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Paul Beaudry
David Green

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ABSTRACT

This paper proposes a new and unified explanation for the following trends observed over the last 25 years: (1) the increased returns to education, (2) the slow measured growth in TFP in an economy undergoing massive changes in its methods of production, and (3) the poor wage performance, relative to TFP growth, of both young high school and college educated workers. The explanation we propose downplays the role of exogenous skill-biased technological change and instead emphasizes how the endogenous choice of modes of organization, influenced by changes in factor supplies, can generate the above observations. For example, we argue that increased education attainment, through its effect of the choice production techniques, may have been the major cause for the increased differential between more and less educated workers over the last quarter of a century. The evidence we examine to test our hypothesis is based on US and Canadian data over the period 1971 - 95. We pay particular attention to explaining the difference between our results and those associated with the skill-biased technical change hypothesis.

Paul Beaudry
Department of Economics
University of British Columbia
997-1873 East Mail
Vancouver, B.C.
CANADA V6T 1Z1
and NBER
beaudry@econ.ubc.edu

David Green
Department of Economics
University of British Columbia
997-1873 East Mail
Vancouver, B.C.
CANADA V6T 1Z1

1 Introduction

Several developed countries have recently experienced declines in the wages of less educated workers relative to those of more educated workers (see Gottschalk and Smeeding (1997) for an overview). Furthermore, this change in the wage structure has often been accompanied by stagnation or decline in real wages for youth of all education levels.[1] These phenomena are of clear policy concern and have attracted considerable attention. However, explanations advanced to explain these trends are often difficult to reconcile with a somewhat different, but nevertheless related puzzle: the slowdown in measured growth of productivity (TFP). This slowdown is surprising given the apparent rapid pace of change in the economy. The object of this paper is to offer a unified explanation for recent trends in both wages and productivity. We examine the validity of our model using data drawn from the US and Canada over the period from 1971-1995. We examine the two countries together since we believe that the mechanism driving trend movements in wages should be common across these two countries.

The explanation we propose departs from many other attempts to understand recent movements in wages in that it downplays the role of exogenous technological change. Instead, we emphasize how the endogenous choice of modes of organization, influenced by changes in factor supplies, affects factor prices. In particular, we argue that increased educational attainment, through its effect on the choice production techniques, may have been the major cause for the increased differential between more and less educated workers over the last quarter of a century.

To understand our explanation, it is helpful to consider a simplified environment in which there is no exogenous technological change but where there is a choice between two means of organizing production: a traditional organization and a modern organization. For concreteness, it may be helpful to associate the traditional organization (or production technology) with assembly line production (Fordism) and the modern form of organization with flexible/team/just-in-time production (e.g., the Japanese model). The distinctive feature of the modern organization we invoke is that it uses relatively more skilled labour and less of other factors in production than the traditional organization. Given this feature, an increase in educational attainment favours the growth of modern type organizations because it decreases the price of their most important input: skilled

[1] See MaCurdy and Mroz (1989) for evidence related to the US and Beaudry and Green (1997) for evidence related to Canada.

labour. The growth of modern firms in turn incites capital to flow toward them and away from firms with traditional means of organization.[2] As we shall show, if modern organisations use capital more efficiently than traditional ones, this process leads wages of less-skilled workers to fall more than those of high skilled workers, resulting in an increase in the returns to skill. Note that during this process, measured technological progress is zero even though the economy may be undergoing massive shifts in observed methods of production. Moreover, wages for both skilled and unskilled workers are growing less than productivity (which is what is observed for younger workers in both Canada and the U.S.) and inequality is increasing. Hence, the process of endogenous organisational choice in response to changes in educational attainment offers a potential explanation for the somewhat paradoxical observed movements in wages and productivity.

Given that we are proposing an alternative explanation of recent wage movements, the real contribution of this paper is to show that the data, on wages, employment, educational attainment, capital accumulation and aggregate output for both Canada and the US over the period 1971-1995, are supportive of the type of story we propose. The empirical framework we use to establish these results is not restricted by our theoretical model since it reduces to the estimation of an aggregate production function (which encompasses possibilities offered by both forms of organization) on which we only impose that it satisfy constant returns and that technological change be either skilled biased or simply (neutral) labour augmenting. The actual evidence in favour of our proposed story comes from parameter estimates derived from this rather unrestrictive empirical framework. The estimation framework allows for the possibility that observable wage and productivity patterns reflect ongoing skill biased technical change, but we find little evidence to this effect. This is clearly at odds with much of the previous literature on wage trends, which often emphasizes skill biased technical change. We arrive at different conclusions from the previous literature because our estimation strategy (1) does not a priori restrict the patterns of complementarity or substitutability among factors, (2) does force our estimated aggregate technology to be consistent with, among others, observed movements in wages, capital and measured productivity and (3) focuses on explaining

[2] Parts of our story are similar to that of Caselli(1996) since both relate to the process of capital reallocation. However, the two differ in that relative wages in our setting respond to changes in factor supplies while they are completely determined by technology in Caselli. In effect, it is this difference that leads us to suggest that changes in educational attainment may be important for understanding wage trends within and between countries. As we will discuss, the evidence presented by Caselli also appears to be consistent with model developed in this paper.

trend (low frequency) movements in the data.

Our emphasis on an endogenous choice of production process as a means of linking together observed movements in wages and factor supplies clearly begs the question of how and when these choices of technique arose. In this respect, we view our analysis as pertaining to an historical period after the initial dissemination of an important new idea (or a general purpose technology[3]) but before the time when the new means of production has superseded the previous one. In this spirit, our empirical work focuses on post-seventies data since this is a period over which measured productivity growth[4] has been rather slow even though the economy appears to have undergone enormous transformations.

The remaining sections of the paper are structured as follows. In Section 2, we present a simple model aimed at highlighting how changes in factor supplies, especially changes in educational attainment, are likely to affect factor prices when the economy has the choice between two techniques of production, where one is more skill intensive than the other. In particular, we want to clarify the conditions under which increased educational attainment increases the return to education, and relate those conditions to common perceptions about new and more traditional modes of organization. In Section 3 we discuss our empirical framework and the data we use to examine the determinants of wage movements. Section 4 presents the empirical results and relates them to the relevant literature. Finally, Section 5 offers concluding comments.

2 Factor Returns in a Model with an Endogenous Choice of Production Processes

The object of this section is to analyse how changes in factor supplies affect factor returns in a economy where two different production processes, or means of organization, co-exist. In particular, let $F^T(U^T, S^T, K^T)$ represent the production possibilities available under the first mode of organization, which we refer to as the traditional mode of organization, and let $F^M(U^M, S^M, K^M)$ represent possibilities under the second or modern form of organization. In both cases, production is allowed to depend on three inputs: physical capital, K, skilled labour, S, and unskilled labour, U. Moreover, we assume that both forms of

[3]See Bresnahan and Trajtenberg (1995) for a discussion and empirical evidence related to the notion of General Purpose Technology.

[4]Measured TFP is in principle is a measure of the arrival of new means of production as opposed to a measure that captures the allocation of factor

organization exhibit constant returns to scale and that total output in the economy is the sum of the outputs from the two forms of organization. Since this exercise is motivated in part by the observation that TFP growth has been rather sluggish over the last quarter of a century, in this section we abstract from any exogenous improvement in technology. This simplification allows us to focus exclusively on the process of endogenous choice of technique in response to changes in factor supplies. Nonetheless, in the empirical section we will reintroduce the possibility of exogenous technological progress.

Let us denote by $p = \{w_u, w_s, r\}$ the vector of factor prices where w_u is the wage of unskilled labour, w_s is the wage of skilled labour, r is the rental price of capital and output is the numeraire. Factors are assumed to be perfectly mobile between firms and the total supply of factors is equal to $\{U, S, K\}$.

