is a large level of reallocation of inputs and outputs across plants, and much of this reallocation occurs within rather than between sectors.
- Resource re-allocation from less to more productive plants plays an important role in aggregate productivity growth, and here firm entry/exit has a dominant effect.
- The pace of reallocation varies secularly, cyclically, and by industry, and affects aggregate rates of growth.

- Plant level heterogeneity can be accounted for by uncertainty, differences in managerial ability, capital vintage, location and disturbances, and the slow diffusion of knowledge between firms.

The OECD (2003b, Chapter 4) has compared the productivity implications of firm dynamics across a number of OECD countries. In relation to higher labour productivity, the evidence suggests that the resource changes within each firm play the dominant role, and that resource reallocation between firms is typically small. The entry and exit of firms had a variable effect, accounting for 20-40% of total labour productivity growth. An exception here is in industries that are experiencing technological change, where firm entry is more important. The within firm component contributed less to MFP growth, and resource reallocation between firms and firm entry and exit contributed more. It found that start-ups in the US were smaller and less productive that for Europe, but those which survived grew faster. The OECD (2003b: Chapter 4) also discusses the effects of product and labour market regulations on this resource re-allocation. This suggests that in countries with more restrictive regulatory regimes, labour productivity increased through capital deepening and improved production processes, while in more open economies faster MFP growth occurred through new firms entering with more appropriate input and technology mixes.

Bartlesman and Doms (2000) and Foster, Haltiwanger and Krizan (1998) also review the factors that may be influencing the patterns of resource re-allocation amongst firms in an industry. They note that differences in managerial and entrepreneurial ability seem to be important, as they make choices about technology and work practices. For instance, changing ownership (eg, through mergers) provides the opportunity to leverage off managerial quality. There is some evidence that the productivity of plants is positively related to the productivity of the firm to which it belongs, and that above-average productivity growth has followed changes of ownership. Productivity dispersion may also be due to slow diffusion of knowledge about new technologies and market opportunities. They note that productivity growth is positively linked to the uptake of technology, although this can occur by existing firms re-tooling as well as by new firms entering.

Mills and Timmins (2004) show that once comparable data is used by excluding zero-employee firms, New Zealand's size distribution and firm dynamics are not outliers amongst OECD countries. Its distribution of firm size is similar to many other OECD countries. Firms also enter and exit at a similar or larger size compared with other OECD countries. Again, while New Zealand also has a relatively high firm turnover rate (annual entries and exits as % of total firm population), Mills and Timmins find that the survival and growth rates of New Zealand firms are not out of line with other OECD countries. Nevertheless, job turnover rates in entering and exiting firms is at the high end of the OECD range. Carroll et al (2002) used a wider measure of job turnover (job creation plus destruction as % of total workforce). This measure would give a clearer overall picture of labour market patterns.

4.2.1 Skill-based effects

Haltiwanger, Lane and Spletzer (2000) use a matched longitudinal US database to look at the relationship between worker skills, wages and firm productivity, both when firms enter and then as learning/selection processes operate over time. Skills are measured by education level. They find that firms make very different choices about the key inputs – technology, capital, organisational structure and worker skill mix – and that these are quite persistent over time. They also note that new businesses exhibit greater heterogeneity of

earnings and productivity than do mature businesses. This reflects the effects of both selection (business failure) and learning (firms adjusting factor mix). They find that differences in productivity, skills and wages are highly correlated – that high productivity workplaces have highly skilled workers and high earnings/worker, and others exhibit low productivity, wages and skills. This suggests that the choice of worker mix is likely to be complementary to the other choices of the firm. They conclude that more mature businesses locate themselves along an upward sloping productivity/skill profile by adjusting their workforce and other input mixes. They also adopt an upward sloping earnings/skills profile. A caveat here is whether sufficient controls have been included to account for unobserved firm heterogeneity. Other factors may be influencing productivity differences.

A firm's earlier choice of skill levels appears to be important for ongoing technology adoption, with the growing dispersion of wages and productivity being linked to differential rates of technological adoption between plants in the same industry. Models of these effects have been formulated by Kremer and Maskin (1996) and Caselli (1999). Kremer and Maskin's model allows increases in plant level segregation of workers by skill. It allows the supply of skills to influence the skill-technology matches within firms, which in turn accentuates wage inequality. It proposes that workers of different skill levels are imperfect substitutes, that different tasks within a firm are complementary, but that different tasks within the firm are differentially sensitive to skill. The model implies that there are several competing forces determining the equilibrium patterns of matching skills and tasks in plants. If a wider range of production tasks is required by the firm, this favours less skill segregation within individual firms, while greater complementarity between tasks favours greater skill segregation. If the overall distribution of skills is compressed, high and low skilled workers will be matched in the same plant, but as the distribution of skills widens this will be less so.

Caselli (1999) also models the effect of technical change on the dispersion of firm wages and productivity. However, he focuses more on the costs faced by high and low skilled workers in re-training when adjusting to the introduction of new technologies. New technologies require different types of skills, and so segregation of skills across plants based on technology use is assumed. The model matches machines and worker skill levels to achieve higher productivity. Since retraining for more skilled workers is less costly, when technological change occurs the demand for more skilled workers increases. Correspondingly, the demand for low skilled workers decreases. They will continue to use older machines, with lower levels of productivity and wages. In this sense, technical change would be skill biased. In the technology diffusion process, capital flows towards the new technologies, and pressures exist for widening wage differentials for skill. This, in turn, increases the opportunities for re-training, and slows the rising wage dispersion.

Kremer and Maskin point to US evidence of economic activity shifting from firms in industries that typically use both high an low skills (eg, General Motors), to industries that used either high skills (eg, Microsoft) or low skills (eg, McDonalds). Perhaps more pertinent evidence is the increasing correlation of wages among workers in establishments, and amongst US states. Those with a wider dispersion of educational attainment are also more segregated by education amongst firms. Caselli provides a range of evidence for the past two decades that is consistent with his model. First, the wages and education of workers are higher at plants with high measures of R&D and technology adoption, plants using more advanced technologies are investing more and skill upgrading across plants and industries is positively correlated with capital-output ratios, and (as with Kremer and Maskin) there has been a substantial increase in

between-plant wage inequality. He also cites evidence that US industries experiencing higher capital to labour ratios have had relatively large increases in wages and the employment of skilled workers.

Dunne, Foster, Haltiwanger and Troske (2002) also explore the US evidence for these models. Kremer and Maskin's model implies that a greater dispersion of skills will yield a wider segregation of workers by skill across plants, and wider cross-plant dispersion of wages and productivity. Caselli's model has similar implications. Since more skilled workers use better machines relative to less skilled workers, skill biased technical change leads to a greater dispersion of labour productivity and increased wage dispersion between plants. Dunne et al note that these mechanisms give rise to two testable hypotheses: that the dispersion of wages and productivity occurring across plants are linked; and that this dispersion of wages and productivity is linked to differential rates of skill biased technology adoption between plants. They find, along with earlier studies, that much of the increase in industry level productivity is associated with resource re-allocation from less to more productive plants within an industry. They also find that between plant wage and productivity dispersion over the 1975-92 period is an important and growing of total dispersion, that much of this between plant dispersion is within industries, and that a substantial fraction of the rising dispersion of wages, and to a lesser extent productivity, is accounted for by the distribution of computer investment across plants.

