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Adele Bergin and Ide Kearney

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Adele Bergin* and Ide Kearney*

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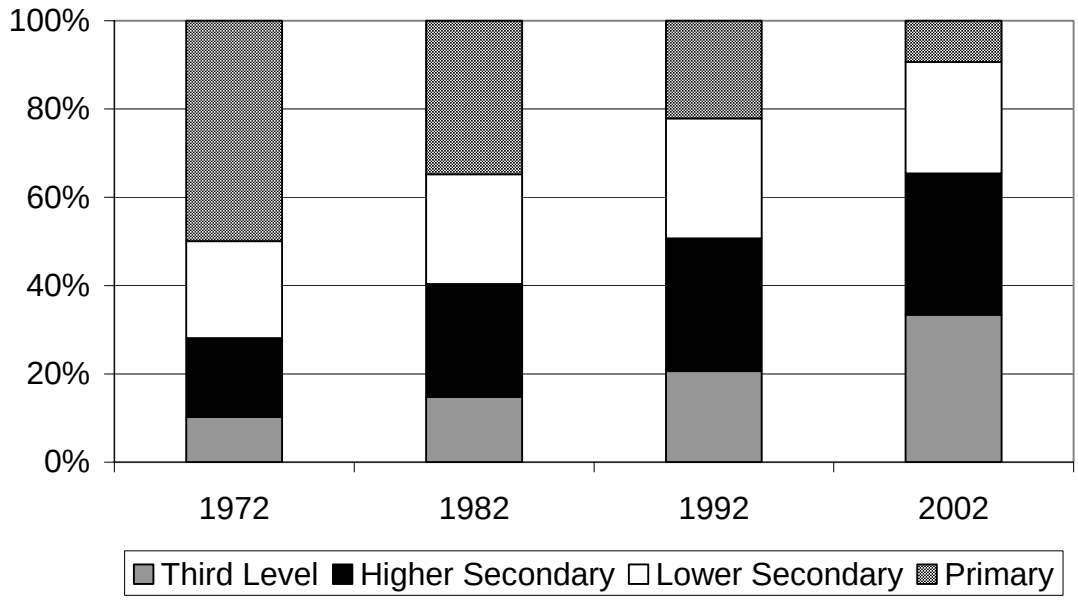
* *Economic and Social Research Institute, Dublin, Ireland*

1. Introduction

Recent developments in growth theory[1] suggest that factors such as human capital accumulation are central to the growth process of an economy through raising productivity and increasing a country's ability to develop and facilitate technology. In these models policies that raise the level of human capital can permanently increase the growth rate. The Irish economy presents a highly interesting case-study of this hypothesis. Ireland[2] is a small, highly-traded economy which witnessed dramatic growth rates in the 1990s with a doubling of output, a 40% increase in employment and a 60% fall in levels of unemployment. This remarkable performance led to rapid convergence in per capita output with the EU average.

Investment in human capital in Ireland occurred later than in other Northern European countries, where investment in human capital expanded after the Second World War. It was not until 1967 that free second level education was introduced in Ireland. This led to a dramatic upgrading in the educational attainment of the labour force over the past three decades (Figure 1.1).[3] The contribution of this rapid rise in human capital to growth in Ireland, particularly in the 1990s, can only be understood within the context of the rise in demand for high-skilled labour worldwide (Nickell and Bell, 1995). Ireland captured its share of this rise through new foreign investment (Barry and Bradley, 1997) and a general move towards more skill-intensive production.

Figure 1: Educational Attainment of the Labour Force



The consequences of this rapid rise in human capital investment for economic growth, given strong external demand for Irish output and a highly open labour market through migration, is the focus of this paper. We develop a small structural model of the Irish labour market that distinguishes between high-skilled and low-skilled labour. Labour input in production is augmented using a measure of human capital

[1] Developed from the seminal contributions of Romer (1986) and Lucas (1988).
[2] Throughout the paper Ireland refers to the Republic of Ireland only.
[3] In the Irish education system lower secondary refers to those with Junior Certificate education, while higher secondary refers to those with Leaving Certificate education.

accumulation, and we allow for increasing returns to scale. The demand for and supply of both types of labour are modelled separately. This model is then used to trace the channels through which investment in human capital impacts on productivity and output. There are several channels through which human capital may contribute to output growth in Ireland. Higher human capital has a direct effect in raising productivity. Rising educational attainment leads to higher participation in the labour force. Furthermore those with higher levels of education are less likely to be unemployed, so rising educational attainment can lead to a reduction in unemployment.

This model is used to examine the impact of the increase in human capital that helped to transform Ireland in the space of two decades into a high productivity and low unemployment economy. This transformation takes place for a given profile of external demand, which changed dramatically over the period, captured in our model by an outward shift in the demand for Irish output and by skill-biased technical progress. This huge shift in demand is critical to understanding why the change in human capital actually mattered. Had demand remained unchanged then the consequences of the rise in human capital would have been a dramatic fall in the high-skilled wage, a negative effect on living standards and a rise in emigration.

Our key findings suggest that the demand for Irish output is relatively sensitive to Ireland's international competitive position. The openness of the labour market, through migration, has accommodated this in the face of rising demand. By international standards, this open labour market gave Ireland a unique advantage and facilitated the rapid convergence to EU living standards witnessed in recent years. Within this context, the rise in human capital played a pivotal role in increasing output and productivity, preventing wage dispersion between high-skilled and low-skilled workers and in boosting employment. We find that had Ireland failed to invest in human capital over the past 20 years, GNP per capita would be over 20 percentage points lower. In our numerical simulations we decompose the growth in output per head into the contributions from employment, participation and productivity. Our results suggest that, with unemployed resources, the biggest benefit to the Irish economy in the 1990s from human capital accumulation was in terms of employment rather than productivity. With the economy now at or close to full-employment the biggest benefit in the future is likely to come from rising labour force participation.

The paper is structured as follows. Section 2 reviews the main theoretical frameworks used in the literature on human capital, and describes some of the methodological issues that arise in empirical work. Section 3 describes the theoretical model we are using and details the key behavioural equations in the model. Section 4 examines the sensitivity of the model to competitiveness. In section 5 we perform a number of shocks to explore the properties of the model. Section 6 concludes.

2. Human Capital and Growth

Two theoretical approaches are used to explore the factors that determine the long-run growth rate of an economy, namely the augmented Solow model and new growth theory. Since the late 1950s, the prevalent view among economists is that the rate of technological change drives a country's long-run growth rate (see Solow, 1956). Solow's neo-classical model can be extended to include human capital by treating it

as an input in the basic production function framework in exactly the same way as physical capital. An increase in human capital (or any input to production) can raise the level of output in the long run, but not the growth rate, because an increased amount of resources have to be devoted to maintaining higher levels of inputs. Sustained per capita output growth can be achieved through technological progress, which is residually determined outside the model.

New growth theory departs from the neo-classical model by endogenising the engine of growth and focussing on explaining technological change. One branch of new growth theory argues that externalities arising from investment can increase an economy's productive potential. Investment in human capital is one channel through which these spillover effects may arise (Lucas, 1988). In these types of models sustained per capita growth can be obtained through sustained human capital accumulation (there are non-decreasing returns to scale to the cumulative factor of production). Therefore policies that raise the level of human capital can permanently increase the growth rate of the economy.

Human capital consists of the ability, skills, knowledge and qualities embodied in people that are accumulated through schooling, training and experience. In empirical work this is generally measured by formal education. Endogenous growth models that focus on human capital include it as a factor input, and argue that the causes of endogenous growth are explicitly related to the stock of human capital as it increases a country's ability to develop and facilitate technology adoption (Katz, 1992). The existence of positive educational externalities means that the benefits of human capital accumulation may not be confined to the individual but might also spill over to other members of society. In doing so they generate macro-economic benefits that cannot be wholly accounted for in the higher earnings of those who undertake the relevant investment. Therefore attempts to model the linkages between human capital and economic growth should take place at the macro level to adequately capture the educational externalities.

There are many channels through which this type of externality may arise. Lucas (1988) emphasises that economies with high levels of human capital have a higher incidence of learning from others and this should contribute to productivity gains.[4] In addition, investment in human capital is assumed to be an increasing function of the stock of human capital. This means that countries with high levels of human capital tend to invest more in human capital and so current investment in human capital can benefit future generations.