A competitive equilibrium in this economy is an allocation of factors between organisational modes $\{U^T, U^M, S^T, S^M, K^T, K^M\}$ and a factor price vector such that:

Given p

(1) $\{U^T, S^T, K^T\}$ maximises $F^T(U^T, S^T, K^T) - w_u U^T - w_S S^T - rK^T$

(2) $\{U^M, S^M, K^M\}$ maximises $F^M(U^M, S^M, K^M) - w_u U^M - w_S S^M - rK^M$

and

(3) $U^T + U^M = U, \quad S^T + S^M = S, \quad K^T + K^M = K.$

Our object is to examine how factor prices in such an economy are affected by changes in factor supplies, and particularly, how prices are likely to change when there is a change in educational attainment (holding total labour $S + U$ constant). Our approach to answering these questions is to posit plausible assumptions about the differences between the two modes of organization and then examine their implications. As we stated in the introduction, it is helpful to picture the traditional mode of organization as assembly line production and the modern organization as the "flexible" production model. Alternatively, one can think of our modern form of organization as embodying the production possibilities often associated with the "new economy" or the "knowledge based" economy.

It is most helpful to cast differences between production possibilities in terms of differences in input use. To this end, let x_p^i denote the optimal quantity of factor x used to produce one unit of output with technology i when prices are equal to p. For example, U_p^T is the amount of unskilled labour used to produce one unit of output with the traditional technology when prices are equal to p. It is also useful to define the economy's aggregate production function, denoted by $F(U, S, K)$, as:

$$F(U,S,K) = \max_{U^T,U^M,S^T,S^M,K^T,K^M} F^T(U^T,S^T,K^T) + F^M(U^M,S^M,K^M)$$

subject to

$$U^T + U^M = U, \quad S^T + S^M = S, \quad K^T + K^M = K$$

We will define the modern mode of production as the one which uses relatively more skilled labour. To give content to the notion that the defining feature of the modern organization is it relative skill biasedness, Assumption 1 states that, at given factor prices, the modern organization uses relatively more skilled labour and relatively less unskilled labour to produce one unit of output, with the relative use of capital between the two forms of organization being less extreme.

Assumption 1: The modern organization's main feature is that it is skilled biased relative to the traditional organization, that is,

$$\frac{U_p^T}{U_p^M} > \frac{K_p^T}{K_p^M} > \frac{S_p^T}{S_P^M}$$

From Assumption 1 we can immediately derive the following Proposition

Proposition 1: If production takes place in both types of organization and Assumption 1 holds, then

(1) an increase in unskilled (skilled) labour leads to a decrease in the wage of skilled (unskilled) labour, that is,

$$\frac{\partial w^s}{\partial U} < 0, \quad \frac{\partial w^u}{\partial S} < 0$$

and

(2) an increase in capital leads both wages to increase, that is,

$$\frac{\partial w^s}{\partial K} > 0, \quad \frac{\partial w^u}{\partial K} > 0$$

Proof: See Appendix 1.

Proposition 1 states that an increase in the quantity of skilled labour causes a decrease in the wage of unskilled labour. This is a somewhat surprising result given the rather minimalist structure we have as yet imposed on the economy. In order to see the intuition behind Proposition 1, it is helpful to consider the extreme case where the modern organization has no use for unskilled labour and the traditional organization has no use for skilled labour (which is just an extreme form of skill biasedness). In this case, an increase in the quantity of skilled labour initially increases the marginal product of capital in modern organisations (holding K^T, K^M fixed). The induced difference in marginal products incites capital to flow towards modern organisations and away from traditional organisations, thereby leading to a decrease in the marginal product, and hence the wage, of unskilled workers. In this sense, the fall in the wage of unskilled workers is directly linked to the flight of capital from traditional organisations. Proposition 1 accordingly indicates that, under Assumption 1, an increase in aggregate capital increases both wages since both sectors benefit from capital accumulation.

An important implication of Proposition 1, as stated in Corollary 1, is that in terms of the aggregate production function, skilled and unskilled labour must be q-substitutes.[5] This observation is particularly important given that it is not uncommon in the empirical literature on wage inequality to choose parameterization of the aggregate technology that exclude the possibility that skilled and unskilled labour are q-substitutes. [6]

Corrollary 1: Under Assumption 1, the aggregate production function is characterized by

(1) skilled and unskilled labour being q-substitutes,

(2) skilled labour and capital being q-complements,

(3) unskilled labour and capital being q-complements.

We now wish to go beyond Proposition 1, to understand how changes in factor supplies affect relatives wage and how an increase in educational attainment ($dS = -dU$) affects wages. In order shed light on these issues, we need to place further structure on our economy. In particular, we need to discuss how capital and labour productivity ($\frac{Y^i}{K^i}$ and $\frac{Y^i}{S^i+U^i}$) compare between the two forms of organization. Since differences in produc-

[5]A pair of factor inputs are defined as q-substitutes if an increase in the quantity of one factor leads to a decrease in the price of the other factor. Otherwise they are q-complements. See Hamermesh (1993) for a discussion. An even more basic point is that, even if Assumption 1 does not hold, if both sectors are active, the aggregate production function must exhibit a pair of factors which are q-substitutes.

[6]For example, multifactor factor CES production functions and certain nested CES production functions exclude the possibility of q-substitutes. Krusell, Rios-Rull, Ohanian and Violante (1996) is an example of an analysis of wage movements which excludes the possibility that skilled and unskilled labour are q-substitutes.

tivity between these types of organisations is not entirely obvious, we consider different possibilities.

Assumption 2A: The modern organization has higher capital productivity that the traditional organization, that is,

$$\frac{1}{K_P^T} < \frac{1}{K_P^M} \leftrightarrow 1 < \frac{K_p^T}{K_P^M}$$

Assumption 2B: The modern organization has higher labour productivity than traditional organisations, that is,

$$\frac{1}{U_P^T + S_P^T} < \frac{1}{U_P^M + S_P^M} \leftrightarrow 1 < \frac{U_P^T + S_p^T}{U_P^T + S_P^M}$$

We can now state the link between factor supplies and relative wages

Proposition 2: If production take place in both types of organizations and Assumptions 1 and 2A hold, then

$$\frac{\partial \frac{w^s}{w^u}}{\partial S} > 0, \quad \frac{\partial \frac{w^s}{w^u}}{\partial K} < 0$$

Proposition 2 indicates that the relationship between factor supplies and relative wages is directly linked to the relative productivity of capital in the two types of organization. The main aspect we want to emphasize from Proposition 2 is that, in an economy with a choice between a traditional and a more skill oriented means of production, an increase in skilled labour can lead to an increase in the returns to skill. At first glance such an effect may appear perverse, but Proposition 2 indicates that it can arise under very reasonable and plausible conditions. In effect, Proposition 2 indicates that an increase in the supply of skilled workers will increase the returns to education whenever the skill biased organization is more productive in terms of its use of capital than the traditional organization. The type of just-in-time type production organizations we have in mind as fitting into our modern category seem specifically designed to enhance the productivity of capital. Thus, we believe that this scenario is quite plausible, and therefore it motivates our desire to investigate whether recent changes in factor supplies, and especially the huge increase in more highly educated workers, could be the driving force behind observed wage movements. Before examining the empirical evidence on this issue, it is also interesting to point out the conditions under which an increase in educational attainment, holding constant the total labour force $(S + U)$, may increase wage inequality.