The work by Abowd, Haltiwanger, Julia Lane and others (2002) links skill levels, firm productivity and the market value of firms. Their approach is demanding of data on firms and workers, and utilises the matched employee-employer and firm market value data sets available for seven US states. This allows the effects of unobserved skills to be calculated as firm market value less tangible assets. They note that these intangible assets valued by the capital market could include knowledge assets, organisational structure, human capital complementarities, although little progress is made on distinguishing which were the important elements. As with other firm dynamics studies, they find a strong positive relationship between skills and firm productivity. They note that the unobserved component is much more important, and is more correlated with wages and market value than is the observed component of skill levels. The data also allows the effects on firm productivity of different distributions of skills in firms to be explored. They find that the most skilled and least skilled workers have a disproportionately positive and negative effect respectively on productivity.

4.3 Sequencing of upskilling and technological change

A related question is whether firms adopting new technologies already have more skilled workforces and higher productivity. Initially, studies such as Krueger (1993) (using cross-sectional data) found a strong correlation between wages and computer use by workers: that is, computer users were better paid than non-users. However, phases of technical change such as the use of computers may not have made the workers using them more productive, thereby causing the increase in wages. Rather, computer use may have been assigned to workers who are more able. Disentangling these two wage effects requires panel data that tracks the wage history of the same employee over time as technology changes. Both Hall and Kramarz (1998) and De la Fuente and Ciccone (2002) note that panel data points to unobserved ability being the primary cause of the wage premium for computer use. In general terms, these studies find that, once controls are made for unobserved individual characteristics (eg reliability, knowledge, trainability), the positive association between the increased use of new technologies and wages disappears.

Contrasting evidence has been provided for New Zealand by Daldy and Gibson (2003) using computer training data in the 1996 Education and Training Survey. They found a significant (12%) wage effect for those who received such training, after controlling for a number of individual, occupation and industry effects.

Doms, Dunne and Troske (1997) used disaggregated US plant-level data that enabled them to match technology use in manufacturing plants in 1988 and 1993 with worker characteristics in 1990. Their data shows that "high tech" plants employ more skilled, higher paid, workers in both production and non-production activities. The fraction of workers employed in scientific, engineering, managerial and precision-craft occupations increases with the use of new technologies, while technologically advanced plants employed higher paid production, technical, clerical and sales workers. However, their data shows little correlation between the act of technology adoption and skill upgrading or wage increases. They find that plants adopting more new technologies had already employed a more skilled workforce (ie, a greater proportion with college degree or better), and have above average productivity in an earlier period. They see the correlation between new technology use and higher wages as reflecting the greater likelihood that plants with more educated and higher paid workforces will adopt more new technologies. Thus, when controls for worker characteristics were included, the wage premium for new technology usage dropped substantially.

Chennels and Van Reenen (1997) use British plant level data to investigate the relationship between the more intensive use of new technologies and wages. They use the 1984 and 1990 Workplace Industrial Relation Surveys, which contain considerable detail on workplace characteristics including the introduction of new technologies, but have limited data on worker skills. They find that plants that utilise technology more intensively pay higher wages. The question explored is the direction of causation – whether the use of new technologies causes higher pay, or whether those with higher pay facilitate technology adoption. They find that the second explanation is correct.

In a similar study, Entorf and Kramarz (1998) use longitudinal matched firm and worker data to look at whether French workers using a range of new technologies received higher pay before, during, or after the adoption of those technologies. The panel data they use for 1985 and 1986 contains data on the same workers and technology introduction by their employing firms. This allows for controls for worker and firm effects. They also find that workers using new technologies are paid more than non-user workers. Again, they find that new technologies are more likely to be used by abler and better paid workers, with the use of computer based technologies yielding a 16% wage advantage – which is of the same order as measured by Krueger (1993). This wage premium is able to be decomposed into 6% for workers with zero experience who begin using those technologies, and 10% due to experience. Once fixed worker characteristics are included, the 6% premium disappears, but a small part of the experience component remains. They suggest that firms select their ablest workers, who were already better paid, to use new technologies. As these workers learn and acquire experience, their wages further increase over time.

Entorf, Gollac and Kramarz (1999) use later observations from the same data set to further explore the effects of new technologies on wages and employment. They continue to find that workers using new technologies were already better paid before their introduction. Controlling for unobserved worker characteristics reduced the wage premium for computer use from 15-20% to below 2%.

4.4 Skills and work organisation

Evidence is accumulating that obtaining the full productivity gains from technical change requires changes in workplace organisation. New workplace practices can include flatter management structures, increased employee involvement in decision making, more team work and a greater emphasis on performance-related pay. Piva, Santarelli and Vivarelli (2003) summarise the literature on the effects of reorganisation and technological change on the demand for skilled and unskilled labour, and conclude that reorganisation and technological change are complementary, which favours workers who are both skilled and adaptable. Caroli (2001) also concludes that organisational change contributes to the gains in productivity obtained from the adoption of new technologies. The OECD (OECD 2004) also argues that it is key to making ICT work. A listing of studies of workplace practices on firm performance is given by Arnal et al (2001), while the OECD (OECD 2004) provides a number of case studies of complementary effects.[11]

Bresnahan, Brynjolfsson and Hitt (1999) analyse US data on how the use of computer technologies by 400 large firms in the manufacturing and service sectors has influenced the relative demand for skilled labour. They find that a cluster of complementary changes in information technology (IT) usage, workplace organisation (WO) and the products that firms provide are changing the skill mix that employers require. They argue that skill requirements and IT usage interact in several ways. One is the substitution of IT for less skilled labour in undertaking repetitive tasks. Far more important is the role of high skilled labour in supporting technology adoption and workplace re-organisation. IT usage supports WO, in that it allows job re-design, the re-allocation of tasks, and access to data sets, allowing changes to the firm's practices and products. They see the increased demand for cognitive skills occurring in three directions: the greater ability to analyse data; greater worker autonomy and responsibility; and the skills for dealing with colleagues, customers and suppliers. Their empirical findings are that changed work practices around measures of IT, human capital (HK) and WO are often highly correlated, and result in higher productivity gains for the firms adopting them. Interestingly, high HK is associated with high productivity, but only in firms that also have high IT and have adopted new WO forms.

Black and Lynch (2000) also explore the effect of changes in workplace practices on plant productivity and wages, using 1994 and 1997 data from a representative sample of US manufacturing establishments. These practices include introducing profit sharing, greater teamwork, and giving employees greater involvement in decision making. They find a positive and significant relationship between the proportion of non-managers using computers and higher productivity. They find less of a relationship between the overall educational level of the plant and labour productivity. In contrast, they find that firms that re-engineer their workplaces to incorporate a number of high performance practices when adopting new technologies have experienced higher productivity, compared to those who retained more traditional workplace practices. They also find that workplace responses are associated with higher wages, although increased usage of profit sharing or stock options results in lower regular pay for technical and clerical/sales workers. Without changes in organisational infrastructure, the effect of technical change appears more limited: workplace practices do appear to matter. However, other results, such as workers in self-managed teams experiencing lower productivity might suggest that other influences are present.

[11] In the first two studies reported here, where cross-sectional data is used, unobserved firm fixed effects may be influencing the measurement of skill/technology/organisation effects.