2.1 Measuring the stock of human capital: methodological issues

Increasingly the empirical literature is focussing on a range of methodological issues and problems involved in estimating the impact of human capital on growth. Failure to take these issues into account can seriously under (or over) estimate the impact of

[4] Other human-capital based models which build on the framework proposed by Lucas include Becker, Murphy and Tamura (1990), who examine the relationship between human capital, fertility and growth, and Rebelo (1991), who proposes an endogenous model that does not require increasing returns to scale.

human capital.[5] De la Fuente and Doménech (2002) argue that counterintuitive results on human capital and growth can be attributed to deficiencies in the data and show that improvements in data quality increase the size and significance of human capital coefficients in growth regressions.[6] Therefore, a central methodological issue relates to how the stock and flow of human capital can best be measured.

Two main approaches are used in empirical work. The first is an output-based approach that focuses on measuring the output of the educational system, specifically average educational attainment. As these data are often not available proxies, usually relating to the inputs of the educational system such as enrolment rates, average years of schooling and the proportion of the labour force that have received various levels of education, are used. These measures do not take into account the quality of education, the educational infrastructure or the relevance of what is learned in terms of it being directly productive, as different types of education can have varying impacts on economic performance.

Early empirical work used school enrolment rates as a proxy for the stock of human capital (Barro, 1991; Mankiw, Romer and Weil, 1992). While the publication of enrolment figures by organisations such as UNESCO and the World Bank provide the means for cross-country analyses to be made, there are severe shortcomings associated with this measure. It may be an acceptable indicator for the flow of human capital but it is not a good proxy for the stock of human capital since average educational attainment responds slowly and with a lag to investment flows (de la Fuente and Doménech, 2002). Other measures of educational attainment have been constructed using data on attainment levels (usually from national censuses) combined with enrolment figures to produce a series of average years of schooling (for example, Barro and Lee, 1993). Attainment levels for intercensal years are estimated by means of interpolation or by transforming enrolment data into attainment figures using a perpetual inventory method or some approximation of it.

Although measures of average years of schooling overcome the stock/flow problem associated with only using enrolment rates Mulligan and Sala-i-Martin (1995) point out several flaws with this proxy. This approach implicitly assumes that workers of different educational attainment are perfectly substitutable for each other. It assumes that productivity differentials among workers are proportional to their differential in educational attainment. As an additional year of education is assumed to increase an individual's human capital in the same proportion, it implies that a person with sixteen years of schooling is sixteen times as productive as a person with one year of schooling. This approach assumes that the elasticity of substitution across workers is constant across regions and time, regardless of factors such as the field of study and the quality of teaching. Finally, some measures based on average years of schooling

[5] De la Fuente and Doménech (2002) cite several studies including Knight, Loayza and Villanueva (1993), Benhabib and Spiegal (1994), Islam (1995), Caselli et al (1996), Hamiliton and Monteagudo (1998) and Pritchett (1999) that find educational variables are insignificant or they have a negative impact in growth regressions.

[6] In addition to measurement issues, De la Fuente and Doménech (2002) point to the existence of sharp breaks and implausible changes in educational attainment levels over very short periods of time as a major cause for the varying results on the impact of human capital on economic growth, especially in cross-country empirical work.

ignore the migration or mortality of individuals, and this provides an upwards bias in the proxy for the stock of human capital.

Another approach to constructing measures of human capital is based on labour income. The starting premise for this type of proxy is that a worker's quality is related to the remuneration they receive in the labour market. This concept of 'productive human capital' means that a person who has studied a particular area that is useful in terms of production will be rewarded by the market with a high wage, and vice versa. Mulligan and Sala-i-Martin (1994) point out that workers' remuneration also depends on the amount of physical capital and technology available in the economy. They argue that the effect of aggregate variables has to be eliminated from individual's wages so they divide each person's wage rate by the wage rate of the zero-skilled worker to isolate the component of wages attributable to skills. This labour income based measure of human capital is the weighted sum of all workers, with the weights being a person's wage relative to the zero-skilled worker.

This measure allows for variable elasticities of substitution across workers, it doesn't assume that productivity increases proportionately with years of education and it also permits changes in relative productivities across regions and time. However, this measure fails to take into account the fact that wages can change for reasons unrelated to changes in human capital and there is an implicit assumption in this measure that the zero-skilled worker is a perfect substitute for any other worker.[7]

The methodology used in this paper for constructing a measure of Irish human capital draws from both the output-based and income-based approach and in doing so overcomes some of the problems described above and yields an index with a high information content.[8] We use Labour Force Survey data, which are available on an annual basis since 1988, to ascertain the level of education completed of those in employment. Those in employment are classified using a four-way educational attainment breakdown: those educated to Primary level standard, those with lower secondary education only, those with higher secondary and those with tertiary level education. We extend the series backwards to 1966 using data from successive *Censuses of Population.*

The next stage in the process involved applying a measure of returns to education, with those educated to primary level assigned as the reference grouping (with a weight of one).[9] These weights also take account of individual characteristics such as years spent in a return to education or training, marital status and urban or rural residence. The estimated returns to education in each educational category were then weighted by the shares of employees in these categories to yield an index of human capital. The human capital index used in this paper overcomes several of the problems associated with using proxies for average educational attainment, such as enrolment rates or average years of schooling. Across educational groups, the index does not

[7] Mulligan and Sala-i-Martin (1995) propose a new methodology to help resolve some of the shortcomings in their previous work based on the construction of index numbers that minimise a function of the expected error made when human capital indices are compared across economies.
[8] A complete description of the methodology and data used to construct the Irish human capital index is available in Appendix 1.
[9] These weights used are the estimates of returns to education from Callan (2003).

assume that all workers are perfect substitutes for each other and it does not assume that additional educational attainment increases skills in the same proportion.

The human capital index indicates a steady rise in the human capital of those at work over time (see Appendix 1). For example, in 1966 the average worker had lower secondary qualifications whereas in 2002 the average worker's human capital was above higher secondary level. In addition, the growth rate of the index has been increasing over time. The average annual increase in the index is 0.48 per cent in the 1970s; it is marginally higher at 0.49 per cent in the 1980s, whereas there was a large increase in the growth rate to 0.56 per cent in the 1990s. The marked increase in educational attainment evident in Figure 1.1 is reflected in the higher growth rate of the human capital index.

2.2 Empirical studies of human capital and growth

In empirical work, the neo-classical approach and endogenous growth theory are associated with growth accounting exercises and macro regressions respectively.[10] Although these are distinct approaches, empirically they are observationally equivalent. Both approaches assume that output growth depends on the rate of growth of human capital although they have very different implications for the effects of human capital investment on the long-run growth rate of an economy. Growth accounting studies estimate the contribution of inputs and total factor productivity to output growth or differences in output per worker across countries.[11] Durkan, Fitzgerald and Harmon (1999) estimate that labour adjusted for educational attainment accounted for around 36 per cent of GNP growth in Ireland over the 1991-96 period and that total factor productivity accounted for half of the growth in the period, with the remainder attributable to capital. Fitz Gerald and Kearney (2000) find that the effects of educational attainment contributed around 0.5 percentage points per annum to growth in Ireland in the 1990s and the contribution from total factor productivity (the residual) was correspondingly lower. In macro regression studies, growth regressions are used to estimate rather than impose the parameters of the aggregate production function. This provides a means of testing directly for the productivity and output effects of human capital.

3. The structure of the model

The broad theoretical framework is a model with one output and two kinds of labour, high-skilled and low-skilled. [12] We model labour supply and labour demand for both kinds of labour separately, and include a measure of human capital accumulation, which captures the productivity effects of a shift from low-skilled to high-skilled labour in employment.

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[10] Sianesi and Van Reenan (2003) provide an excellent review of the macro-economic literature on the returns to education.

[11] Temple (2000) warns that growth accounting results need to be interpreted cautiously. For example, if a change in labour force quality is said to contribute, say, 10 percentage points to growth, it does not follow that growth would be 10 percentage points lower in the absence of the change in labour quality as educational attainment may have indirect effects on output through investment, labour force participation and total factor productivity.

[12] We define high-skilled as those who have at least a higher secondary qualification and low-skilled as those with at most a lower secondary qualification. While we have data on labour supply in more detail, more disaggregation would make modelling work intractable.

Within this framework we develop a structural model of the labour market which allows for increasing returns to scale due to human capital accumulation and an increase in the skill-intensity of labour demand over time.[13] The productivity effects of increasing returns to scale are modelled using an output equation based on the SOE model of firm location, while skill-bias in the demand for labour is captured by allowing for changes in the demand for high-skilled labour relative to low-skilled labour over time. We model the participation decision for the high-skilled and low-skilled working age population separately. The high-skilled labour market clears through wage adjustment and migration flows. The low-skilled labour market does not clear when the replacement ratio is above a certain specified threshold; below that threshold the low-skilled labour market clears. Appendix 2 to this paper contains technical details of the model estimation and a full listing of model equations.