Proposition 3: If Assumption 1, 2A and 2B hold, and if the modern organization's relatively higher labour productivity is more pronounced than capital productivity, that is,

$$1 < \frac{U_P^T + S_P^T}{U_P^M + S_P^M} < \frac{K_p^T}{K_P^M}$$

then

$$\left(\frac{\partial(\frac{w^s}{w^u})}{\partial(\frac{S}{U})}\right)_{S+U=cst} > 0$$

and

$$\left(\frac{\partial w^u}{\partial(\frac{S}{U})}\right)_{S+U=cst} < 0, \qquad \left(\frac{\partial w^s}{\partial(\frac{S}{U})}\right)_{S+U=cst} < 0$$

Proposition 3 echoes Proposition 2 by indicating that an increase in educational attainment can very plausibly lead to an increase in the returns to education. Actually, the conditions underlying Proposition 3 appear surprisingly consistent with much of the popular opinion regarding the "new economy". In particular, Proposition 3 holds if the modern organization is skilled biased and more productive[7], especially in terms of labour productivity $\frac{Y^i}{S^i+K^i}$, than the traditional organization. It should be clear that in this two organization-type economy, an increase in educational attainment would induce a transformation of the economy, as more and more factors are allocated to the modern form of organization. At the same time, properly measured TFP growth would be zero.

3 Data and Empirical Implementation

The previous section suggests that changes in the skill distribution of the labour force, through its effect on the choice of methods of production, can potentially explain the wage and productivity puzzles set out in the introduction. In particular, we have shown that an increase in the amount of skilled workers can simultaneously explain why: (1) wages of both skilled and unskilled young workers grew less than TFP growth, (2) why the returns to education increased and (3) why an economy may appear to undergo massive transformations towards more productive means of production without that change generating large increases in measures of TFP. Moreover, we have argued that the conditions

[7]The two types of organisations can co-exist in equilibrium under Assumptions 2A and 2B as long as the modern organization is not more productive in terms of skilled and unskilled labour taken individually.

under which such a pattern would arise appear to reflect many popular views about the characteristics of the "flexible/team/just-in-time" organization.

The object of this section is to provide a framework for examining whether this story of endogenous technical choice actually fits the data reasonably well. An important goal in deciding on a framework is to insure that it nests alternative explanations. For example, we are particularly concerned with comparisons relative to explanations based on an exogenous skill biased technical change. To this end, we examine the implications of our story in terms of properties of the aggregate production function.[8] Focusing on the aggregate production function makes it easy to compare our results with previous work.

Let $F(\theta_t^U U_t, \theta_t^S S_t, K_t)$ represent the aggregate production, where now θ_t^U and θ_t^S have been included to represent, respectively, the possibility of unskilled and skilled labour augmenting technical progress. The three equations on which we base our empirical investigation are the two marginal product conditions for wages, that is,

$$w_t^U = \theta_t^U F_1(\theta_t^U U_t, \theta_t^S S_t, K_t) = \theta_t^U F_1(\frac{\theta_t^U U_t}{K_t}, \frac{\theta_t^S S_t}{K_t}, 1)$$

$$w_t^S = \theta_t^S F_2(\theta_t^U U_t, \theta_t^S S_t, K_t) = \theta_t^S F_2(\frac{\theta_t^U U_t}{K_t}, \frac{\theta_t^S S_t}{K_t}, 1)$$

and the production function

$$Y_t = F(\theta_t^U U_t, \theta_t^S S_t, K_t)$$

In the marginal product conditions, we have exploited the property of homogeneity of degree zero implied by the assumption of constant returns to scale.

The log-linear approximation [9] to the above conditions can be written as

$$\log(w_t^S) \approx \alpha_0 + \alpha_1 \log(\frac{\theta_t^S S_t}{K_t}) + \alpha_2 \log(\frac{\theta_t^U U_t}{K_t}) + \log \theta_t^S \quad (1)$$

$$\log(w_t^U) \approx \beta_0 + \beta_1 \log(\frac{\theta_t^U U_t}{K_t}) + \beta_2 \log(\frac{\theta_t^S S_t}{K_t}) + \log \theta_t^U \quad (2)$$

[8]Alternatively, we could have tried to examine implication of our model in terms of its predictions of capital movements towards modern/more skill-intensive sectors. However, we have chosen not to do so since the evidence presented in Caselli (1996) actually speak to this effect. For this reason, we believe the work by Caselli is very complementary to our study.

[9]Instead of taking a log-linear approximation, we could alternatively specify a flexible functional form such as a translog production function. In further estimation not included in the paper, we found our results to be robust to such a modification.

$$\Delta\log(Y_t) \approx \left(\frac{s_t^U+s_{t-1}^U}{2}\right)\Delta\log(U_t) + \left(\frac{s_t^S+s_{t-1}^S}{2}\right)\Delta\log(S_t) + \left(1-\left(\frac{s_t^U+s_{t-1}^U}{2}\right)-\left(\frac{s_t^S+s_{t-1}^S}{2}\right)\right)\Delta\log(K_t) + \Delta TFP_t \quad (3)$$

where TFP represents the log of total factor productivity[10] which in turn can be stated in terms of unskilled and skilled labour augmenting technological progress as in equation (4).

$$TFP_t \approx s_t^U \log(\theta_t^U) + s_t^S \log(\theta_t^S) \quad (4)$$

In equation (4), $s_t^i, i = \{U, S\}$ represent the income shares of skilled and unskilled labour respectively. Note that if we impose that technological progress be non-skilled biased, that is $\theta_t^U = \theta_t^S$, then equations (1) and (2) can be easily expressed in terms only of observables since $\theta_t^U = \theta_t^S$ can be expressed as a function of an observable (TFP), from equation (4). However, we want to allow for the possibility that technical change may be skill biased. Therefore, we define λ as the parameter that governs the degree to which technological change is skilled biased, that is, [11]

$$\log(\theta_t^U) = \lambda \log(\theta_t^S) \quad (5).$$

Notice that if λ is zero, all measured TPF growth is attributed to skilled-labor augmenting technological progress. In contrast, when λ approaches infinity all TPF growth is attributable to unskilled-labor augmenting technological progress. Using equations (4) and (5), we can rewrite equations (1) and (2) as follows,[12]

[10] Our means of calculating TFP_T is that most commonly used in the productivity literature. One rational for this particular approximation is that it becomes an exact index if the production function has the Translog form. See Hulten 1998 for a discussion.

[11] In our empirical work we normalize θ^i to be 1 in 1971, for $i = U, S$. This normalization implies that λ only governs the degree of added skill-biasedness over the post seventies period.

[12] Alternatively we could write these equations as

$$\log\left(\frac{w_t^S}{\frac{TFP_t}{s^U\lambda+s^S}}\right) = \alpha_0 + \alpha_1 \log\left(\frac{\frac{TFP_t}{s^U\lambda+s^S}S_t}{K_t}\right) + \alpha_2 \log\left(\frac{\frac{\lambda TFP_t}{s^U\lambda+s^S}U_t}{K_t}\right) + \epsilon_t^S \quad (6')$$

$$\log\left(\frac{w_t^U}{\frac{\lambda TFP_t}{s^U\lambda+s^S}}\right) = \beta_0 + \beta_1 \log\left(\frac{\frac{\lambda TFP_t}{s^U\lambda+s^S}U_t}{K_t}\right) + \beta_2 \log\left(\frac{\frac{TFP_t}{s^U\lambda+s^S}S_t}{K_t}\right) + \epsilon_t^U \quad (7')$$

$$\log(w_t^S) = \alpha_0 + \alpha_1 \log(\frac{S_t}{K_t}) + \alpha_2 \log(\frac{U_t}{K_t}) + (1 + \alpha_1 + \lambda\alpha_2)\frac{TFP_t}{s_t^U\lambda + s_t^S} + \epsilon_t^S, \quad (6)$$

$$\log(w_t^U) = \beta_0 + \beta_1 \log(\frac{U_t}{K_t}) + \beta_2 \log(\frac{S_t}{K_t}) + (\lambda + \lambda\beta_1 + \beta_2)\frac{TFP_t}{s_t^U\lambda + s_t^S} + \epsilon_t^U, \quad (7)$$

where ϵ_t^U and ϵ_t^S are approximation errors that are assumed to be uncorrelated with other variables. Note that there are three restrictions on parameters that should be satisfied if the aggregate production function is convex: (1) $\alpha_1 < 0$ and $\beta_2 < 0$ (own wage effects are negative), (2) $\alpha_1 * \beta_1 - \alpha_2 * \beta_2 > 0$ (concavity), and (3) $\alpha_1 = (\frac{s^U}{s^S})\beta_2$ (symmetry). Along with our estimates of Equations (6) and (7) we will report test statistics relating to each of these restrictions.