Caroli and Van Reenen (2001) look more explicitly at "skill biased organisational change", encompassing features such as less hierarchy and more decentralisation, and increased worker autonomy and responsibility. They see the benefits of decentralisation as being reduced cost of communication and monitoring within the hierarchy, more responsiveness to market changes, and the potential for increased job satisfaction. There are also risks involved. In terms of theoretical undergirding, they point to the work of Milgrom and Roberts (1990, 1995) and others who seek to model the ways the internal organisation and practices of firms is structured to capture the complementarities amongst WO, IT and HK. This literature points to the possibility of combinations of WO, IT and HK that involve high and low levels of skills. This can lead to skill levels across the organisation becoming more homogeneous, with discontinuities between combinations that cause re-organisation to be costly.

Caroli and Van Reenen (2001) provide econometric evidence for France and Britain across a broad range of establishments on the effect of the timing of organisational change on increasing the demand for skills, and on how firm productivity is affected by the combination of decentralisation and HK deepening. They report three findings: that establishments that introduce changes in organisation are significantly more likely to reduce their demand for unskilled workers; that organisational change (OC) is negatively associated with rising skill premia, and that the probability of introducing changes in organisation, such as de-layering hierarchies, is depressed by shortages of skilled workers; that OC leads to significantly faster productivity growth in skill intensive firms, than OC in unskilled firms.

4.5 Technology diffusion and adjustment

The literature reviewed so far points to a number of factors that influence the diffusion and application of new technologies in firms and industries over time. Acemoglu (2002) points to the endogenous nature of the supply of skills and new technologies. The firm dynamics literature identifies factors influencing the dispersion of productivity amongst firms, particularly plant level segregation of workers by high-low skill-technology matches.

The OECD has been undertaking a major project on the factors influencing economic growth, with earlier output including *The New Economy: Beyond The Hype*, (OECD 2001), and *The Sources of Economic Growth in OECD Countries* (OECD 2003b). More recent evidence on ICT adoption is provided in *The Economic Impact of ICT* (OECD 2004). These reports note that productivity improvements arising from ICT can occur through three broad channels. One channel is increased investment and productivity in the sectors that are developing or producing ICT technologies. Another is through increasing investment in ICT in other industries (for purposes such as accounting or inventory management), causing capital deepening and boosting labour productivity. A third channel is through spillovers into other areas of the economy (for example, through the internet or other networks, which enhance communications and allow such transactions to be managed differently).[12] The OECD (OECD 2004) identifies three broad groups of factors that are influencing the rate of ICT diffusion at the firm level. First, the regulatory environment affects the ability of firms to take advantage of opportunities. The OECD reports propose a broad policy framework that promotes product market competition, flexibility in the labour market, and firm entry and exit. Second, firms differ in their ability

[12] Estimations of the productivity effects of the so-called "new economy" are summarised by Temple (2002) and Stiroh (1999), with ICT contributing around 0.5 percentage points annually to the US productivity surge in 1995-99 period.

to absorb ICT. The firm's absorptive capacity will stem in part from the firm's skill base and level of innovative activity. The reorganisation of work practices is again identified as an important source of gains. Spillover effects around learning from the increased use of ICT also support adoption by remaining firms. Third, large differences persist in the costs of investment in ICT across OECD countries.

Basu et al (2003) explore the reasons why TFP might have accelerated in the US, but not in the UK. They argue that differences in investments in unmeasured intangible organisational capital in industries utilising ICT provides the best explanation of the divergent MFP performance after 1995. Benefiting from ICT appears to require substantial co-investments in complementary learning and organisational change, leading to lags of about 5 years between ICT capital investments and productivity growth in the ICT-using industries. This lagged effect appears to be stronger for the US than for the UK, where MFP growth does not appear to be correlated with lagged ICT growth. They suggest that another factor that may be influencing the UK ICT investments may be the need for skilled labour in the accumulation of complementary capital. They note that the UK has lower levels of skills than the US as measured by the percentage of the work force with degree or higher qualifications. Other factors, such as differences between the countries in terms of rigidities in product and labour markets, or business cycle effects, or in productivity measurement, do not appear to have a significant effect on US-UK differences in productivity growth.

Chapter 6 of the OECD's report (OECD 2004) on the economic impacts of ICT analyses the Australian experience of productivity effects over the 1990s, using a firm-based longitudinal dataset. The aggregate effects of firm-level effects indicate that ICT usage contributed a relatively small 0.2 percentage points to Australia's annual MFP growth rate of 1.8%. Their analysis of firm level data found ICT influences in all the industries studied, although ICT capital deepening was particularly strong in service industries especially finance and insurance, and was also above average in manufacturing, electricity and gas and water. It also found a significant positive relationship between increased ICT use and increasing sector wages/skill levels, the use of advanced business practices (eg, business planning, inter-firm comparisons), complementary organisational variables (measured by an intensity of firm restructuring variable), and product innovation. Causation was not determined. ICT uptake was earlier and stronger in large firms. They found that the firm level labour productivity effects tended to taper off over time. Thus, the adoption of ICT appears to provide a level increase rather than a permanent increase in the growth rate.

Related Australian papers (see Barnes and Kennard (2002) and Parham (2004)) suggest that the accumulation skills had only a limited role in Australia's productivity surge during the 1990s, with growth in skills contributing only about 20% of the annual growth in MFP. Parham attaches greater weight to the increased openness of the Australian economy, increased R&D, and a rapid uptake and use of information and communication technologies (ICT). Nevertheless, these authors suggest that the accumulation of physical and human capital in the past has laid a long term foundation for the productivity growth now occurring. This suggests that the present level of skills may not be a significant constraint on growth. Thus, in relation to capital deepening and MFP growth, the contribution of skills needs to be looked at alongside other inputs, such as the innovation system and capital market effects.

The New Zealand evidence is less developed. Black, Guy and McLellan (2003) summarise labour productivity data for New Zealand industries for 1988-93 and 1993-2002, and make comparisons with Australian industries. These data reflect different rates

of productivity growth amongst industries. MFP growth has, however, been uneven across nine broad industry sectors through the 1990s – being better in primary industries, retail and wholesale trade, and personal and community services, but poorer in utilities, manufacturing, mining, and transport and communications. In general, they found that New Zealand has poorer aggregate MFP and labour productivity than Australia, and also particularly in manufacturing. Industry-level investigations allow closer scrutiny of the factors influencing productivity. For instance, Engelbrecht and Xayavong (2004) find a strong correlation between ICT use and labour productivity growth across 29 New Zealand industries. They derive an ICT intensity index from input-output data, and classify industries into more ICT intensive and less ICT intensive categories. The evidence suggests that productivity growth is higher in the ICT intensive industries, though weak overall. Parham and Roberts (2004) explore Australia and New Zealand productivity differences in more detail. They suggest that once periods of rapid labour utilisation, and hard to measure industries, are excluded, that New Zealand's labour productivity for the period 1996-2002 trails behind Australia by 2%. They contend that capital accumulation appears to be lower in New Zealand, particularly in the uptake of ICT, while the growth in skills in the working age population lags behind Australia.

5 Firm and industry knowledge spillovers

The third mechanism whereby increases in an individual's skill levels might give rise to improvements in the productivity of firms is through their direct effect on other workers or other firms. These complementary effects stem can give rise to knowledge spillovers. They will increase the returns to inputs in the firms they influence. A more complex interaction occurs at the national level where poor expectations may be influencing decisions about longer term investments in technologies and skills, and leading to lower productivity outcomes. These three avenues are considered in turn. (R&D spillovers are not discussed.)