3.1 Output and Input Determination

We begin with an overview of the underpinnings of the determination of output and factor inputs in our model. This is based on the work of Bradley and Fitz Gerald (1988) where output and factor inputs in a small open economy are determined in a two-stage optimisation procedure. They begin with a 'world production function' where world output is a function of factor inputs in all countries. Assuming weak homothetic separability[14], to rule out the possibility that a firm can combine factors from different countries in producing a single output, each individual country cost function can then be written as a function of factor prices and output in that country alone. This allows the development of a two-stage optimisation procedure in determining output and factor inputs in an individual country. In the first stage firms choose the cost minimising input bundle conditional on output and factor prices in that country alone. This cost function can be used to estimate conditional factor demand functions. Given these factor demands, firms then determine their allocation of world output between countries in the second stage of the optimisation procedure. Domestic output is a function of world output and relative unit costs, derived from the cost function in the first stage.

This framework means that we can estimate the output equation and the factor demand equations in two separate stages. The first stage involves estimation of factor demands under the assumption of cost minimisation behaviour. We use the CES production function for two factors, labour (L) and capital (K), to derive the factor demand equations. The constant returns to scale CES production function was developed by Arrow, Chenery, Minhas and Solow (1961); Brown and de Cani (1963) modified this to allow for non-constant returns to scale as follows:

$$Q = A\left[\delta(K)^{-\rho} + (1-\delta)(L)^{-\rho}\right]^{-\mu/\rho} \qquad (1a)$$

where A is the 'scale' parameter, ρ is the 'substitution' parameter (the constant elasticity of substitution $\sigma = 1/(1-\rho)$), and δ is the 'distribution' parameter since it

[13] This paper builds on the labour market model developed and used in Fitz Gerald and Kearney (2000) and Barrett, Fitz Gerald and Nolan (2002).

[14] Note that the assumption of homotheticity implies that returns to scale are identical across all countries.

determines the distribution of income through factor payments. The Brown and de Cani specification assumes the function is homogenous of degree μ where μ is the returns to scale parameter (=1 for constant returns to scale, >1 increasing returns to scale, <1 decreasing returns to scale).

In variations on the CES function the labour and capital terms are augmented to include technical progress embodied in labour and capital respectively (see for example Bradley and Fanning, 1984). We augment the labour input with an index of the human capital embodied in employed labour, *HK*, and allow for the possibility of non-constant returns to scale. These are not factor-specific returns to scale, instead this specification implies that human capital accumulation has boosted the augmented labour-capital mix in production.[15]

Assuming cost minimization behaviour in this first stage, we can derive the demand for labour equation for the CES production function above as follows:

$$\log \tilde{L} = \frac{1}{\mu}\log Q - \frac{1}{\mu}\log A + \frac{\sigma}{1-\sigma}\log(1-\delta) + \frac{\sigma}{1-\sigma}\log\left[\left(\frac{R}{W}\right)^{1-\sigma}\left(\frac{\delta}{1-\delta}\right)^{\sigma} + 1\right] \qquad (1b)$$

where $\tilde{L} = L * HK$. This equation is non-linear in the parameters and cannot be estimated directly. Typically indirect estimation is done either using the marginal productivity condition which allows for direct estimation of σ, the elasticity of substitution, and μ, the returns to scale parameter, or using the ratio of the marginal productivity condition for labour and capital, which allows for estimation of σ and δ, the distribution parameter. These estimates can then be used to linearise the equation, in logs, in a second-stage estimation of the remaining parameters A and δ, or A and μ respectively. We use the marginal productivity condition approach, as detailed in Appendix 2, since this facilitates direct testing of the increasing returns to scale hypothesis. The implied elasticity of substitution is 0.19 and the returns to scale parameter is 1.27, indicating substantial increasing returns to scale.

The relative demand for high-skilled labour is modelled separately from total labour demand[16] again assuming cost minimisation behaviour. We use the translog cost function in estimation, which relaxes the assumption of a constant elasticity of substitution that underlies the CES function. Earlier work on the relative demand for high-skilled labour suggests that the elasticity of substitution has fallen over time, not least due to the very large increase in the share of high-skilled labour in total employment (see Kearney, 1997). The cost share equation for high-skilled labour derived from the translog cost function is given by:

$$S_{LH} = \alpha_H + \alpha_{HH}\log(W_H) + \alpha_{HL}\log(W)_L + \alpha_{HT}T \qquad (2)$$

where S_{LH} is the share of high-skilled wage bill in the total wage bill, W_H is the high-skilled wage rate, W_L is the low-skilled wage rate and T is a time trend. Cost

[15] Of course the capital input itself is also technically augmented over time through capital-specific technological progress, e.g. R&D expenditures. We do not explore this further since we do not estimate the demand for capital.

[16] This imposes weak separability between the high-skilled/low-skilled labour bundle and other factors of production.

minimisation behaviour implies that α_{HH}=- α_{HL} where the elasticity of substitution σ_{HL} is σ_{HL}= 1+(α_{HL} / $S_{LH}.S_{LL}$). The coefficient α_{HT} allows for skill-bias in technical progress. Because in this model we have only one composite good, this parameter is crucial. The enormous shift in the structure of production in Ireland over the past twenty years, towards more skill-intensive production and towards more skill-intensive sectors, is embodied in this parameter.

The estimation results, reported in Appendix 2, imply that over time high-skilled labour has become less substitutable for low-skilled labour as its share in the total labour bundle has risen so that by the mid to late 1990s there is essentially a zero elasticity of substitution. As we would expect, technical progress is biased towards high-skilled labour in production.

We do not include capital in the model. This in turn means that the unit cost that feeds through into the output equation in the second-stage is unit labour costs. In our empirical model we estimate the high-level "location" decision as a function of world output and relative unit labour costs:

$$Q = f(Q_W, c_i) \tag{3a}$$

where Q is Irish output, Q_W is world output, and c_i is unit labour costs in country i. Firms select a location for production on the basis of world demand and Ireland's relative cost competitiveness.[17] As the Irish economy is largely traded, we adopt this specification to model GNP.

In the empirical equation (3b), world demand is proxied by US GDP (GDP_{USA}), given the influence of US multinationals in the Irish traded sector. The equation also includes a separate term to capture the effect of the acceleration in FDI flows in the 1990s. This 'FDI term' is constant till 1990 and grows at the same rate as US GDP in subsequent years. This is designed to capture the increase in the elasticity of Irish output with respect to foreign output from 1990 onwards due to the enhanced role of FDI. Effectively this causes the demand curve for Irish output to shift outwards in the 1990s. Competitiveness is measured using two terms, Irish unit labour costs (*ULC*) relative to the UK (ULC_{UK}*e_{UK}) and Germany (ULC_{GER}*e_{GER}). These countries are chosen as representative of Ireland's main trading partners. Any gain in Irish competitiveness results in an increase in market share and faster growth than the world economy. Any loss of competitiveness reverses this process.

$$\begin{aligned}\log(GNP) = 10.73 - 0.27\log\left(\frac{ULC}{ULC_{GER} * e_{GER}}\right) - 0.37\log\left(\frac{ULC}{ULC_{UK} * e_{UK}}\right) \\ +1.11\log(GDP_{USA}) + 1.32\log(GDP_{USA}) * D_{90}\end{aligned} \tag{3b}$$

The regression results are given in Appendix 2, and the implied long-run relationship is shown in equation (3b). The elasticity of Irish output with respect to US GDP is greater than unity, at 1.11, reflecting the high dependence of the Irish economy on the US multinational sector, while the long-run 'FDI term' is even higher. The unit labour

[17] Bradley and Fitz Gerald, 1988.

cost elasticities suggest that in the long-run firm location is sensitive to Ireland's international competitive position vis-à-vis the UK and Germany.

Human capital accumulation (*HK*) is endogenised in the model as a simple weighted average of high-skilled (L_H) and low-skilled (L_L) labour as follows:

$$HK = \omega_H L_H + \omega_L L_L \tag{4}$$

This is derived as a function of those employed rather than of the population. Therefore it will only change in response to a shift in the demand for high-skilled relative to low-skilled labour through the parameter α_{HT}.

3.2 Labour Supply

We model labour supply for high-skilled and low-skilled labour separately. In modelling the demand for labour they are treated as different factors of production for the firm. As domestic production has become more technologically advanced and the educational levels of the workforce have improved, high-skilled and low-skilled workers have become less substitutable. In the long-run, those with high levels of education are typically more mobile and will emigrate (immigrate) in periods of low (high) labour demand so unemployment rates among these workers are relatively stable. In contrast, those with lower levels of education either withdraw from the workforce or are unemployed in periods of low labour demand. This means that the unemployment rate for low-skilled workers will be higher then the unemployment rate for high-skilled workers. At the margin we assume that the high-skilled labour market clears through migration and wage adjustment.