Before discussing the data we use to estimate Equations (6) and (7), it is necessary to indicate how estimates of $\alpha_1, \alpha_2, \beta_1$ and β_2 can be used to examine the relevance of our hypothesis regarding endogenous technical choice. To this end, let us begin by clearly stating our three hypotheses.

Hypothesis (1): The economy is transiting between two modes of organisation, where one is skilled biased relative to the other, and this is causing skilled and unskilled workers to be q-substitutes (Proposition 1 and Corrollary 1).

Hypothesis (2): The difference in productivities between the two forms of organisation is such that an increase in educational attainment decreases the wages of both skilled and unskilled workers and increases the returns to education (Proposition 3). Moreover, an increase in capital accumulation causes the returns to skill to fall (Propositions 2).

Hypothesis (3): Changes in the supply of factors, through their effect on the choice of production processes, explains most of the trend movements in wages over the period studied.

Given the parameter estimates obtained from equations (6) and (7), testing these hypotheses is very straightforward. First, Hypothesis 1 can be tested by examining whether β_2 and α_2 are negative since this corresponds to the test of whether skilled and unskilled labor are q-substitutes. Hypothesis 2 can be tested in a similar fashion. In particular, the suggestion that increased educational attainment increases the returns to education corresponds to the restriction that $(\beta_2 - \alpha_1) - (\frac{S}{U}) * (\beta_1 - \alpha_2)$ be negative. Futhermore, the suggestion that decreased wages can be attributable to observable increases in educational attainment can be tested by examining whether $\beta_2 - (\frac{S}{U}) * \beta_1 < 0$ and $\alpha_1 - (\frac{S}{U}) * \alpha_2 < 0$. Finally, whether an increase in capital leads to a decrease in wage inequality depends on whether $\alpha_1 + \alpha_2 - \beta_1 - \beta_2 > 0$. By testing all these conditions, we are actually testing whether the endogenous choice of a skilled biased technology, induced by the increase in education attainment, can be reasonably thought as having contributed to the observed decline in wages and increased wage inequality.[13] However, such a testing approach does not tell us what fraction of observed movements can be attributed to such a process. In order to answer this last hypothesis, (Hypothesis 3), we need to calculate the fraction of wage changes that can be attributable to changes in factor supplies. For comparison, we can also ask to what extent observed trends in wages are attributable to exogenous changes in technology. Obviously, this answer will depend on the extent to which we observe λ to be different from 1. For example, if λ is found to be one, this would indicate that exogenous skill-biased technological change is unlikely to be an important factor in explaining the increase in the returns to education.

3.1 Data

We use both US and Canadian data to estimate equations (6) and (7). For each country this requires six data series: quantity and real wage indexes for skilled labour, quantity and wage indexes for unskilled labour, a measure of aggregate output, and a measure of the real aggregate capital stock. The data on wages and labour quantities for the US are drawn from the March Current Population Survey (CPS) for the years 1971-1995. For Canada, the corresponding data are drawn from the Surveys of Consumer Finance (SCFs) for the available years between 1971 and 1995. The data collected is for all individuals over age 15. [14] The data on aggregate output is from the OECD National Accounts and

[13] Our tests do not discriminate between the model presented in Section 2 and any other model with the same general equilibrium mapping from inputs to factor prices. For example, Albrecht and Vroman (1998) present a matching model with many of the same predictions.

[14] The years 1972, 1972, 1976, 1978, 1980 and 1983 were not collected in the SCF series. The SCF files before 1980 are family files and include earnings and labour supply information only for heads and spouses. The files from 1981 on are individual files and contain observations on all individuals over age 16. We take the ratio of total weeks worked by all individuals over total weeks worked by heads and spouses in Canada in 1981 and use that ratio to weight up the total weeks values calculated from the pre-1981 Canadian data. In earlier work (Beaudry and Green(1997)) we found that using all individuals versus only heads and spouses had little impact on wage and employment patterns after 1981.

correspond to real GDP minus indirect taxes and subsidies. The price deflator used for calculating real output and real wages is the country specific GDP deflator. The variables denominated in real Canadian dollars are translated into US dollars using a purchasing power parity value of .78 US/CAN in 1989. [15] The capital stocks where constructed by cumulating the net investment series over the period 1960 to 1996, where the initial capital stock was set in accordance with the 1960 level reported in Flows and Stocks of Fixed Capital (OECD). [16]

Following the earlier literature (e.g., Katz and Murphy(1992)), we will associate the notion of a skilled worker with a university graduate and that of an unskilled worker with someone who has education equivalent to a high school diploma or less. [17] Also as in the earlier literature, we seek wage indexes that reflect movements that can reasonably be related to productivity rather than changes in composition and institutions. Thus, we focus on the wages of young men who work full year-full time since we believe that the wages for this group most likely reflect changes in marginal productivity (in contrast to wages for older workers which may also reflect internal labour market considerations). We chose males to avoid issues related to secular changes in the labour force attachment of women.[18] Thus, we construct a real wage index for skilled workers as the average weekly wage of full-year/full-time university educated males with 0 to 5 years experience. For the unskilled wage index we use the average weekly wage of full-year/full time high school or less educated males with 0 to 5 years experience. [19] The nominal wage indexes created

[15]This is the OECD estimate for 1989.

[16]Our method of constructing comparable capital stocks follows Diewert and & Fox (1997) and results in series which are very close to that reported in Flows and Stocks of Fixed Capital (OECD). We took care in constructing the Canadian Capital stock to treat depreciation and the relative price deflator of equipment similarly to that used for the US.

[17]The specific education groupings we use are as follows. For the U.S. before 1992, we define three education categories used in creating wage and quantity indexes: high school or less (years of completed schooling less than or equal to 12; some post-secondary (years of completed schooling greater than 12 and less than 16); and university (years of completed schooling greater than or equal to 16). For the U.S. after 1992: categories relating to education levels less than or equal to high school diploma; categories related to post-secondary education less than completing a BA; categories related to a completed BA or more. For Canada: high school or less (categories relating to less than high school education and some or completed high school); some post-secondary (categories relating to post-secondary education other than completed BA and post-graduate degrees); university (completed BA and post-graduate degrees).

[18]We also checked the robustness of our conclusions to using indexes created from different base age and sex groups.

[19]Full-year/full-time workers are defined as 49 or more weeks worked in the reference year with usual weekly hours of 35 or more for the US data and 50 weeks or more with usual hours of 30 or more in the Canadian data. We equate 0 to 5 years experience to being age 23 to 28 for university educated workers and to being age 19 to 24 for high school educated workers.In constructing the averages we use the weights

in this way are transformed into real terms using country specific GDP deflators.

In contrast to the wage indexes, in constructing the low and high skill quantity indexes we wish to include all relevant labour employed, where our measure of labour employed is total weeks worked. In principle, this simply involves adding up weeks worked by all low skilled (high school or less educated) workers and by all high skilled (BA or more educated) workers, properly weighted using sampling weights reported in the SCF and CPS. Thus, we include weeks worked by both males and females of all experience levels and regardless of full year/full time status. [20] In fact, three main complications arise in calculating these indexes. First, individuals who have more than a high school education but less than a BA can potentially be seen as part of either the low skilled or the high skilled labour force for the purposes of generating values of marginal products and hence wages. Thus, we need to count up quantities of labour for all three types of workers (high school or less, post-secondary less than BA, and BA or more) and then attribute the labour supplied by those with a post-secondary education less than a BA to the main categories of interest. Second, in both the SCF and the CPS the education categories underwent substantial revisions toward the end of our sample period (1989 and 1992, respectively). Third, simply adding up weeks worked within educational categories treats labour supplied by more and less experienced workers and by males and females as perfectly substitutable. This seems inappropriate and we follow a general methodology outlined in Katz and Murphy(1992) to address this.