5.1 Within firm effects

Knowledge complementarities within the firm can take a number of forms. The actions of entrepreneurs and senior managers, including their failures, can have effects across firms or down hierarchies. Workers are more productive where there is an existing stock of knowledge, either in the form of experienced and skilled staff, or of knowledge management systems. Mentoring facilitates knowledge transfers and supports learning by doing. Effective knowledge management routines reduce search costs and assist problem solving. Working with specialists in teams utilises the complementary skill bases held by team members. Some portion of these knowledge transfers or processes may be priced in terms of wages or reflected in the intangible value of the firm, and be internalised within the decision making of the firm. Knowledge spillovers are externality effects that directly improve the productivity of other workers and firms. They may be priced or unpriced. Their extent is hard to gauge.

A person's earnings can be influenced by "who you are" (their individual characteristics), "where you work" (firm effects), and "who you work with" (co-labourer effects). A worker's earnings progression does not depend only on the abilities they bring, but also the environment in which they work. Abowd and Kramarz (1999) report evidence on the size of firm effects. These range in some studies from being quite low, up to the point where

the firm effect can explain as much of earnings variation as do personal characteristics. In the former case, the firms in the industry may be more homogeneous and so changing jobs will do little for earnings, or firms may be more segregated in the types of skills that they employ. Higher firm effects suggests that significant productivity differences occur between firms, perhaps because of organisational structure or management practices. Lengermann (2002) explores the co-labourer effect, where the presence of other skills in a team raise the worker's productivity. His analysis sought to estimate the influence of the average characteristics of other workers in a firm on an individual employee's wages. Further, as Blundell et al (1999b, p6) report, individuals working in an industry experiencing technological progress can also receive higher returns to education. In this literature it is possible that the measure of worker characteristics is not picking up the full range of abilities that are valued by firms, with the other effects being over-estimated.

The processes and practices that managers put in place can also substantially influence workers' effectiveness. The management models described in S 3.2.1 note a range of effects. Ichniowski and Shaw (2003) refer to the differences in the "connective capital" of workers brought about by differences between innovative and traditional human resource systems. In the former, a worker's access to the knowledge and skills of co-workers is important in teamwork and problem solving. Similarly, operating routines and dynamic capabilities are used to synthesise information into effective internal technical, organisational and managerial processes that enable a firm to maintaining competitive advantage in a changing environment. Thus, effective managers increase the productivity of their subordinates.

Battu, Belfield, and Sloane (2001) look at knowledge spillovers within the workplace. Using the UK Workplace Employee Relations Survey and data on workforce characteristics of firms, they provide evidence on how own earnings are affected by co-workers' education. They find that there is a positive and substantial association between own earnings and mean workplace years of education, but negative interactions between own and co-worker education levels. They suggest that education is less valued at workplaces where education levels are already high. A question with this study is how effectively other firm-specific effects, like organisation or management practices, are controlled for.

5.2 Knowledge spillovers between firms

Knowledge spillovers can also occur between firms in an industry (the so-called Marshal-Arrow-Romer (MAR) knowledge externalities).[13] Where there is a greater the stock of shared knowledge in an industry, the individual or firm will be more productive. This can occur generally across an industry through the diffusion of R&D knowledge embedded in better technologies and practices. Externalities can be associated with experimenting with organisational design, as successful designs are relatively easy to imitate. Locally, there can be a geographic concentration of specialisation (at the firm level, or in the workforces employed) which improves the matching of inputs in production, and the achievement of economies of scale.

Duranton and Puga (2003) identify three main mechanisms giving rise to agglomeration effects. They are the *sharing* of inputs (where indivisible facilities can be supported by the geographical industry concentration), *matching* (through improving frequency and quality

[13] Evidence on a wider range of agglomeration economies is examined by Rosenthal and Strange (2003).

of transactions in input and output markets), and *learning* (where proximity increases the level and quality of knowledge generated and transferred between firms). A large indivisible facility provides increasing returns to scale, and lower costs of services to its users. Thicker labour markets with more agents and transactions increase competition, lower search costs, and allow better matches between firms and the skills required. Better matching arising from "thick" input markets generates externalities, in that it allows increased firm specialisation with economies of scale in production, and permits specialisation by workers. Thicker markets also lessen bilateral relationships between buyers and sellers, and the resulting risks of hold-up. Geographical proximity encourages knowledge spillovers by lowering transaction and communication costs. Increased face to face contacts are helpful for the transfer of tacit information. Proximity to other skilled individuals assists knowledge acquisition, thereby aiding knowledge diffusion through an industry. The greater inter-dependence and exchange amongst firms in a localised industry also appears likely to enhance absorbtive capacity and stimulate innovative activity.

Crawford (2004) summarises the econometric evidence on the size of agglomeration effects. Several studies are cited that identify economically significant effects from agglomeration on labour productivity. These effects seem to operate primarily through linkages between denser urban areas and human capital. Evidence on the relative importance of the three specific mechanisms giving rise to these effects is more difficult to establish. Dumais, Ellison, and Glaeser (1997) found evidence that labour market specialisation was by far the most significant mechanism. Using data on firm dynamics in US manufacturing industries, they found that this effect appears to arise from the importance of shared labour markets, where the occupational mix of the firm is closer to that of its potential customers and suppliers. It has proved difficult to distinguish the knowledge spillovers operating within and between industries. However, Audretsch and Feldman (2003), in exploring the spatial dimension of knowledge spillovers and innovative activity, report evidence showing geographical concentrations of patent citations and product innovations, after controlling for industry agglomeration effects. Co-agglomeration effects between industries vary greatly, with only three resourced based industries showing significant effects in terms of accessing inputs from a single supplier.

5.3 Path dependence in skill/technology choices

A related line of inquiry concerns the possibility, at the industry or national level, of low skill levels and skill shortages leading to a low skill/low technology equilibrium. A number of influences may be present. Several of the firm dynamics findings noted earlier point to potentially significant path dependence in skill/technology choices at the firm level. The rate of diffusion of ICT will be influenced at the firm level by the costs of adoption, which will include what they can learn from other firm's experience of implementing the technology. Persistent skill shortages may also have implications for capital deepening. With sunk investments in capital, labour, technology and organisation, and significant adjustment costs, it may be costly and demanding for a firm to change its input mix while the benefits may only appear over the long haul. The challenge is to understand better what would generate and sustain a low skill/low technology equilibrium, and whether these effects are significant in practice for policy purposes.

Acemoglu (1996) and Redding (1996) provide models of the choices of skill level and technologies that operate nationally. In Acemoglu's model, firms and workers make investments in physical and human capital before production begins. Matching of workers

and firms is assumed to occur randomly, possibly because search is costly. Their investments are made before the match is known. The model yields the result that an increase in the average level of human capital can yield increasing private returns. This is because the expectation by firms of higher skill levels encourages them to make greater capital investments. With random matching, some workers with lower skills will be matched with firms making higher capital investments. This yields an external effect. Paul David (2001, pp37,38) notes two limitations of Acemoglu's analysis, both related to the random matching assumption. First, there may be ways of increasing the co-ordination of expectations, such as providing market information, or increasing the level of work-based training. Second, the mismatching of workers and firms, and consequent wasted investment, is likely to yield risk averse behaviour to limit it, such as devising selection rules.