This captures key features of the Irish labour market in recent years. For high-skilled labour, the model assumes a constant unemployment rate with migration flows ensuring that the high-skilled labour market always clears. For low-skilled labour the situation is more complicated. Until the late 1990s, the replacement ratio for low-skilled labour was above the market clearing wage rate, so the low-skilled labour market adjusts via changes in the unemployment rate. However, in more recent years, as the demand for low-skilled labour has increased, wage bargaining has become a feature of the low-skilled labour market. To allow for this change the model includes a threshold replacement ratio below which the low-skilled labour market clears, and above which the low-skilled wage rate is a simple function of the replacement ratio.

3.2.1 High-Skilled Labour Supply

The supply of high-skilled labour (N_H) consists of a series of equations determining the participation decision and the population, which in turn is driven by migration. The high-skilled participation decision is modelled as a function of the real high-skilled consumption wage (W_H/PC) and a time trend (*T*), with the labour supply semi-elasticity imposed at 0.21[18] taken from a recent microeconomic study of participation behaviour in Ireland (Doris, 2001). Underlying this estimate is a relatively high

[18] This estimated elasticity of labour supply for high-skilled labour is taken from microeconomic studies (Doris, 2001) and calibrated in the model.

female labour supply elasticity[19], as women's participation is more sensitive to changes in labour market conditions. The estimated coefficient on the time trend (see Appendix 2 for details) suggests that, in the absence of increases in real wages, the participation rate would be falling slowly over time.

$$\left(\frac{N_H}{POP_H}\right) = 3.17 + 0.21\log\left(\frac{W_H}{P_C}\right) + -0.002T \quad (5)$$

The high skilled population (POP_H) is a function of the natural increase (NI_H) and net immigration (M), where migration is assumed to be driven by lagged changes in the relative wage between Ireland and the UK ($relw$). It is assumed that all migration is high-skilled, with approximately 75% of migrants being in the 15-64 age group.[20] This reflects the fact that high-skilled workers are mobile and will migrate if labour demand is low.[21]

$$POP_{H,t} = NI_{H,t} + 0.75M_t + POP_{H,t-1} \quad (6a)$$

$$M_t = f\left(relw_{t-1}\right) \quad (6b)$$

The estimating equation (6c) nests equations (6a) and (6b), the long-run coefficients are as follows:

$$POP_H = -1035.9 + 1711.8\log(relw) + 1.80t^2 \quad (6c)$$

We assume a fixed frictional unemployment rate so that these equations together determine the changes in the wage rate necessary to clear the market.

3.2.2 Low-Skilled Labour Supply: Regime Switch

The equations determining the supply of low-skilled labour combine to determine either the low-skilled unemployment rate or the low-skilled wage rate depending on the level of the replacement ratio. With a high replacement ratio the low-skilled labour market does not clear since there is an effective floor on wages, and therefore changes in labour supply just alter the unemployment rate. Below a specified threshold however the market wage exceeds this floor and the low-skilled labour market clears. The low-skilled participation decision is modelled as a function of the real low-skilled consumption wage and a time trend with the semi-elasticity of labour supply 0.73 calibrated from Doris (2001).

$$\left(\frac{N_L}{POP_L}\right) = 21.53 + 0.73\log\left(\frac{W_L}{P_C}\right) - 0.01T \quad (7)$$

[19] See Doris (2001) for a discussion of the difference between male and female participation elasticities.
[20] Barrett and Trace (1998) show that returning migrants and immigrants to Ireland in the mid-1990s have high levels of educational attainment.
[21] Fahey, Fitz Gerald and Maître (1998).

4 Underlying wage elasticities in the model

In this section we look at the underlying wage elasticities in the model. Because the model uses only long-run coefficients, thereby eschewing differences in the speed of adjustment in different segments of the labour and output markets, it gives a direct estimate of the long-run sensitivity of the economy to competitiveness. We begin by looking at the determination of output and labour. The sensitivity of output to wages is relatively high and increases under increasing returns to scale. This indicates that Ireland's international competitiveness is an important factor in driving output. For a given level of output the results show that the level of employment is not very responsive to wage changes. And finally the dramatic shift in demand towards high-skilled labour and emerging dominance of high-skilled labour in total employment means that the composition of employment for a given level of output is unaffected by changes in the relative wage.[22] We then turn to the labour supply elasticities in the model: high-skilled labour supply is highly elastic because of the ready availability of migration flows. This has been a critical factor in maintaining Irish competitiveness given the strong growth in the demand for high-skilled labour.

Table 1 summarises the estimated wage elasticities in the model. The constant-output own elasticity of demand for labour can be derived from equation (1b) as $\varepsilon_{LL} = -\sigma(1-S_L)$ where S_L is the labour share (see Hamermesh (1993)), and is very low averaging just under –0.10. Employment from the labour demand equation feeds directly into unit labour costs, which in turn feed directly into the output equation (3b). Solving for output as a function of the wage, the elasticity of output with respect to the average wage ε_{QW} can be derived as follows, where *e* denotes the elasticity of output with respect to unit labour costs:

$$\varepsilon_{QW} = \frac{\mu e}{\mu - (1-\mu)e}\left[1 + \varepsilon_{LL}\right] \qquad (8)$$

This is increasing in the parameter μ, the presence of increasing returns to scale increases the sensitivity of the economy to international competitiveness. The output elasticity with respect to wages averages -0.67 (Table 1). This suggests that, *ceteris paribus*, relative competitiveness is an important factor in driving GNP.

The relative demand for high-skilled labour, equation (2), can be used to derive the constant-labour elasticity of demand for high-skilled (ε_{LHLH}) and low-skilled labour (ε_{LLLL}) respectively, together with the elasticity of substitution between the two types of labour σ_{HL}. The estimated coefficient on the time trend in equation (2), 0.01, indicates that *ceteris paribus*, the share of high-skilled labour gains one percentage point relative to low-skilled labour in each year, implying very significant skill-bias in labour demand over time. This is reflected in the share of high-skilled labour, which rose from 65% to 80% between 1980 and 2000. This emerging dominance of high-skilled labour in total employment has consequences for the sensitivity of the composition of employment to changes in the relative wage. As shown in Table 1,

[22] The model treats consumer prices as exogenous. While this simplification may seem strange, previous research has found that in the long-run, Irish consumer prices are largely externally determined (Fitz Gerald and Shortall, 1998).

both the own elasticities of demand and the elasticity of substitution between high- and low-skilled labour are very low, approximately zero by the end of the period.

Table 1: Long-run elasticities in the model

	Output	Labour demand				Labour Supply		
		Total	Relative			High-Skilled		Low-Skilled
	ε_{QW}	ε_{LL}	ε_{LHLH}	ε_{LLLL}	σ_{HL}	εv_{NHNH}	ε_{NHNH}^{*}	ε_{NLNL}^{*}
1980-85	-0.67	-0.09	-0.08	-0.16	0.24	2.82	0.28	1.38
1986-90	-0.67	-0.09	-0.05	-0.13	0.17	2.44	0.29	1.41
1991-95	-0.67	-0.09	-0.02	-0.05	0.07	2.14	0.29	1.42
1996-00	-0.66	-0.10	0.00	0.01	-0.01	1.74	0.29	1.37

* Estimates from Doris (2001) calibrated in participation equations.

Given the demand for labour determined by the output and labour demand equations, its interaction with the supply of labour then determines the equilibrium wage level and the unemployment rate. The elasticities of labour supply with respect to the wage for high-skilled (ε_{NHNH}) and low-skilled labour (ε_{NLNL}) are calibrated in the model from Doris (2001). These imply that in the absence of migration, high-skilled labour supply is relatively insensitive to the wage, while low-skilled labour supply is highly sensitive to the wage.

However this story is further complicated by the relatively high replacement ratio in the low-skilled labour market and by migration in the high-skilled labour market. In the low-skilled labour market, under market clearing the sensitivity to wages is high, with an elasticity of labour supply averaging 1.4. However, because the model embeds a threshold replacement ratio, the wage rate remains fixed above that threshold and it is the unemployment rate that adjusts to changes in labour demand.