In order to create a consistent quantity measure that does not treat all workers with the same education level as perfect substitutes, we re-weight contributions to the education specific quantity indexes using relative wages. In particular, for each of the three education groups, we divide individuals by gender and into 11 age categories. [21] For each education/gender/age group we calculate the average wage over the sample period and

assigned to each worker in the SCF for Canada and the March Supplemental weight from the CPS for the US. For the US, we used only observations for which earnings were not imputed.Average weekly wages are calculated as annual earnings in the year before the survey was taken divided by total weeks worked in that year. In the CPS, weeks are reported in categories in early years. We use a constructed variable from the Unicon CPS tapes in which averages are imputed for each of those categories. Annual earnings includes both farm and non-farm self-employed income because these cannot be separated from paid employment earnings for spouses in the pre-1981 Canadian data. In the US data, the earnings measures are top-coded and we follow the practice (see Katz and Murphy(1992)) of multiplying each top-coded earnings value by 1.45.

[20]In addition, because of data restrictions in the pre-1980 Canadian data, we include weeks worked by self-employed as well as paid employed workers.

[21]Each category from age 16 to age 65 is five years wide and the last category is age 66 or more.

the total weeks worked in each year. We divide the average wage for the group by the average wage of an education specific base group and then multiply the resulting ratio times the group specific total weeks worked. We then add up the reweighted total quantities for each relevant educational category for each year. We choose the base groups to match the wage index. Thus, for the high school educated we use males aged 19 to 24 and for both the post-secondary (not BA) and university educated we use males aged 23 to 28. This procedure treats relative wages as measures of relative productivity and thus gives us total quantities in young male equivalent weeks.[22] Once the initial quantity series were constructed, we adjusted them to account for the education definition changes as discussed in Appendix 2.

Finally, we need to apportion the movements in the post-secondary(not BA) series between the low and high skilled categories. To do this we use the weights reported in Katz and Murphy(1992), which are based on a regression of post- secondary wages on those of high school and university educated workers using US data. This yields a division of 0.69 of the post-secondary(no BA) quantities being assigned to the high school quantity measure and 0.29 being assigned to the university measure. The rationale behind this procedure is that post-secondary(no BA) workers are like each of the other education classes to the extent their wage movements are similar. [23]

3.2 A First Look at the Data

Figures 1 through 4 depict the movements in real weekly earnings of young men working full-year full-time over the period 1971 to 1996. Figure 1 corresponds to the earnings of US men with 0 to 5 years of experience and with no-post secondary education. Figure 2 corresponds to the earnings of US male college graduates with 0 to 5 years of work experience. Figures 3 and 4 are the corresponding figures for Canada. The first aspect to notice from these figures is that the movements have been quite different across countries and across education groupings. For example, young US men with no post-secondary

[22] We normalized the quantity indices in 1971 to assure that the product of the quantity index times wage index constitued an wage bill equal to that observed in the national income and product accounts in 1971. The factor shares for the rest of the sample are then constructed using the product of the quantity measure times the wage measure. Using factor shares derived entirely from the national income accounts does not change our results.

[23] We ran a similar regression using pooled Canadian and US data and obtained a quite similar implied division. We also tried a range of different divisions of the post-secondary quantities. Our results are robust to these variations. We chose to use the Katz and Murphy(1992) weights in order to make our results more easily comparable with the existing literature.

education witnessed a steady decline in wages while their Canadian counterparts first experienced a substantial increase in the seventies followed by a sustained decline. In contrast, the US university graduates first experienced a decline in real earnings over the seventies followed by an increase in the eighties. The Canadian university graduates witnessed the least movement of all. One striking observation is that none of these groups experience any substantial increase in real earnings over the entirety of the period. It is important to emphasize that we are finding poor wage performance even though we are deflating wages using the gdp deflator. In effect, the gdp deflator constitutes a much more conservative measure of inflation over this period than the consumer price index and therefore creates real wage series that are less subject to being criticized for downward bias.

Figures 5 and 6 depict the movements in quantities of factors over this period. Figure 5 corresponds to movements observed in the US and Figure 6 corresponds to movements observed in Canada. The figures report changes in the log of each series with the series being normalized to 1 in 1971. One important feature that emerges in both countries is that the quantity of skilled labour, as measured by university graduates [24], has increase dramatically. Although growth in skilled labour has surpassed the growth in GDP in both countries, the growth has been particularly strong in Canada with a log-difference of close to 1.4. This higher rate of skill growth in Canada reflects in part the lower initial level as of 1971. In contrast to skilled labour, the quantity of unskilled labour has grown quite slowly in both countries. Obviously, these two observations imply that educational attainment has increased substantially in both countries.

It should also be noted that, while capital grew quite substantially in both countries over the period, the capital output ratios stayed relatively constant.[25] The last element to take from Figures 5b and 6b is that growth in TFP was quite minimal in both countries. For example, our measure of TFP for the US indicates a growth of approximately 7% over the entire period.[26] It must be recalled that our TFP numbers are somewhat different from many in the literature since we are explicity accounting for two educational groupings. In the case of Canada, our measure of growth in TFP over the entire period is somewhat

[24]Recall that the university category includes a fraction of post-secondary graduates.

[25]During this period the relative price of capital fell quite substantially. This fall helps to account for the sustained growth in capital even though the savings rates fell significantly.

[26]For the US, the observed movements in wages and in TFP imply that the rental rate on capital increased over the period by approximately 15%. Given the changes in the real interest rates over this period, this implied movement for the rental rate on capital appears plaussible.

higher since it is close to 11%. It is worth noting that almost all of the TFP growth observed in Canada over this period occured during the seventies. In effect, since the early eighties, our measure of TFP for Canada does not indicate any significant positive trend.

Finally, Figures 7 and 8 provide some indication of why we prefer to focus on the wages of young workers, as a measure of marginal products, as opposed to the wages of older workers. In Figures 7 and 8 we plot the wages of two groups of men with no-post secondary education. One group is restricted to individuals with 0 to 5 years of experience, while the second group is composed of individuals with over ten years of experience. Figure 7 is based on US data and Figure 8 is based on Canadian data. The striking aspect to notice from these figures is that the wages of the more experience group do not fall when the wages of the less experience group fall. We view this pattern as possible evidence of institutional or contractual rigidities whereby older workers may be protected from experiencing wage loss. Hence, this suggests that the wages of older workers may not be as closely linked to marginal productivity as those of young workers.

In summary, Figures 1 through 8 set out the puzzle addressed by this paper, that is, how can the observed wage movements be explained in a manner that is commensurate with observed movements in factor supplies and changes in technology (TFP)? In particular, can a model of endogenous technological choice reconcile these puzzles and thereby help understand the relationships among these trends?

4 Empirical Results

We turn now to estimation of equations (6) and (7). Recall from our earlier discussion that the three key hypotheses relating to the endogenous technological choice model can be tested using combinations of the estimated α and β coefficients from those equations. In addition, the estimation is set up in a way that allows skill biased technical change to play a role. In particular, estimates of λ near 1 indicate no role for ongoing skill biased technical change, estimates near zero correspond to all measured TFP growth being attributed to skill biased technical change, and large values of λ indicate technical change that is unskilled labour augmenting. To obtain estimates of the αs, βs and λ, we implement (6) and (7) using a non- linear least squares estimator.