The model of Redding (1996) investigates the effects of joint decision making by workers about investment in education, and by entrepreneurs in terms of their investments in R&D. In Redding's model, workers are again randomly matched with entrepreneurs. This inter-dependence again allows the possibility of multiple equilibria, with the outcome depending on expectations about the other party's level of investment. One outcome is low levels of skills and innovation, which reflects a failure of coordination. Alternatively, credible commitments to raising skill levels could also raise R&D expenditure. This suggests that skill acquisition and R&D are strategic complements. Governments may, therefore, have a role in coordinating expectations. One testing of Redding's model is provided by Nickell and Nicolitas (1997). They investigate whether there is any connection between the shortage of human capital and rates of capital investment or R&D. They use data for UK manufacturing firms for the period 1976-94, and on the proportion of firms whose output is constrained by shortages of skilled and unskilled labour. Their finding is that a permanent 10 percentage point increase in the number of firms reporting skilled labour shortages led to a permanent 10% reduction in capital investment and a temporary 4% reduction in R&D expenditure. A more recent UK study using firm level data by Forth and Mason (2004) finds that firm performance is improved by the rapid adoption and use of ICT, but this is hindered by deficiencies in skills for adopting ICT.

Other evidence that incentives to invest in human capital and technology are interdependent comes from a number of comparisons of UK, US and European industry performance, in particular the studies undertaken by the UK's National Institute for Economic and Social Research (NIESR) (and reported briefly in S 3.3). These studies document and seek to explain the wide differences in the technological strategies being followed by countries in similar industries. Following Finegold and Soskice (1988), a number of authors have argued that the UK is trapped in a low skill equilibrium. Keep and Mayhew (1999) and Caroli (2001) argue that the availability of a skilled workforce is a significant factor in the persistence of a low skill/technology strategy. The suggestion is that it is a systems failure that requires a coordinated response across a range of policies and institutions. The dominant mechanism proposed is the kind referred to by Acemoglu where there is little demand for skilled workers, the incentives to train are reduced, while the limited supply of skills influenced firms' technology investment decisions. Some (such as Caroli (2001)) put more stress on poaching externalities, arguing that the adoption of new technologies requires a higher proportion of general skills, which firms have less incentive to invest in, and which must therefore be provided by the general education system. Still others utilise an industry spillover story, where individual firms wanting to break out of a low skill equilibrium would need to finance a disproportionate share of R&D, as beneficial externalities from other firm's R&D activities are absent.

One might provisionally conclude that there is a case to be answered as to why different technological trajectories are sustained over time, for example between the UK and Germany. However, more rigour appears needed in identifying the key factors hindering the transition out of a low skill equilibrium. Little comment is made on the differences in labour market regulations in the UK-Europe comparisons, for example, and whether wage compression in Europe is making a significant difference. Nor is it clear why increasing the supply of skilled workers would be a major policy option for addressing the issue.

What gives rise to low technology/skill matches is clearly important. The question is how these technology diffusion and adjustment processes would benefit from governments taking a greater role in coordination. The evidence is less persuasive that a systems failure is involved that requires a coordinated response across a range of policies and institutions. There is evidence for the UK that persistent shortages of skilled labour may be influencing technology adoption and capital investments. The case for further increases the supply of skilled workers depends on whether other factors are more critical. More analysis is needed of the rationale and evidence for path dependence, and of how governments might make an improvement. There may, for instance, be significant costs associated with firms changing their input mix, given sunk investments in capital, labour, technology and organisation, leading to slow rates of adjustment. The policy specifics here will be influenced by the economy being analysed.

6 Work-based skill acquisition

Worker skills are determined by endowed ability, family background factors, accumulated knowledge from formal education, and learning in the workplace. Work-based learning can occur through learning-by-doing, formal employer-funded or government-funded training, investments by earlier employers, and informal knowledge transfers from other workers. Since a significant proportion of knowledge accumulation occurs on the job, or is required by continuous learning in response to technological obsolescence, the adequacy of work-based training is important. The standard model of human capital formation suggests that training will be provided in sufficient quantities by market forces, and that there is no basis for government intervention. Other commentators have pointed to evidence on labour market imperfections which suggest that employers and workers will tend to under-invest in training. The section considers the rationale and scope for government intervention in work-based training, and the factors that should influence the design of suitable interventions.

In the knowledge accumulation process, the knowledge acquired in one period complements the skills available in next. The stock of knowledge in one period permits further rounds of skill development and product innovation, with consequential productivity effects. Thus, skills can be expected to be more productive in environments where there is an existing high stock of knowledge. This effect can influence a firm's policies around recruitment, the building up of firm-specific knowledge, information retrieval processes, or the use of teams. One important implication is that the likelihood of getting training appears to rise with the prior level of educational attainment. Firms spend more on training those who already have qualifications. Conversely, those with few educational qualifications are likely to face more limited training opportunities in the workforce. Thus, the observed patterns of provision and participation in training tend to amplify skill gaps, rather than compensate for low levels of prior educational attainment.

6.1 Analysis of work-based training

In decentralised labour markets, the dominant model for thinking about firm-based human capital investments is that of Becker (see Acemoglu and Pischke (1999)). Skill acquisition is viewed here as an investment decision. In the absence of capital and labour market imperfections, this model substantially relies on workers and employers to finance the optimal level of work-based training. Workers evaluate investments in education, based on likely improvements in future earning streams, the cost of training and any earnings foregone. They may also accept lower or no wages early in their career while their skills are being built up. Employers, faced with risks of labour turnover or poaching by other employers, will base a worker's wages on their current productivity. They will invest mainly in firm-specific knowledge (which by definition is not valued elsewhere), and require training wages to be paid to fund the acquisition of generic skills that can be used by other employers. Workers will, in effect, be required to bear the full cost of general training. In the Becker model, no externalities are involved, and there is no case for government intervention on efficiency grounds.

The OECD (1999) and Long et al (2000) identify a number of factors that are systematically associated with employment-based training, which are broadly in line with the predictions of the Becker model. Those in jobs longer are more likely to receive formal training, while the extent of training falls off with age. Employer funded training increases with tenure, while higher labour turnover lowers the incentives on businesses to invest in training. Men tend to receive more financial support, while women receive less training in total because of their less continuous employment. The level of on-the-job training increases with the size of the firms, possibly because larger firms have larger internal labour markets and career paths, and hence greater opportunities to reap the benefits of the training (see Long et al. (2000)). Employer funded training reinforces skill differences, with more educated workers being trained more, although NZ is one of several OECD countries where there is a more even distribution of training.

A substantial proportion of training is informal. The OECD (2003a) cites Australian and US evidence that informal training accounts for at least half of all training, although it should be noted that informal on-the-job training is more difficult to measure. This training may take the form of general work experience, the upgrading of technical skills, the acquiring of firm specific information, or the development of a wider range of skills. The OECD (1998, p 60) finds that the earnings effects of work experience are significant, and that the effects of additional years in work since formal education have effects of a similar order to years of schooling. However, Loewenstein and Spletzer (1998) found that off-site training paid for by the firm had larger effects on wages than on-the-job training. This could be because informal training contains larger levels of specific skills, while formal training allows accreditation of the skills received. Thus, if worker expertise is unclear, recruiting firms may reduce wage offers. These factors seem likely to increase the wage effects from formal training.

(i) limitations of the Becker model

One difficulty with the Becker model is that firms are observed to fund a substantial amount of general training. The OECD (2003a, p246) notes that firms fully pay for more than 70% of formal vocational training, and that most of this training is quite general in nature. In the Becker model, employers would not pay for such training, but would require workers to accept a training wage. Recouping training costs by paying workers wages below their productivity is not possible, as it would encourage workers to change jobs.