With a closed labour market, the high-skilled labour market would clear at a much higher wage rate. However, the inclusion of migration in the high-skilled population means that participation is very sensitive to changes in wages. With endogenous migration the full labour supply elasticity for high-skilled labour, $\varepsilon v_{NHNH,}$ can be derived by substituting the population equation (6) into the participation equation (5) and differentiating as follows[23]:

$$\frac{dN_H}{dW_H} = a_{52}.\left[b_{61} + b_{62}\left(\log\left(\frac{W_H}{PC}\right) + \log(relw) \right) + b_{63}\left(T - 1967\right)^2 \right] + b_{62}\left[a_{51} + a_{53}T\right] \quad (9)$$

where $\varepsilon v_{\text{NHNH}} = \frac{dN_H}{dW_H}.\frac{W_H}{N_H}$. With an open labour market the high-skilled labour supply elasticity is itself a function of the real consumption wage[24], and this makes it highly elastic. As can be seen in Table 1, in the early 1980s a 1% increase in W_H would have

[23] The estimating equation for the population equation (6c) includes a lagged dependent variable, the long-run-coefficients for this equation are then derived by dividing through by ($1-a_{64}$), these long-run coefficients are denoted b_{6i} in derivation (9).

[24] Labour supply is a non-linear function of the real wage and hence we cannot algebraically solve for an inverse wage equation.

increased labour supply by 2.8%, by the late 1990s this had fallen to 1.7% (due to the scale effects of an increasing population) but it is still much higher than the labour supply elasticity for low-skilled labour and has very important consequences for the functioning of the model as we will see in the next section.

5. Simulation Results

In this section we perform a number of supply-side shocks to the model. In the first shock, we hold the skill levels of the population unchanged over a twenty-year period. This traces the long-run impact of rising investment in human capital on the economy. The second shock examines the impact of an increase in the skill levels of the population. In the third shock we explore the role of migration in the model and consider the likely effect of increased high-skilled immigration, while in the fourth shock we look at the effects of an increase in low-skilled immigration.

To examine the effects of the threshold switch in the low-skilled labour market each shock is run twice. When the low-skilled wage is above the replacement ratio threshold, the low-skilled labour market adjusts via changes in the unemployment rate, denoted as "(a) no market clearing". When the low-skilled wage is below the replacement ratio threshold, the regime switch in the model is activated so that changes in wages and participation adjust to clear the market, denoted as "(b) market clearing".

I Effect of investment in education

This shock looks at what would have happened if the educational attainment of the population were held fixed at its 1980 level[25]. This is a very dramatic shock because it assumes an unchanged demand for labour in the face of a much less educated workforce, which is clearly unrealistic. The results are equally dramatic: GNP per head is down by over 20 percentage points, roughly half of the convergence with the EU-15 countries that took place over the past twenty years. Furthermore this fall in welfare is concentrated within the low-skilled population. While large-scale immigration of skilled labour helps to contain some of the negative impact of this scenario, in reality many firms would not have considered locating in Ireland if the existing population skill levels were so low. Furthermore the large-scale immigration would have put unsustainable pressure on existing infrastructure, in particular housing.

Table 2 details the long run effects of not investing in human capital for twenty years. Although we do not model the short-run dynamics of the labour market, the likely short-run response to such a shock helps in understanding the long run impact. This shock would cause a very big reduction over time in the supply of skilled labour matched by a very much bigger increase in the supply of unskilled labour. In the short run the impact of such a reduction in the supply of skilled labour would have been a dramatic rise in skilled wage rates. As a result, there would have been continuous immigration flows into the country until the high-skilled wage adjusted to bring the high-skilled labour market into equilibrium.

[25] Note that because of immigration of skilled labour the final educational mix is higher than that pertaining in 1980.

In the long-run there would have been massive immigration to meet the unmet demand for skilled labour. Despite this, unit labour costs would have been higher and GNP lower than in the benchmark. Without a dramatic fall in the unskilled wage, the unemployment rate would have been over 17 percentage points higher. The distributive effects of this would have been profound. The rise in unemployment would have put impossible pressure on the public finances – pressure which is not modelled here. Instead the replacement ratio would have had to fall and with it unskilled wage rates to make the economy more competitive. This would have involved a further increase in wage dispersion between skilled and unskilled labour.

II Higher skill level of the working age population

This simulation examines the impact of moving 10,000 from the low-skilled to the high-skilled population aged 15-64, equivalent to an increase in the high-skilled population of roughly one percentage point in each year.

Table 2 details the results of this simulation. The ultimate increase in the high-skilled population would have been less than the original shock as the fall in the high skilled wage would have reduced the attractiveness of Ireland for migrants and encouraged emigration. The shock to the low-skilled population would have led to a fall in the supply of low-skilled labour. This would have resulted in a fall in the low-skilled unemployment rate of almost 1 percentage point.

This modest positive shock to skill levels in the population would have added 0.2 percentage points to the level of GNP in the long run. This would have occurred because the increased supply of high-skilled labour would have reduced the high-skilled wage rate and increased international competitiveness. This highlights the critical role a high-skilled population has to medium-term growth in output and employment. Under this simulation Ireland is more competitive on world markets and unemployment is lower, while the dispersion between high-skilled and low-skilled wages narrows. It would have added almost half a percentage point to GNP per head in the long run, a significant welfare increase.

When the low-skilled wage falls below the replacement ratio threshold, the regime switch in the model is activated so that changes in wages and participation adjust to clear the market. In this case, the profile of the shock changes somewhat (column II(b) in Table 2), although the long run impact on GNP per capita is similar.

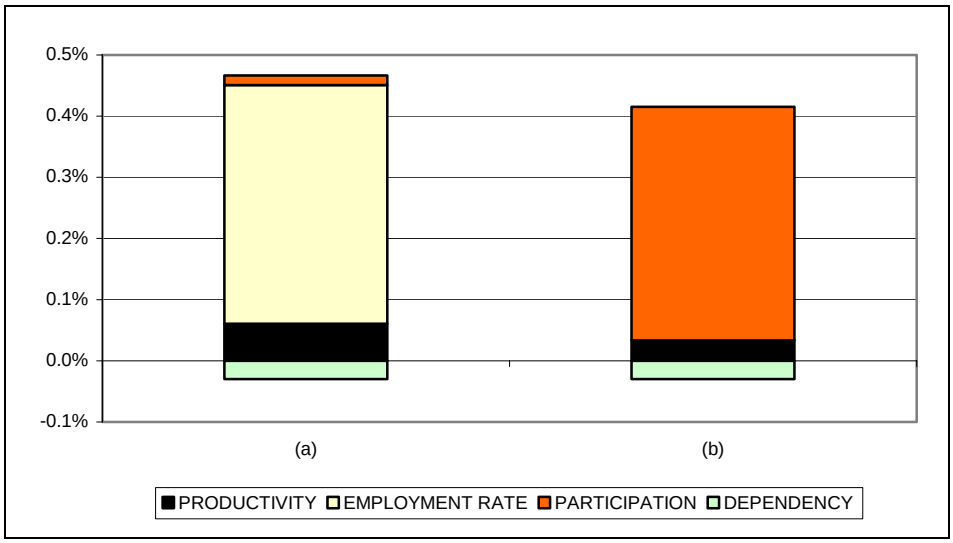
To understand more fully the channels through which this shock operates it is useful to decompose GNP per capita into a number of individual components, namely productivity, employment, participation and dependency, as follows[26]:

[26] POPT is the total population, POP is the working age (aged 15-64) population, L is total employment (aged 15-64), N is the labour force (aged 15-64).

$$\underbrace{\frac{GNP}{POPT}}_{\text{GNP per capita}} = \underbrace{\frac{GNP}{L}}_{\text{Productivity}} \cdot \underbrace{\frac{L}{N}}_{\text{Employment Rate}} \cdot \underbrace{\frac{N}{POP}}_{\text{Participation Rate}} \cdot \underbrace{\frac{POP}{POPT}}_{\text{Dependency Rate}} \qquad (10)$$

The first term on the right hand side of equation (10) measures productivity (output per employee) the second term measures employment as a proportion of the labour force (equal to one minus the unemployment rate), the third term measures the participation rate and the final term measures the inverse of the dependency rate. Figure 1 plots the contribution each component makes to GNP per capita under the two regimes operating in the low-skilled labour market. In case (a) there is no adjustment of the low-skilled wage rate to improved labour market conditions; the bulk of the adjustment comes from shifting low-skilled workers from unemployment to employment. In case (b) the low-skilled wage rises by 0.8 percentage points increasing participation in the low-skilled labour market.

Figure 1: Decomposition of GNP per capita, skill mix shock



The contrast between the two regimes is instructive. In both cases productivity makes a modest positive contribution to the growth in GNP per head while the dependency rate has a marginal negative effect due to emigration.[27] However it is the dominant contributions of either the employment rate or the participation rate that stands out. In moving from an economy with unemployed resources (case (a)), to a full-employment economy (case (b)), the main benefits of growth switch from rising employment to rising participation, specifically triggered by rising low-skilled wages.

Table 2: Simulation Results

	I a	I b	II a	II b	III a	III b	IV a	IV b
	% change							
GNP per head	-20.6	-21.0	0.4	0.4	0.2	0.2	-0.3	-0.2

[27] 75% of migration is assumed to be of working-age in the model with the remainder in the dependent age category.