We begin with estimates based on pooled data from both Canada and the US. We want to focus mainly on results from the pooled data since this allows for the maximum variation in our data (as can be seem from the different patterns observed in Figures 1 through 4) and therefore is likely to provide the most powerful tests. Furthermore, the model we are considering involves the choice between two major forms of organisation (or general purpose technologies) that we would expect to be known and available in both Canada and the US. If we could find support for models of this sort in only one of these two economies, that would cast doubt on the veracity of the model. Alternatively, if we find the model summarizes reasonably well the Canadian and US data, this lends greater credence to the theory. In our estimation using the pooled data, we force the α_1, α_2, β_1 and β_2 estimates to be the same for Canada and the US but allow for different intercepts and different λs for each country. Thus, we are in effect imposing the restriction that the production functions are the same in the two countries, while at the same time allowing differences in the degree of efficiency of mastering these technologies as measured by θ^s and θ^u. In particular, such a specification allows for there to have been different rates of skill biased technical change in Canada and the US over the last 25 years. We have chosen such a specification in order to allow the skilled-biased technical change hypothesis to have greater play. However, restricting the two countries to experience the same degree of skill-biasedness does not change our results.

Table 1 presents results from joint, non-linear least squares estimation of equations (6) and (7) using wage measures based on individuals with 0 to 5 years of experience (i.e., the same wage data presented in figures 1-4). [27] Before discussing the implications of the estimates for the competing theories, it is worth checking whether the estimates comply with the implications of a competitive framework. The requirements are, first, that the own wage effects for unskilled and skilled workers (β_1 and α_1, respectively) be negative. This condition is never rejected, with the own price effect for skilled workers being significantly different from zero at conventional significance levels. Second, given that the estimated parameters correspond to an underlying production function, we expect them to indicate that the production function is concave. This corresponds to checking whether $\delta = (\beta_1 * \alpha_1 - \beta_2 * \alpha_2)$ is positive. The implied value for δ and its associated standard error are given in the row denoted "T1" at the bottom of the table. While the sign of delta disagrees with theory, the hypothesis that it is not statistically significantly different from small positive values cannot be rejected at the 1% level of significance.

[27] The dataset used in this estimation contains all the Canadian and Us data we have. Thus, for Canada it contains observations on the years 1971, 1973, 1975,1977, 1979, 1981, 1982, 1984-1995. For the US we have observations on 1971-1994, inclusive.

Finally, theory implies a symmetric relationship between the cross-effect terms (α_2 and β_2). Since we are working in logs, this corresponds to testing the restriction that $\beta_2 =$ S/U*α_2 [28] The row denoted "T2" at the bottom of the table reports the Wald statistic corresponding to the test of this restriction. The test statistic indicates that the restriction cannot be rejected at the 5% level of significance. Thus, overall, the estimates correspond relatively well to that of a competitive model.

What do the estimates imply for the three hypotheses set out in section (3.0)? The first hypothesis states that skilled and unskilled labour are q-substitutes, which in turn implies that both α_2 and β_2 are less than zero. The results in Table 1 indicate that these estimated parameters are negative and are statistically significantly different from zero at conventional significance levels. Thus, it appears to be the case that increases in the amount of skilled labour, for example, leads to decreases in unskilled wages. The second hypothesis states that: i) an increase in educational attainment (holding the total amount of labour constant) decreases the wages of both skilled and unskilled workers; ii) that such an increase in educational attainment increases the returns to education; and iii) that an increase in capital accumulation causes wages to rise and the returns to skill to fall. The first of these statements corresponds to $(\beta_2 - S/U * \beta_1)$ and $(\alpha_1 - S/U * \alpha_2)$ being negative. [29] Estimates of these terms are given in the rows denoted "T3" and "T4", respectively. Both terms are negative and statistically significantly different from zero at conventional significance levels. The hypothesis that increased educational attainment leads to increases in the returns to education is also corroborated by the data. This corresponds to the calculated term $(\beta_2 - \alpha_1) - (S/U) * (\beta_1 - \alpha_2)$ being negative, which is presented along with its standard error in the "T5" row in the table. **This is the test that we consider to be the most important** and central to our story since it is the test of whether observed increases in educational attainment could plausibly be a major cause for the observed increase in the returns to education. The estimated value for this statistics is negative and statistically significantly different from zero at conventional significance levels. Finally, whether increased capital accumulation leads to decreased returns to skill corresponds to $(\alpha_1 + \alpha_2 - \beta_1 - \beta_2)$ positive . This term and its associated standard error are presented in the row denoted "T6" in the table. The estimated term

[28] S/U equals the average of the ratios of the quantity of skilled labour to unskilled labour in the last period of the sample for Canada and the US. We choose the end of sample values to make the case most relevant for current use.

[29] The S/U term again needs to included because the estimation is in logs. S/U is defined in a previous footnote.

indicates that capital accumulation has the predicted effect of diminishing returns to skill, although the estimate is poorly defined.

To provide an idea of the size of the impact of increasing skill levels on wages and wage ratios, we used the estimates in Table 1 Column 1 to perform a simple experiment. We calculated fitted values for log wages using the estimated coefficients and first period values of factor quantities and TFP. We then multiplied the quantity of skilled labour by 1.5 and reduced the quantity of unskilled labour by enough to leave the total amount of labour unchanged. Using these new labour values and the first period capital and TFP numbers, we recalculated the fitted log wages. This provides an estimate of the size of the impact of an increase in the skill level of the population along the lines set out in the T5 measure. Performing this experiment for the US, we find that increasing the skill level in this way would result in a change in low skilled log wages of -.29, a change in high skilled log wages of -.13 and a change in the ratio of skilled to unskilled wages of .167. For Canada, the three corresponding numbers are, -.32, -.14, and .162. Thus, a 50% increase in skilled labour, holding total labour constant, would lead to substantial drops in wage levels and a substantial increase in the wage differential between skill groups. The actual quantity of skilled labour increased by approximately 100% in the two countries over our sample period.

The λ coefficients reported in Table 1 are of considerable interest in understanding the role of skill biasedness of technical change in wage patterns. To reiterate, estimates of λ near zero correspond to skill biased technical change while estimates much larger than one correspond to unskilled biased technical change. A value of 1 corresponds to the hypothesis that there is no skill bias to the technical change captured in the TFP numbers. We allowed λ to differ in Canada and the US, and we find that in neither case can we reject the restriction that λ equals 1 at conventional significance levels. Both estimates are also economically substantively different from zero. Both, however, are also not sharply defined. In the remaining columns of Table 1 we investigate the implications of different specific values for λ. In column 3 we report results from an estimation in which we fix λ equal to 1 in both countries, recalling that this restriction cannot be rejected using this data. The results in terms of estimates of key parameters are very similar to those from column 1, where the λ's are not fixed. Once again, increases in the education level of the population leads to decreased wages for both skilled and unskilled workers and an increase in inequality (row T5). In contrast, the results in column 5, obtained in estimation where the λ's are set to zero, are sharply different. The own wage effect for unskilled workers is now significantly positive and the concavity and symmetry restrictions are much more resoundingly rejected than with λ either free or set to 1. We take this as evidence that a purely skill biased technical change does not fit the data well, in the sense of not providing economically sensible results.

Hypothesis 3 from section (3.0) states that the change in the supply of factors explains most of the trend movements in wages in Canada and the US over the last 25 years. Note that this is the exact opposite of most studies which conclude that the wage movements must be the result of an unspecified demand shift. It enters the realm of reasonable explanations because of the finding that skilled and unskilled labour are q-substitutes. To evaluate this hypothesis we examine the fit of predicted wages from the model to the observed data and the contribution to that fit of factor quantity movements. Figures 9 and 10 contain plots of our log wage measures (i.e., the log wages of males with 5 years of experience) for the US and Canada respectively, along with fitted predictions for those log wages. [30] Lines representing plus and minus 2 times the standard error of those predictions are also plotted. The plotted series for the US indicate substantial success for the model: for both the low and high skilled wage series the fitted wage line just appears as a somewhat smoothed version of the true wage line. For the unskilled wage, the true wage line lies within the plus or minus two standard error band around the fitted line at almost all points. For the skilled wage, with its more tightly defined error band, the true wage line passes out of the band more often but is still substantially similar to the fitted line. For Canada, the model performs well at capturing long term patterns but does less well in some of the shorter term fluctuations. Thus, for the unskilled wage series in Figure 10, the fitted and true series follow quite different patterns in the 70s. However, the model provides quite accurate fits both for the post-1980 period for the unskilled wage and the whole period for the skilled wage. The conclusion from these figures is that the model performs rather well in fitting wages apart from for unskilled wages in Canada before 1980.