There have also been studies of the extent to which employers pay training wages. Loewenstein and Spletzer (1998) using US longitudinal data, note that employers almost always pay the explicit costs of training. Barron, Berger, and Black (1999) found that training lowers starting wages, but that the estimated effects are small. They also found, when controls are made for unobserved worker ability, that the effect of training on wages was small relative to the large and robust effects on productivity growth. They suggested that firms pay most of the cost and reap most of the benefits from training.

Another difficulty with Becker's model is that the evidence points to firms paying wage increases following training that are less than the gains in firm productivity. The growth in the worker's wages do not equate to the increase in their productivity from training. The gains in productivity also accrue to the firm in terms of increased profitability. For instance, Loewenstein and Spletzer (1998, p142) note evidence that "the existing empirical evidence suggests that employers realize an inordinate share of the returns to training", with productivity growth about five times as large as wage growth. Similarly, Dearden, Reed, and van Reenen (2000) explore the direct effects of firm-based training on industry productivity using longitudinal UK industry data on wages, training and productivity, and find that a 5 percentage point increase in workers trained is associated with a 4% increase in worker value added and a 1.6% increase in wages.

One approach to explaining why general training is so prevalent without training wages utilises the imperfect competition model. With employers having monopsony power in the demand for labour, workers are paid less than their marginal productivity. Where this occurs, workers will not gain the full benefits of training and will tend to under-invest. Imperfect competition could be occurring for several reasons (see David (2001, pp9-15) and Acemoglu and Pischke (1999)). The first relates to the problems associated with information asymmetry and monitoring, where different levels of information are held by the transacting parties. This occurs in labour contracting matters, such as recruitment when the expertise of the applicant is incompletely known, or in assessing work effort where the level of shirking is unknown. Incomplete information tends to turn general skills into specific skills, and less useful to future employers when recruiting. The second explanation for imperfect competition arises from mobility or exit costs associated with moving between employers. The search and mobility costs associated with finding a better wages with another employer generate rents for the present employer. This allows the current employer to pay wages below the worker's productivity and recoup training costs. Stevens (1999) suggests that imperfect competition can also arise where skills are only partially transferable, and are not useful for many other employers.

Acemoglu and Pischke (1999) and Acemoglu (2001, Chapter 5) note, however, that one consequence of the compression of wages is that firms have an incentive to increase training back towards the competitive equilibrium. This is because they are able to reap the productivity gains not passed on to workers in higher wages. Acemoglu (2001) sets out evidence on the relationship between wage compression and training in several contexts where proxies for wage compression can be found, namely minimum wages, union effects, and the cross-country effects of labour market institutions. He cites some evidence of positive effects of wage compression on training levels, especially in cross-country comparisons.

Another interpretation of this evidence on training is that a firm's wage structure may be influenced by incentives to encourage work commitment, reward effort, and reduce worker turnover. For example, "efficiency wages" may be paid that are initially low but increase over the worker's tenure. Such a practice could limit shirking because of the threat of

firing. In this case, the presence of general training or wages initially below worker productivity is less of a problem. Thus, Cappelli (2002) provides evidence that US employers routinely provide financial support for a significant percentage of their employees to pursue post-secondary education, but that a high proportion of those employees have to wait for a year before gaining access. He suggests that the payment of assistance for part-time study acts as a screening device that helps to identify above average ability workers, while delaying employee access to assistance reduces turnover. Firms recoup their investment from retaining higher productivity workers and reducing recruitment costs. In both human capital and efficiency wage models, wages can be expected to rise over time. David (2001) argues that distinguishing these two stories empirically is difficult. Training practices may also be used to screen workers, where information on the worker's ability and motivation are hard to obtain directly.

(ii) poaching and the distribution of benefits between employers

Where general training is provided, scope exists for workers to leave their current employer before the full benefits of training have been reaped. If the pay scales do not reflect training-based productivity improvements, this reduces the incentives on employees to invest, and increases their incentives to change jobs to get a better wage/productivity match. As a consequence, much work-based training appears to be funded by employers (OECD (2003a)). This provides scope for "poaching externalities" and the under-provision of training by the current employer.

A variety of evidence is available on the effect of training on labour mobility. Blundell et al (1999b) reports studies that have found employer-provided training is quite portable. In the UK, the returns from on-the-job training undertaken with a previous employer are similar to the return from that training with the current employer. Similarly, Blundell, Dearden and Meghir (1999a) find that employer provided training leading to qualifications gives positive returns for both current and earlier employer. Further, Loewenstein and Spletzer (1998) cite US evidence where past spells of general training have larger effects on wages than current spells of general training. However, Dearden et al (1997) cite evidence that firms who train also tend to retain those workers. They examine the relationship between training and job mobility in Britain using two longitudinal data sets. They find that employers who provide training have a lower than average probability of losing workers who received training in previous periods, especially if the training was employer funded.

There is a tension here between the benefits of better matching flowing from labour turnover, and the disincentives on employers to invest in training. As in the Becker model, increasing competition in the labour market increases the scope for "poaching". If positive or similar returns accrue to future employers, as the evidence suggests, poaching would be beneficial. Conversely, as post-training wages rose towards the level of the worker's productivity, the benefits to firms from funding training would reduce, and so would the level.

6.2 Scope for intervention

Government intervention should be considered for those types of transaction where decentralised market forces are unlikely to provide the desired levels of skills. This would occur where all of the costs or benefits are not taken into account by the parties in their decisions on investing in skills. Evidence of market failure in work-based training is a

necessary but not sufficient basis for government intervention. It provides the starting point for further inquiries around the nature and effectiveness of intervening. A major consideration concerns the nature of the market failure that the intervention is seeking to correct. The choice of market failure to target, such as information asymmetries, imperfect competition, or credit constraints, will influence the design of the intervention. The scope for the government to make cost effective improvements also has to be established, given existing policy settings and the effectiveness of options for change. Regulatory and/or institutional failure may be greater for some interventions than for others. For instance, Stevens (1999) comments on a UK scheme that was complex to operate, while Jennings (1992) and Borland, Chapman, and Rimmer (1992) look at the limitations of an Australian industry levy scheme.

(i) capital market concerns

Separating out the relative importance of these market failure effects is important in the design of interventions (see OECD (2003a, p249), Acemoglu and Pischke (1999)). An initial step is to ask whether the primary problem lies in the labour or capital markets. There may be cases where workers' demand for training exceeds the level that employers are willing to fund. The OECD (2003a, p249), David (2001, pp9-15) and Stevens (1999) have noted the possibility of workers having difficulty raising the capital needed to finance training, and causing under-investment. Conceptually, this is a similar issue to pre-employment tertiary education where the human capital generates an expected future earnings that cannot be used as collateral in borrowing. The level of this concern is unclear. The OECD considers that credit constraints may be more important for low skilled and older workers, and those working part time work and in small firms. The effect would be lessened where the employer did not pay a training wage, and/or the employee was trained in the employer's time. In terms of policy design, a similar pattern of assistance to that occurring in formal tertiary education could encourage workers to seek off-the-job training that may not yield the sort of skills required by the firm.

(ii) labour market imperfections

As discussed earlier, there are two broad types of labour market imperfections. The first relates to the problems associated with information asymmetry and monitoring, as in recruitment when the expertise of the applicant is incompletely known. Workers and firms can adopt a number of practices that reduce these effects, such as by signalling ability with educational credentials, screening job applicants for suitability, and aligning the incentives of agents. The concern is that these steps will be only partially successful. The second broad type arises from the distribution of the costs and benefits of work-based skill acquisition between workers and employers. With wages below productivity, workers will under-invest in training. At the same time, employers can afford to fund general training. However, this level of investment may still be sub-optimal. What is not clear from arguments about market failure is the extent to which they lead to under-investment in work-based training. As noted earlier, there is little evidence on the relative importance of these two broad types of labour market imperfections, or the size of their effects. The OECD (2003a, p239) concludes similarly from its review of the evidence, that there is some indication of under-provision of training, although the extent of the problem is difficult to quantify.