GNP per worker	-1.4	-0.2	0.1	0.0	0.2	0.2	0.0	0.0
GNP	-5.0	-2.9	0.2	0.1	0.6	0.6	0.0	0.1
Total Employment	-3.7	-2.7	0.2	0.1	0.4	0.4	0.0	0.1
High-skilled	-3.7	-0.3	0.2	0.1	0.4	0.4	0.0	0.1
Low-skilled	-3.5	-7.3	0.1	0.1	0.4	0.4	0.0	0.0
Labour supply	18.5	-2.9	-0.2	0.1	0.3	0.4	0.3	0.1
High-skilled	-3.7	-0.3	0.2	0.1	0.4	0.4	0.0	0.1
Low-skilled	53.3	-7.3	-0.9	0.1	0.0	0.4	0.9	0.0
Population 15-64	21.2	24.9	-0.3	-0.3	0.4	0.4	0.4	0.4
High-skilled	-6.1	-3.2	0.3	0.2	0.7	0.7	0.0	0.0
Low-skilled	53.3	60.8	-0.9	-0.9	0.0	0.0	0.9	0.9
Unit labour costs	8.4	4.7	-0.3	-0.2	-0.9	-0.9	0.0	-0.1
Average wage	7.3	4.7	-0.3	-0.2	-0.8	-0.7	0.0	-0.1
High-skilled	9.1	10.9	-0.4	-0.4	-1.0	-1.0	0.0	0.0
Low-skilled	0.0	-27.5	0.0	0.8	0.0	0.3	0.0	-0.6
Income per head	-15.1	-18.6	0.1	0.2	-0.7	-0.7	-0.4	-0.5
Income per worker	6.9	4.5	-0.3	-0.2	-0.8	-0.7	0.0	-0.1
in thousands:								
Net immigration	815.0	947.7	-8.5	-9.4	13.3	13.3	0.0	0.9
as % of labour force:								
Unemployment rate	17.2	-0.2	-0.4	0.0	-0.1	0.0	0.3	0.0
Low-skilled unemployment rate	31.4	0.0	-0.9	0.0	-0.3	0.0	0.7	0.0

I Hold education levels constant at 1980.
II Move 10,000 from low- to high-skilled working age population.
III Add 10,000 to high-skilled immigration.
IV Add 10,000 to low-skilled immigration.
(a) no market clearing, (b) market clearing

III Effect of higher high-skilled immigration

The role of migration is crucial in the functioning of the high-skilled labour market and hence in the determination of wage and employment levels. Here we examine the impact of an increase in immigration of 10,000. Given the specification of the model, this effectively translates into a rise in high-skilled labour supply.

Table 4 shows the long run effects of higher high-skilled immigration. The increase in the high-skilled labour supply exerts downwards pressure on the high-skilled wage, which falls by about 1 percentage points in the long run. This improvement in competitiveness leads to an increase in output, employment and productivity. Employment for low-skilled workers also rises, with a consequent fall in the unemployment rate.[28]

IV Effect of higher low-skilled immigration

While the assumption that all migration is high-skilled is appropriate for the 1980s and most of the 1990s (Barrett and Trace, 1998), data on more recent immigration flows suggests that there is a growing number of low-skilled migrants coming to Ireland. To explore the likely impact of low-skilled immigration in the model, we shock the low-skilled natural increase in the population by 10,000. Such a scenario can be thought of as an administrative decision to encourage low-skilled immigration.

[28] This replicates the results of Barrett, Fitz Gerald and Nolan (2002) who find that immigration of skilled or experienced workers in the mid-1990s may have helped reduce earnings inequality and unemployment of those with limited education.

With a binding replacement ratio, low-skilled immigration has no effect on output or employment except to raise unemployment. Under market clearing the low-skilled wage rate falls by 0.6 percentage points, however because the elasticity of demand for low-skilled labour is so close to zero, and because low-skilled employment is such a small share of total employment, this has little effect on the average wage rate, which falls by a marginal 0.1 percentage points, and hence has very little effect on the level of GNP and total employment. The distributive and welfare effects of low-skilled immigration in the model are negative; wage dispersion between high- and low-skilled workers increases and GNP per capita, income per head and income per worker are all lower.

6. Conclusions

As a small and highly-traded economy Ireland is sensitive to international competitiveness. In this paper we find that Ireland maintained, and indeed improved, its competitive position in the 1990s through the rapid adjustment of high-skilled labour supply to demand driven by investment in education and strong migration flows. This human capital accumulation had a key role in generating, and migration in facilitating, the rapid convergence of Irish living standards to the EU average in the 1990s. Furthermore, the rise in education levels has helped prevent wage dispersion and promoted strong employment growth. Furthermore, the positive impact of human capital estimated in the model is, if anything, an underestimate because the model does not capture the effect of human capital accumulation on the growth in and skill-intensive nature of foreign direct investment flows into Ireland.

The main benefit of Irelands' convergence in the 1990s came in terms of rising employment. In economies where the supply of skilled labour through migration may be less elastic than in Ireland, it is likely that more of the benefits would come through in terms of productivity. For the future, the emergence of infrastructural constraints in Ireland in the late 1990s, in particular in the housing market, is also likely reduce the elasticity of high-skilled labour supply in the future as the recent boom in Irish house prices could reduce the attractiveness of Ireland for potential immigrants, since many immigrants are in the household formation age group.

The simulation results suggest that the low-skilled labour market is vulnerable, in particular we find that low-skilled immigration has negative welfare effects and promotes wage dispersion, similar to the adverse wage effects of US immigration discussed in Borjas (2003). By the 1990s in Ireland there was effectively a zero elasticity of substitution between high- and low-skilled labour so that an increase in wage dispersion would have no effect on the relative demand for low-skilled labour. In a world of high unemployment, which is concentrated among the lower skilled, these results suggest that policies which raise the skill levels of the population will be more effective at tackling unemployment over the medium term than attempts to reduce the replacement rate through erosion of the welfare state. Of course this is not a quick fix solution to high unemployment since changing the educational attainment of the population takes many years.

A1 Construction of the Human Capital Index

To construct the human capital index, we use Labour Force Survey (LFS) data, which is available on an annual basis from 1988, to ascertain the level of education completed of those aged 15 to 64 in employment. In the LFS employees are classified using a four-way educational attainment breakdown, those educated to primary level standard, those with lower secondary attainment (Junior Certificate only), those with higher secondary (Leaving Certificate) and those with third level education.[29] The series is extended back to 1966 using data from successive Censuses of Population. Attempts were made to correct for a change in the Census education questions that occurred in 1991 and for breaks in the LFS data. The shares of employees in each educational category were then weighted using estimates of the returns to education to derive an index of human capital.

A1.1 Labour Force Survey Data

The LFS contains annual data on employment by highest level of education completed.[30] There are several breaks and inconsistencies in this data, the most serious of which arises when comparing the 1998 and 1999 surveys. In 1998 respondents were asked about the highest level of formal education they had completed but in subsequent years this question only referred to *successful* completions. This means that respondents who have completed a syllabus are only included if they have taken the relevant exams or submitted dissertations, thesis etc. and passed. The survey also changed from a respondent-based survey to an interview-based survey and there was a change in the classification system used. Between 1998 and 1999 there was a sharp increase in the share of total employment of those with higher secondary and a concomitant decline of the shares of those who completed third level and lower secondary education. We correct for this at a later stage by adjusting for the difference between the computed human capital index and what a human capital index based solely on Census data would imply for 1999.

A1.2 Census Data

Census data from 1991 refers to the highest level of both full-time and part-time education that was actually completed for those whose full-time education has ceased. For the years up to and including 1986 Census questions were confined to full-time education and respondents had to state the age at which their full-time education ceased and the type of educational establishment attended. No attempt was made to ascertain whether or not courses were completed and if qualifications were obtained. This means that prior to 1991, Census data related to the highest level of education *attended* as distinct from *completed*. Therefore we assign an educational level to these people based on the age their education ceased.[31]

In addition, approximately 100,000 people in each of the Census years do not state the age at which their-full time education ceased and, prior to the 1991 Census, no details

[29] Technical and Vocational qualifications and those with Post-Leaving Certificates are included in the Leaving Certificate category.

[30] In 1998 the Quarterly National Household Survey (QNHS) replaced the Labour Force Survey and we use the second quarter QNHS data from 1998. We choose the second quarter so that the timing of the survey is consistent with when the Labour Force Survey took place.