In Table 2, we present results from calculations designed to evaluate the importance of factor quantity movements versus productivity changes in explaining the wage patterns. In the first column, we present actual log wage changes and fitted comparisons based on the estimates from the first column of Table 1. In forming the fitted wage changes, we use actual values for labour quantities, capital and TFP series. [31] The first column in the

[30] The fitted wage series are constructed using the point estimates for coefficients reported in column 1 of Table 1 in conjunction with the actual series for labour quantities, capital and TFP.

[31] The numbers in the table are based on the average of the first three years fitted or actual log wages

table confirms the results from Figures 9 and 10: changes in fitted wages for low and high skilled workers and in the difference in log wages between low and high school workers over the US sample period are quite close to the relevant changes in actual wages. This is striking because the model was not estimated in a way that forced it to fit these wage changes. For Canada, the fitted changes are also quite close to the actual changes, though they do not perform quite as well as for the US. In column 2, we repeat the exercise but hold TFP constant at a value equal to its country specific average from the first three years in the sample when creating the fitted log wages. The closer is the fitted value in column 2 to the corresponding actual value, the more of the relevant wage change can be explained by factor movements (labour and capital) alone. The differences between the fitted values in columns 1 and 2 represent the added impact of TFP movements. For the US, column 2 indicates that factor movements account for over 90% of changes in low skilled wages and the skilled/unskilled wage ratio, and 75% of changes in the skilled wage. Changes in TFP then over explain what is left of the true wage changes and do not create nearly as large effects as the factor quantity changes. For Canada, the factor quantities alone over predict wage changes while TFP movements again play a smaller relative role. Thus, movements in quantities of unskilled labour, skilled labour and capital explain much of the observed wage movements without need to resort to explanations based on productivity movements.

In total, the estimates provide substantial corroboration for the implications of the endogenous technical choice model. This is our main empirical result: that our two sector theoretical model, which seeks to provide a consistent way to think about movements in wages, capital, labour and productivity, corresponds well with the data from two countries. Moreover, the fact that the estimates of λ for the two countries are neither statistically nor economically substantially different from 1, and that setting the λ to zero provides economically nonsensical results, indicates that the model fits the data without any need to resort to an ongoing, unobserved skill biased demand shock. [32] We turn now to demonstrating the robustness of this result to several variations in data construction and model refinement.

Our approach to investigating the impacts of factor quantity movements and technical change differ from earliers papers, among other dimensions, in that we require our expla-

and the average of the last three fitted or actual log wages.

[32] In fact, the Canadian λ is farther away from 1 and the fact that it is greater than 1 indicates that the data, if anything, fits better with unskilled labour favouring technical change.

nation to directly match productivity movements as represented in our TFP measures. This has benefits in that it ensures that we do not end up with contradictions such as explanations for wage movements not fitting well with observed productivity movements. The disadvantage is that is places weight on a quantity that is notoriously difficult to measure: TFP. Difficulties in measuring the impact of new technologies, in particular, may suggest that any conventional measure of TFP understates true productivity growth. To evaluate the implications of potential errors in this direction, we re-estimated our pooled country model using data in which we multiplied the TFP series in each country by two.[33] The results are presented in column 1 of Table 3 and are very similar to those in column 1 of Table 1. Own wage effects are still negative and symmetry restrictions are not rejected, though concavity is rejected. Most importantly, the λ estimates remain close to one for both countries and increasing the skill level of the economy causes statistically significant declines in both unskilled and skilled wages and in the skilled/unskilled wage differential (row T5). As a result, conclusions that implications of the endogenous technical choice model are satisfied and that there is little evidence of skill biasedness in technical change are robust to errors in the form of substantially understating TFP growth.[34]

A further concern relating to technology changes is that by focussing on long movements over a period running from the early 1970s to the 1990s, we are obscuring the period of real technical change: the 1980s and 1990s. This might be the point of view of researchers who stress the importance of the introduction of computers in transforming the labour market (e.g. Krueger(1993)). To assess this possibility, we re-estimated our pooled country model using only post 1980 data. The results, reported in column 3 of Table 3 are again quite similar to those in column 1 of Table 1. Again, we cannot reject the restrictions that the λ parameters equal 1 at conventional significance levels. Again, the estimates imply that increased educational levels reduce skilled and unskilled wages and increase skilled/unskilled wage differentials. Using only post-1980s data, however, the US λ coefficient is more in accord with a skill biased dimension to productivity change, and the education impact on the wage differential is not well defined. Thus, we conclude that the endogenous technical change fits for the 1980s and 1990s as well as for our whole sample period, but that there may be some element of skill biasedness present in more

[33] After multiply our TFP measures by two, we obtain growth rates of TFP that are similar to more conventional measures which only allow for one type of labor: for example Diewert and Fox (1997).

[34] It is worth noting that we use price indexes in creating the capital series that have explicitly been revised to take account of the impact of technological changes, thereby mitigating potential errors relating to technology based mismeasurement.

recent years.

As a final robustness check, in column 5 of Table 3 we present results using a different wage index. In particular, we replace the wage index constructed for full year/full time males with 0 to 5 years experience with one constructed for full year/full time males with 0 to 10 years experience. While we believe that the 0 to 5 years experience group is preferred because it is likely to be a group for whom wage setting is less encumbered by institutional constraints that could mask productivity, it is also a group being observed at an unstable point in their labour history. As a result, there may be concerns that our wage measure reflects poor matches as much as true productivity. This should be less true of individuals with slightly more experience. The results using the 0 to 10 year experience wage index are very similar to those in Table 1. The estimates do not permit rejection of symmetry and concavity, λ estimates are neither statistically significantly nor economically very different from 1, and the estimates fit with the wage predicitions of the endogenous technical change model.

Table 4 repeats the estimations in Table 3 but with λ set to 1, a restriction that could not be rejected in any specification reported in Table 3. The results in Table 4 serve to reinforce conclusions that patterns in accordance with the endogenous technical choice model are robust to data variations in a number of dimensions. Setting λ equal to 1 sharpens the definition of these estimated patterns and shows that a model without any skill biasedness both fits the data well and is robust to credible data variations.

Tables 5, 6 and 7 contain results from estimation of our model using country specific data. For the US estimation, reported in Table 5 and 6, we use all data years between 1971 and 1994. For the Canadian estimation,we use the 19 observations available between 1971 and 1995. [35] Column 1 of Table 5 presents results for the US allowing λ to vary. The results based on the US alone show larger, though also less well defined, own and cross wage effects for the low skilled workers compared to the pooled sample results. The main difference relative to the pooled results is that the own and cross wage effects for the more skilled is estimated very close to zero and poorly defined, and the estimate of lambda is large (suggesting, if anything, unskilled biased technical change) and very poorly defined. Nonetheless, the derived values in T3, T4 and T5 indicate that increased educational attainment causes reductions in unskilled wages, modest reductions in skilled wages and an increase in the skilled/unskilled wage differential, which is consistent with

[35] The specific years used are: 1971, 1973, 1975, 1977, 1979, 1981, 1982, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994 and 1995.

our previous results. Given the lack of precision in the estimate of λ, we first investigate the implications of setting λ to either 1 or 0 and secondly, in Table 6 we examine the robustness of the results when we substitue our wage index based on men with 0-5 years of experience with one based on men with 0-10 years of experience. Column 2 of the Table 5 reports the US results with λ set to 1. Imposing the absence of skill biased of technical change in this way leads to better defined own and cross-wage effects and reinforces the conclusion that increased educational attainment leads to declining wages for both skill groups and an increase in the between group differential. As in the λ free case, we cannot reject concavity and symmetry restrictions at the 5% level of significance. In contrast, estimates from the case where λ is set to 0 (Column 3 of Table 5) do not fit with a competitive model, as the own wage effect for unskilled labour is statistically signficantly positive and both concavity and symmetry can be decisively rejected. In Table 6, we reproduce the estimates of Table 5A using a wage measure based on men with 0-10 years of experience. The main aspects to note from this Table is that it generally offers more precise estimates than in Table 5 but noentheless leads to the same same conclusions. For example, when λ is set free, it offers a less imprecise measure of λ.