There may be some scope for government to address the market failure directly. If information asymmetries about the nature and quality of training received are serious, and constrain an employee's willingness to invest in training, then one policy option frequently

adopted is for government to assist in certifying the quality of training programs. There may also be scope for making labour markets more flexible, and for reducing mobility costs. Interventions along these lines would encourage workers to be paid wages closer to their productivity. Nevertheless, designing such interventions may be difficult, and may be limited in their scope and effectiveness.

Second-best options to increase training by employers, such as through government subsidies or industry levies or regulation, do not address the causes of market failure directly, and so may have unintended consequences. With government subsidies, those bearing the costs of training are unlikely to be those receiving the benefits. Subsidised general training risks an inefficient substitution of formal general training for informal or customised training. It may also encourage employers to shift the costs of training onto taxpayers, and do little to increase training. This potential for training to focus on skills not being sought by employers may be one reason why government-funded training appears to yield poorer wage and productivity outcomes. As a result, in the design of such schemes, attention should be given to promoting training that is tailored to the needs of particular firms, and limits the scope for employer gaming.

The OECD (2003a, p249) outlines a number of co-financing arrangements used in member countries that allow employers and workers to generate more tailored training assistance packages that encourage lifelong learning outcomes. These schemes aim to increase the financing costs borne by employers and employees (as they reap most of the returns), and to strengthen the incentives for learners and providers to seek effective training options. This represents a shift from the direct subsidisation of external providers, and provides more flexibility for training programmes to be negotiated that yield the sorts of skills needed by firms. These range from tax and subsidy arrangements for employers, tax incentives and individual learning accounts for employees, and training time accounts, pay-back clauses and apprenticeships. As the OECD notes, these schemes have strengths and weaknesses which need to be taken into account in policy design. They allow schemes to reflect assessments of the relative importance of capital and labour market imperfections.

In designing interventions around work-based training, several features of the New Zealand environment would need to be taken into account.[14] The first feature is the need for lifelong learning to address skill obsolescence with technical change. A lower level of work-based training might be one factor influencing the skill shortages presently being experienced. New Zealand has lower workforce skill levels, compared with say Australia (see (New Zealand Treasury 2001a), and Parham and Roberts (2004)) The second is the more limited training opportunities faced by those entering the workforce with few educational qualifications. Where in the knowledge accumulation process are these skill deficits best addressed? Third, the relatively small size distribution of New Zealand firms, together with the relatively high level of job turnover seems likely to lead to fewer opportunities for on-the-job training.

[14] Maria Gobbi (1998) has reviewed the findings of the 1996 HLFS Education and Training Survey. The Survey found that just under half of all employees were participating in some kind of education or training at that time. The median hours for on and off the job training were about 20 hours annually, which suggests that many employees received relatively little formal training. This survey excludes on-the-job mentoring and learning by doing. The data is also quite dated. *Firm Foundations* (Knuckey *et al* 2002) also contains data on training levels.

7 Concluding comments

Skills and knowledge contribute in complex ways to a firm's pursuit of efficiency, innovation and market opportunities. Much remains unclear. This review of literature has explored the three main ways whereby raising skill levels will affect firm productivity. Higher skills can raise a worker's own productivity, the productivity of tasks that they perform with capital or technology, and can directly affect the productivity of other workers and other firms. This section draws out the key insights identified, the areas where further work seems likely to be productive, and some implications for policies around work based skills.

There is general agreement that workforce skills are important for growth. Entrepreneurial and managerial skills are clearly important. Given that technical change is broadly skill-biased, the relative demand for technical skills has increased with technological change. Firm dynamics studies point to technology uptake being associated with firms having a skilled workforce. On the other hand, the factors like investment in R&D and access to venture finance are also important in driving technology adoption. From this evidence, the importance of increasing skill levels, relative to other policies, is hard to gauge. For example, recent Australian studies suggest that increases in skills had only a limited role in Australia's productivity surge during the 1990s. Greater weight was attributed to the increased openness of the Australian economy, increased R&D, and a rapid uptake and use of ICT. Nevertheless, they suggest that the accumulation of human capital in previous decades laid a long term foundation for the productivity growth that is now occurring (for example in ICT uptake). Different evidence comes from the detailed comparisons of manufacturing plants and service sector firms in the UK and European countries, which point to large differences in shop floor, supervisory and managerial skill levels, with significantly lower levels of plant productivity in the UK.

7.1 Skills as determinants of firm productivity

A range of skills is required for a firm to make productivity improvements. Entrepreneurial ability is needed to identify and respond to market and innovation opportunities. Managerial capability is essential to provide the leadership and organisational skills to oversee the effectiveness of production processes. Employees' technical skills improve the effectiveness of production processes, and allow advantage to be taken of technological improvements.

Entrepreneurship performs a number of functions, including the recognition of market opportunities, risk taking, R&D and innovation, the re-allocation of resources amongst firms, arbitrage, and market coordination. Two broad types of entrepreneurial activity have been identified. Breakthrough inventions are contributed disproportionately by smaller independent entrepreneurs, while cumulative, incremental improvements are undertaken by larger firms with substantial R&D activities. These types are complementary, but require different skill sets. Smaller entrepreneurs tend to be generalists who require a range of competencies. They need innate skills such as imagination and attitudes to risk, competencies that can be acquired like analytical abilities and technical knowledge, and skills that are obtained through experience like sound judgment. In contrast, the large firm's R&D activity requires researchers to be highly equipped, with a mastery of current technical knowledge and analytical methods.

Policy settings have a major influence on the extent and direction of entrepreneurial activity. Regulatory "rules of the game" affect the structure of payoffs that entrepreneurs face, and determine whether they act in productive or unproductive ways. Pro-competitive regulations improve productivity by providing more scope for entering firms to explore new business opportunities and disseminate new technologies, allowing resource re-allocation through firm dynamics, and limiting rent-seeking and slack in the use of inputs. Policies that affect firm entry and exit costs, such as employment protection legislation and administrative barriers around firm registration and bankruptcy, allow new firms to enter to respond to market opportunities, and the threat of that entry constrains the behaviour of incumbent firms. Access to financial resources is also important to support firm creation and entrepreneurial activity.

Managerial capabilities are also central to raising firm productivity. It is the role of managers to choose production processes, to ensure that these are implemented effectively, to remove inefficiencies, and to move the firm outwards towards its production frontier. Management hierarchies allow talented individuals to hold more senior positions and exert more influence. A wide skill set is required, including the strategic ability to adapt to a changing environment, the organisational and supervision skills to run the business, people and communication skills, and an appreciation of information acquisition and learning processes. Managers are also involved in the design and operation of human resources management practices. These provide a coherent incentive system which enhances workers' contribution to the productivity of the firm. They include work in teams, flexible job assignments, training, and incentive pay, but also pledges of employment security which helped the adoption of change, and good communication that identifies worker concerns and opportunities for productivity improvements. The firm's knowledge management processes appear to contribute positively to firm innovation and productivity, as does its ability to find, assimilate and utilise new external knowledge. Management has a key role in the development of these knowledge bases and structuring the knowledge held within the firm into operating routines that guide "business as usual", and dynamic capabilities which enable firms to respond to change.