[31] Specifically, those aged 15 and under when their full-time education ceased were classified as having primary education, those aged 16 and 40% of those aged 17 when full-time education ceased are included in the lower secondary category, 30% of those aged nineteen when their education ceased and all ages above that are included in the third level category, with the remainder included in the higher secondary Category.

of their education level was given. Previous work assumed that people in the 'not stated' category had primary or no formal education.[32] However, more recent Censuses provide the educational breakdown of these individuals. For example, in the 1996 Census less then 66 per cent of those who did not state the age at which their full-time education ceased have either primary of no formal education but over 26 per cent had third level education with the remainder having either lower secondary or higher secondary qualifications. Similar patterns are evident in the 1991 and 2002 Census data. We applied the percentages of each age group by highest level of education completed, including those in the 'not stated' category from the 1996 Census, to the Census data prior to 1991, which effectively increases the estimate of human capital in earlier years. This revised measure may still underestimate educational attainment and so provide a downwards bias to our human capital index.[33]

A1.3 Weights used to construct the Human Capital Index

The weights attached to the various educational qualifications were obtained from estimates of returns to education for the year 2000.[34] Callan (2003) estimates wage premia attached to educational qualifications controlling for individual characteristics such as years worked, years spent in training, sex, marital status and years not worked. The weights are Primary 1.00; Lower secondary 1.11; Higher secondary 1.27;Third level 1.68. These show positive returns to education that increase with higher educational attainment.

A1.4 Construction of the Human Capital Index

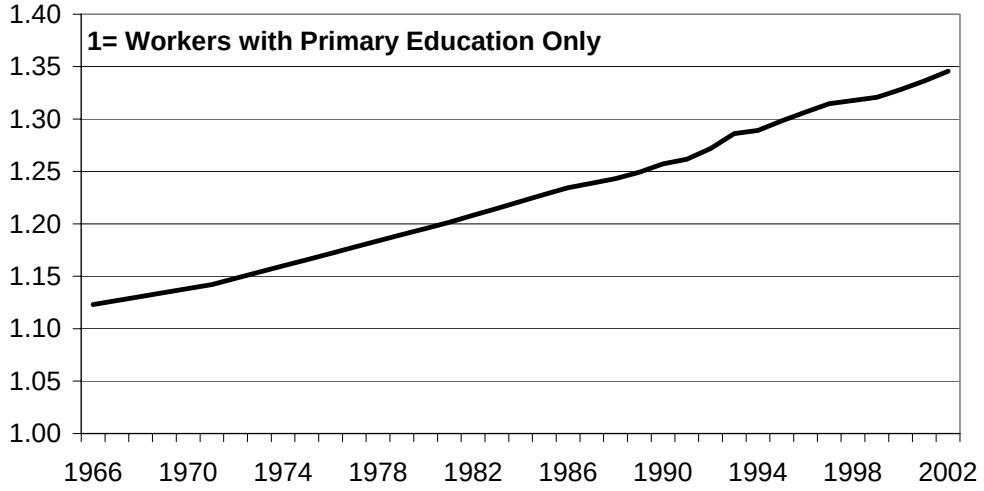
The shares of employees in each educational category are weighted using estimates of the returns to education to yield an index of human capital, with those educated to primary level assigned as the reference grouping (with a weight of one). The series is based on Census data prior to 1988, which is completed by linear interpolation. Figure A1 shows the human capital index from 1966 to 2002. From the graph we can see the steady rise in the human capital of those at work. For example, in 1966 the average worker had lower secondary qualifications whereas in 2002 the average worker's human capital was above higher secondary level.

[32] See Fitz Gerald, J. and I. Kearney (2000), Duffy, D., J. Fitz Gerald, J. Hore and I. Kearney, (2001) and Fitz Gerald, J., C. McCarthy, E. Morgenroth and P. O'Connell eds (2003).

[33] Including the education levels of the 'not stated' in the series based on assigning an educational level to individuals relating to the age their education ceased brings the series closer to the series based on education level completed, which is available from the 1991 Census on. However, it underestimates the numbers with higher educational attainment and overestimates the numbers with lower educational attainment.

[34] A complete description of the methodology and estimation is available in Callan, T (2003).

Figure A1: Human Capital Index for Individuals aged 15 to 64 in Employment



A2 Equation Estimation, Model Listing and Data Sources

Equation Estimation

Eq. 1b: Labour Demand Equation

The marginal productivity condition for labour derived from equation (1a) is log-linear and hence allows for direct estimation of both the elasticity of substitution and the returns to scale parameter using simple OLS techniques (see Griliches and Ringstad, 1971)[35]:

$$\log\left(\frac{GNP}{LNA * HK}\right)_t = a_{11} + a_{12}\log\left(\frac{W}{PC}\right)_t + a_{13}\log(LNA * HK)_t \qquad \text{(A.1a)}$$

where σ =a12/(1+a13) is elasticity of substitution and μ=1+a13/(1-a12) is the returns to scale parameter. To estimate δ, the distribution parameter, we estimated a long-run factor proportions relation, which is the ratio of the marginal productivity conditions for both capital and labour. However our results yielded estimates of δ close to zero[36], so instead we calibrate an estimate of δ=0.4 taken from recent estimates for the Irish manufacturing sector.[37] Using our estimates of σ, μ and δ, the scale parameter *A* can then be estimated directly as coefficient a14 in the following equation:

[35] In empirical estimation of equation (1b) the variables *Q L W* and *P* are measured by GNP, LNA, W and PC respectively.

[36] We estimated various specifications; using investment rather than the capital stock, allowing free estimated of σ, imposing our estimate of σ from Table 3.1.

[37] This estimate comes from the labour demand equation for the manufacturing sector used in the current (2004) version of the HERMIN-Ireland model. Sensitivity analysis around the value of delta, varying from 0.999 to 0.001, indicated that this alters the estimate of the constant A in equation (1b) but has no significant effect on the behavioural properties of the model. This parameter captures the allocation of factors in the production of output and hence the distribution of factor income, however since the model does not include capital it has no important role in our model.

$$e^{-\mu\left(\log(LNA*HK)_t-\frac{1}{\mu}\log GNP_t-\frac{\sigma}{1-\sigma}\log(1-\delta)-\frac{\sigma}{1-\sigma}\log\left[\left(\frac{PK_t}{W_t}\right)^{1-\sigma}\left(\frac{\delta}{1-\delta}\right)^{\sigma}+1\right]\right)}=a_{14} \quad \text{(A.1b)}$$

The estimation results are presented in Table A2.1. All coefficients are significant, with an implied elasticity of substitution of 0.19 and an implied returns to scale parameter of 1.27. This supports the hypothesis of increasing returns to scale.[38]

Eq. 2: Relative demand for skilled labour

$$\left(\frac{WH*LNAH}{YWNA}\right)_t=a_{21}+a_{22}\log\left(\frac{WH}{WL}\right)_t+a_{23}T_t \quad \text{(A.2)}$$

Eq 3: Output determination

$$\begin{aligned}\log(GNP)_t=\;&a_{31}+a_{32}\log\left(\frac{ULC}{ULC_{GER}*e_{GER}}\right)_t+a_{33}\log\left(\frac{ULC}{ULC_{UK}*e_{UK}}\right)_t \\ &+a_{34}\log(GDP_{US})_t+a_{35}\log(GDP_{US})_t*D90_t+a_{36}\log(GNP)_{t-1}\end{aligned} \quad \text{(A.3)}$$

Eq 4: Human Capital

$$HK_t-\left(\frac{LNAL}{LNA}\right)_t=a_{41}\left(\frac{LNAH}{LNA}\right)_t \quad \text{(A.4)}$$

Eq. 5: High-Skilled Participation

In this equation the coefficient a_{52} is a semi-elasticity of labour supply with respect to the wage, the value of this coefficient is imposed in estimation at a_{52}=0.21 based on Doris (2001) labour supply elasticity estimates.

$$\left(\frac{NH}{POPH}\right)_t=a_{51}+a_{52}\log\left(\frac{WH}{PC}\right)_t+a_{53}T_t \quad \text{(A.5)}$$

Eq. 6c: High-Skilled Population

This equation includes a quadratic time trend term set equal to one in the first year of estimation, this captures the non-linearities in the growth of POPH. Excluding this

[38] We also estimated the marginal productivity condition assuming constant returns to scale, μ=1, this restriction leads to a much higher estimated elasticity of substitution at 0.51. These estimates are only valid under the maintained assumption of homotheticity implicit in our CES specification.

term implies explosive estimates with the coefficient on the lagged dependent variable greater than one.

$$POPH_t = a_{61} + a_{62}\log\left(\frac{\frac{WH*(1-TY)}{PC}}{\frac{W_{UK}*(1-TY_{UK})}{PC_{UK}}}\right)_{t-1} + a_{63}\left(T_t - 1967\right)^2 + a_{64}POPH_{t-1} \quad \text{(A.6)}$$