The range of technical skills and abilities that are required in the workplace are only partly formed within the education/training system. There is a robust and positive relationship between an individual's education and their earnings, and in response to subjects taken. However, formal education explains a relatively small amount of the overall dispersion of earnings. Returns to years of work experience imply the accumulation of skills on the job. Other cognitive capacities and behavioural traits, such as motivation, trustworthiness, and industriousness, seem to have an influence on earnings outcomes equal to formal education. Adaptability, problem solving, and inter-personal skills are also thought to be important in responding to technical change. Thus, the linkage between the education/training system and firm productivity is weaker where a significant sub-set of the skills required are formed inside the firm, or where the cognitive abilities sought are innate.

7.2 Skill/technology interactions

Improvements in workforce skills can support the introduction and effective use of new technologies. There is broad agreement that the adoption of new technologies has been associated with increases in the relative demand for skilled labour. At the aggregate level, associations have been found between measures of technical change, such as R&D expenditure or computerisation, and the relative demand for skilled workers. The

evidence suggests that this association arises because the adoption of new technologies increases the demand for skilled workers and replaces less skilled workers. Skill availability also interacts with investment/innovation decisions. Even with substantial increases in the supply of skilled labour, over the past two decades the earnings premium for skills has risen or remained high. Thus, increases in the supply of skilled labour can induce the development of skill-complementary technologies.

The firm dynamics literature points to the differences in the productivity of firms within an industry being both marked and persistent. Productivity increases as innovative firms enter, poorly run new businesses fail, and continuing firms adjust their mix of skills and technology. Resource re-allocation from less to more productive plants within an industry, and from firm entry/exit, play an important role in aggregate MFP growth. Plants with higher levels of firm productivity have higher workplace skills. There is US evidence of different skill-technology matches amongst plants, giving rise to a growing dispersion of wages and productivity between plants within the same industry. This, in turn, is linked to different rates of technological adoption. A related set of studies provides evidence that plants adopting new technologies appear to have already employed more able workers. In particular, the evidence suggests that workers are better paid because they are abler, rather than because they are utilising newer technologies. Thus firms may be employing a more skilled workforce in order to be more advanced technologically.

Other evidence indicates that obtaining the full productivity gains from technical change, particularly from the diffusion of computer based technologies, requires substantial changes in workplace organisation. This includes flatter management structures, more team work, and performance-related pay. These changes alter the skill mix that employers require. They reduce the demand for less skilled labour for repetitive tasks, and increase the skill levels required for analysing data and for worker autonomy and responsibility. Firm re-organisation allows alternative combinations of skills to be drawn together to take advantage of the complementarities between human capital, information technologies and organisational change. Some commentators have suggested that rapid workplace organisation may account for a larger fraction of the productivity gains than does technological change alone.

More recently, attention has been given to the productivity effects of ICT diffusion across industries. The OECD has identified three broad groups of factors that are influencing the rate of diffusion. First, the regulatory environment affects the ability of firms to take advantage of opportunities, in particular product market competition, flexibility in the labour market, and firm entry and exit. Second, firms differ in their ability to absorb ICT, arising from the firm's skill base and level of innovative activity. Another important source of productivity gains is the reorganisation of work practices. Spillover effects around learning from the increased use by industries of ICT also supports adoption by remaining firms. Third, large differences persist in the costs of investing in ICT across OECD countries. There also seem to be timing effects. The investments required in complementary learning and organisational change can lead to substantial lags between ICT capital investments and productivity growth in the ICT-using industries.

7.3 Knowledge spillovers

The third mechanism whereby increases in an individual's skill levels might give rise to improvements in the productivity of firms is through the direct effects on other workers or other firms. The importance of these knowledge externalities or spillovers is hard to

assess. The actions of senior managers can have effects on subordinates, while knowledge management systems and mentoring facilitates knowledge transfers. Increased individual skill levels can have substantial effects on the productivity of co-workers and firms. There is evidence that where a person works can explain as much of earnings variation as does worker characteristics. The processes and practices that managers put in place can therefore substantially influence workers' effectiveness and wages, or be reflected in the intangible value of the firm.

Knowledge spillovers also occur between firms in an industry. Where the stock of shared knowledge in an industry is greater, firms will be more productive. These spillovers can occur through three mechanisms, namely the sharing of inputs, matching, and learning. Evidence on these effects has proved difficult to obtain, but the matching effect appears to be more important. Thicker labour markets allow better matches between firms and the skills required, as well as increased specialisation by workers. Geographical proximity also encourages spillovers associated with learning, by easing the transfer of information, especially of tacit information, through face to face contacts.

Nationally, low skill levels and skill shortages may influence the choices by firms about the technologies to adopt. It has been argued that a coordination problem exists between the demand for and supply of skills, which leads to a degree of path dependence in decisions about technology adoption and skill investments. Given relatively long development times, firms may choose technologies conditional on the expected supply of skills in the workforce, while educational investment by individuals may be influenced by expectations about the future availability of jobs.

The factors giving rise to low technology/skill matches are clearly important, and will influence the role for government. However, it is not clear what perpetuates low skill equilibriums over time, or hinders economies from transitioning out of them. There is evidence for the UK that persistent shortages of skilled labour may be influencing technology adoption and capital investments. The case for further increases the supply of skilled workers depends on whether other factors are more critical. The UK evidence that a systems failure is involved requiring a coordinated response across a range of policies and institutions is unclear about policy specifics. There may, for instance, be significant costs associated with firms changing their input mix, given sunk investments in capital, labour, technology and organisation, leading to slow rates of adjustment. For instance, more recent evidence points to the importance of building up organisational capital to obtain the productivity benefits of ICT use. The policy specifics here will be influenced by the economy being analysed.

7.4 Work-based skill acquisition

The adequacy of work-based training is important for a number of reasons. First, with ongoing technical change, continuous learning will be required to maintain the stock of skills in the existing workforce and offset skill obsolescence. Second, much knowledge accumulation occurs on the job. Those leaving school with few educational qualifications are likely to face more limited training opportunities in the workforce, which will tend to amplify the skill gap rather than compensate for low levels of educational attainment. Third, the persistence of skill shortages may be affecting technology adoption and capital deepening. If labour shortages continue, firms will need to respond by increasing training and/or substituting capital for labour in future investments.

The dominant view of human capital formation in the workplace is that the market will provide general and firm specific forms of training in sufficient quantities, with no need for government intervention. However, a good deal of contrary evidence exists, especially on the extent of employer-funded general training, and on wage growth following training being much less than productivity growth. This implies that labour market imperfections are occurring to some extent, and that employers and workers will tend to under-invest in training. However, the literature provides little evidence of either the level of imperfect competition or of the size of the under-investment effect.

More sharply focussed policy work is warranted here. A major consideration concerns the nature of the market failure that the intervention is seeking to target, such as information asymmetries, imperfect competition in the labour market, or credit constraints. The design of any interventions depends on which types of market failure are thought to be more important. A number of co-financing arrangements are being used in OECD member countries that allow employers and workers to generate more tailored training assistance packages and encourage lifelong learning outcomes. They provide scope for training programmes to be negotiated that yield the types of skills needed by firms. The extent of regulatory and/or institutional failure with particular interventions would also have to be taken into account, such as encouraging the substitution of formal general training for informal or customised training, or shifting the costs of training onto taxpayers with little increase in training.

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