Eq. 7: Low-Skilled Participation

In this equation the coefficient a_{72} is a semi-elasticity of labour supply with respect to the wage, the value of this coefficient is imposed in estimation at a_{72}=0.73 based on Doris (2001) labour supply elasticity estimates.

$$\left(\frac{NL}{POPL}\right)_t = a_{71} + a_{72}\log\left(\frac{WL}{PC}\right)_t + a_{73}T_t \quad \text{(A.7)}$$

Table A1: Estimation of Model Equations[39]

	(A.1a)	(A.1b)	(A.2)	(A.3)	(A.4)	(A.5)	(A.6)	(A.7)
a_{i1}	1.27		-19.08	2.85	1.46	3.17	-119.8	21.53
	(5.0)		(-17.9)	(5.3)	(101.9)	(0.8)	(-2.3)	(7.8)
a_{i2}	0.23		0.16	-0.07		-0.001	198.0	-0.01
	(3.2)		(4.7)	(-3.7)		(-0.8)	(3.3)	(-8.3)
a_{i3}	0.21		0.01	-0.10			0.21	
	(3.5)		(18.7)	(-2.4)			(3.6)	
a_{i4}		3.92		0.29			0.88	
		(61.1)		(6.19)			(16.85)	
a_{i5}				0.35				
				(4.4)				
a_{i6}				0.73				
				(14.4)				
Rho(1)	0.62		0.71		0.87	0.80		0.53
R^2	0.98	0.83	0.99	0.998	0.999	0.83	0.998	0.94
std.err.	0.02	0.02	0.007	0.01	0.006	0.01	14.67	0.02
D.W.	1.64	0.81	1.97	1.43	2.70	2.03	2.58	1.39
from	1966	1966	1966	1970	1966	1979	1968	1979
to	2000	2000	2000	2001	2000	2000	2000	2000

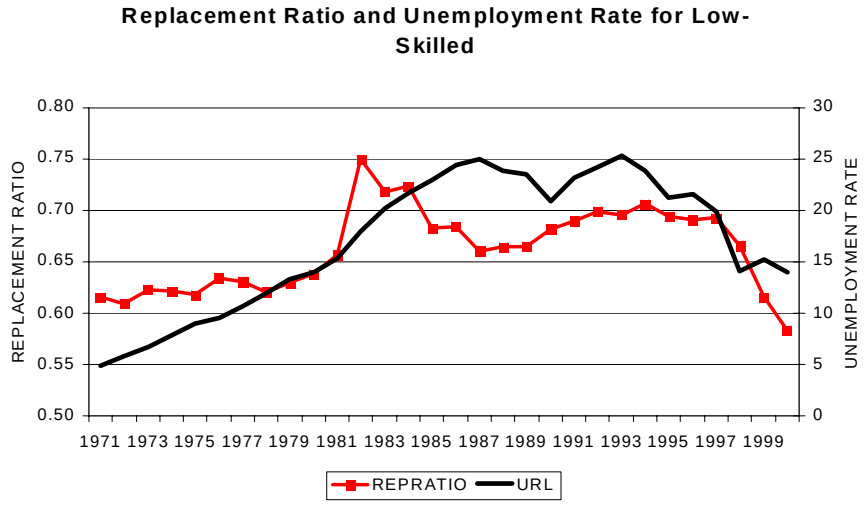
Model Listing

Threshold switch in determination of low-skilled labour supply and wage rate:

[39] t-statistics in parentheses, estimation by least-squares, Rho(1) denotes estimated first-order autocorrelation coefficient using Cochrane-Orcutt techniques.

In the low-skilled labour market the wage rate in the 1980s and early 1990s was mainly driven by the rate of social welfare, setting a wage floor above a level that would clear the market. Figure A2 plots the replacement ratio (defined as the social welfare rate divided by the low-skilled wage rate) for the low-skilled against their unemployment rate. Between the 1970s and the 1980s the replacement ratio rose by over 6 percentage points on average. Over that period the unemployment rate rocketed and it was not until the late 1990s that both the replacement ratio and the unemployment rate started to fall significantly. While essentially arbitrary at the margin, the graph suggests that a replacement ratio above 0.65 could be reasonably used as a threshold replacement ratio.

Figure A2: Replacement ratio and unemployment rate for low-skilled



Within the low-skilled labour market if the replacement ratio is above this 0.65 threshold then the low-skilled wage rate is determined by the replacement ratio. If the replacement ratio falls below this threshold then the low-skilled labour market clears using the same mechanism as in the high-skilled labour market, with the participation equation determining the wage rate and a fixed unemployment rate.

$$\text{If} \quad \frac{WSW_t}{WL_{t-1}} > WL\_MIN \tag{A.8}$$

then

$$WL_t = \frac{WSW_t}{WL\_MIN}$$
$$NL_t = POPL_t * \left[a_{71} + 0.73 * \log\left(\frac{WL}{PC}\right)_t + a_{72} T_t \right] \tag{A.9}$$

else

$$WL_t = e^{\frac{1}{0.73} * \left[\left(\frac{NL}{POPL}\right)_t - a_{71} - a_{72} T_t \right] + \log(PC)_t}$$
$$NL_t = LL_t * FIXL_t \tag{A.10}$$

Other equations which close the model

$$W_t = \left(\frac{WH_t * LNAH_t + WL_t * LNAL_t}{LNA_t} \right) \quad \text{(A.11)}$$

$$LNAL_t = LNA_t - LNAH_t \quad \text{(A.12)}$$

$$LH_t = LNAH_t + LAH_t \quad \text{(A.13)}$$

$$LL_t = LNAL_t + LAL_t \quad \text{(A.14)}$$

$$L_t = LH_t + LL_t \quad \text{(A.15)}$$

$$\frac{NH_t}{LH_t} = FIXH_t \quad \text{(A.16)}$$

$$N_t = NH_t + NL_t \quad \text{(A.17)}$$

$$M_t = (POPH_t - POPH_{t-1} - NIPOPH_t) / 0.75 \quad \text{(A.18)}$$

$$POPD_t = POPD_{t-1} + NIPOPD_t + 0.25 * M_t \quad \text{(A.19)}$$

$$POPT_t = POP_t + POPD_t \quad \text{(A.20)}$$

$$POPL_t = POPL_{t-1} + NIPOPL_t \quad \text{(A.21)}$$

$$POP_t = POPL_t + POPH_t \quad \text{(A.22)}$$

$$YWNA_t = WH_t * LNAH_t + WL_t * LNAL_t \quad \text{(A.23)}$$

$$ULC_t = YWNA_t / GNP_t \quad \text{(A.24)}$$

Variable definitions and Data Sources

All data from ESRI databank (Bergin and Fitz Gerald, 2004) unless otherwise stated.

GNP:	Constant price GNP.
LNA:	Non-agricultural employment, total.
HK:	Human capital index, see Appendix 1.
PC:	Personal consumption deflator.
PK:	Cost of capital in Irish manufacturing sector.
WL:	Low-skilled wage, measured as average wage in clothing sector.
WH:	High-skilled wage, measured as average wage in non-agricultural sector excluding clothing.
LNAH:	Non-agricultural employment, high-skilled.
ULC_{UK}:	Wage bill as share of constant price GDP, UK.
e_{UK}:	Exchange rate Irish pounds per £ sterling.
ULC_{GER}:	Wage bill as share of constant price GDP, Germany.
e_{GER}:	Exchange rate Irish pounds per DM.
GDP_{US}:	Constant price GDP, US.
D90:	shift dummy variable, = 1 1990 onwards, =0 before 1990
NH:	High-skilled labour supply.
POPH:	High-skilled population of working age, where high-skilled is defined as those aged 15-64 with at least higher secondary education.
T:	Annual time trend, measured as actual calendar year.
NL :	Low-skilled labour supply.
POPL:	Low-skilled population of working age, where low-skilled is defined as those aged 15-64 with education below higher secondary level.

TY: Average rate of direct taxation on personal income.
W_{UK}: Wage rate in business sector, UK.
TY_{UK}: Average rate of direct taxation on personal income, UK.
PC_{UK}: Consumer price index, UK.
WSW: Average rate of unemployment benefit for 1 adult and 3 dependents.
WL_MIN: threshold replacement ratio, = 0.65.
LAH: High-skilled employment in agriculture.
LAL: Low-skilled employment in agriculture.
M: Net immigration.
POPD: Dependent population, aged below 15 and above 64.
NIPOPD: Natural increase in dependent population.
NIPOPH: Natural increase in high-skilled population.
NIPOPL: Natural increase in low-skilled population.
FIXH: Fixed high-skilled unemployment rate.
FIXL: Fixed low-skilled unemployment rate.

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