In contrast to the US results, estimation with Canadian data alone (Table 7) yields well defined coefficient estimates for the own and cross wage effects for skilled workers, along with an estimate of lambda that is quite close to one. Increased educational attainment again causes falling wage levels and increased wage differentials, though the latter is now not well defined. Symmetry and concavity cannot be rejected at standard significance levels and the estimate of λ is very close to 1. As in the pooled and US estimates, setting λ to 1 gives further definition to these results but does not change them. Setting λ to zero again yields results that reject the competitive framework, including a positive and statistically significant own wage effect for unskilled labour. Overall, these estimates indicate a good fit of the model to Canadian data but a less well defined fit (though still one that is consistent with our theory) for the US when λ is allowed to vary. This is somewhat surprising given that the results for the pooled data as represented in Figures 9 and 10. There, the estimated coefficients implied a better fit for the US data. Together, these exercises indicate that using data from both countries helps us obtain more precision on key parameters but that the basic wage patterns predicted by the model are present in both countries. We believe that any organizational or technological change large enough to affect relative wages in one of these countries ought to be observed in the data from the other country as well, given that the two countries have so much in common. Thus, the fact that the predictions of the endogenous technical choice model are broadly supported in both countries is an important piece of corroborative evidence in favour of the model. The fact that results obtained when λ is set to zero are economically nonsensical and that results when λ equals 1 are both economically sensical and similar to those for the λ varying case points away from a model emphasizing skill biased technical change.

4.1 Possible Endogeneity of Educational Attainment

Up to now, we have assumed that the error term in equations (6) and (7) (which we interpret as an approximation error) is uncorrelated with the regressors. In particular, we have assumed that the observed increase in the education level in the population in not being driven by this residual. In this subsection we want to verify the robustness of our results with respect to the possible endogeneity of educational attainment. This requires us to find a set of appropriate instruments. In the case of education, changes in demographics appear to be a reasonable candidate since they are likely exogenous and they have contributed to changes in the educational attainment of the population. In effect, over the period 1971-95, much of the increase in the number of individuals with a college degree can be attributed to the entry of the baby boom cohort. To see this, Figure 12 plots for our sample period the proportion of individuals between the ages of 25 and 29 with a college degree. The somewhat surprising aspect to note from Figure 12 is the relative stability of the proportion of individuals with a college degree, especially over the 1975-90 period. If this figure were be extended to the 50s and 60s, we would find a much different pattern since college attainment between successive birth cohorts was increasing quite rapidly over this earlier period. In contrast, all the cohorts within the baby boom generation have approximately the same degree of college attainment.[36] These observations imply that that the increase in the relative number of individuals with a college degree over our sample period was driven mainly by the entry of large cohorts, with higher but stable educational attainment, replacing retiring cohorts with lower educational attainment, that is, the increased educational attainment of the population over our period is not being driven primarily by successive cohorts becoming more and more educated. Such a pattern suggests that demographic variables are goods candidates for examining possible biases associated with the endogeneity of education choices.

Table 8 reports estimates of equations (6) and (7) for our pooled data when demo-

[36]We thank Thomas Lemieux for informing us of the observation

graphics variables are used as instruments for the quantities of skilled and unskilled labor. Table 8 is constructed to allow direct comparison with the results presented in Table 1. The three demographic variables we use to instrument our labor quantity variables are the number of individuals between 16 and 70 years of age in a given year which are respectively (a) born before 1945, (b) born between 1945 and 1960 and (c) born after 1960. The demographic variables actually predict the labor quantity variables very well (first stage $R^2 > .88$) with the exception of the quantity of low skilled workers in Canada (first stage $R^2 = .26$). The main element to note from Table 8 is that is provides a pattern of results very similar to that found in Table 1. In particular, for the case where λ is set free, we find that the own and cross effects of quantity on wages are significantly negative, that the estimates of λ are not very supportive of the skilled biased technical change view and that the statistic T5 again supports the view that an increased in educational attainment likely increases the return to education. Furthermore, when we impose $\lambda = 1$ we find reasonable results, while when we impose $\lambda = 0$ we find strong evidence against the competitive model. Overall, we interpret the results of Table 8 as suggesting that the endogeneity of the educational choice in unlikely to be biasing our inferences.

4.2 Explaining Differences Relative to the Previous Literature

The results of the previous section give support to the hypothesis that endogenous technical choice may be central for understanding recent co-movements between wages, factor supplies and productivity. In this light, it is necessary to ask why our results differ so substantially from much of the literature which favors an alternative explanation whereby it is exogenous skill biased technological change, mitigated by the effects of supply, which drives wages movements. In particular, we want to clarify why our results differ from those of Katz and Murphy (1992). Is it the methodology? Is it different data?

Figure 11 helps visualize that our wage data exhibits much the same pattern in terms of relative wages as that emphasised in previous studies. In particular, Figure 11 plots the relative weekly earnings in the US for our two education groups of young men (that is, the log-ratio of the series presented in Figures 1 and 2). This series shows a sustained decline over the seventies, followed by a large increase in the eighties that decelerates in the nineties. This pattern is very similar to that reported in Katz and Murphy (1992) even though we are working with weekly earnings of full-year full-time young male workers as opposed to hourly wages for both men and women. In order to get a precise comparision between our results and those from Katz & Murphy, Table 9 reports the result of estimating the main regression in Katz and Murphy using our data on relative wages and quantities. The regression in Katz and Murphy that is most closely related to our work corresponds to regressing relative wages on relative quatities plus a time trend, that is, in our notation:

$$\log(\frac{w^s}{w^u}) = \gamma_0 + \gamma_1 \log(\frac{S_t}{U_t}) + \gamma_2 t,$$

Row 1 of Table 9 reports the result of this regression using our earnings measure for young men (0 to 5 years of experience) over the period 1971 to 1995. Since Katz & Murphy's data finished in 1987, Row 2 of Table 9 reports the results for the sample from 1971 to 1987. Finally, Row 3 reports results for this more limited sample (71-87) but where, instead of using earning for men with 1 to 5 years of experience, we use earning for all full-time full-year men between the ages of 20 and 60. This latter change is made to make our results more easily comparable to those of Katz & Murphy since they use data averaged over all age groups. For the period 1963 to 1987, Katz & Murphy obtain estimates (standard errors) equal to $\gamma_1 = -.71(.15)$ and $\gamma_2 = .033(.007)$.[37] γ_1 and γ_2 reported in Table 9 accord well with those of Katz and Murphy. In particular the estimates in the second and third row, which use a similar sample, are very close. Therefore, we conclude that we are getting different results not because we have constructed the data differently, but because of something more fundamental.

To explain the difference between our results and Katz & Murphy's it is useful to recall basic issues of inference in time series econometrics. In particular, when discussing the co-movements between a set of time series, it is necessary to be explicit about which frequency one is focusing upon: is the study focusing on short-term/high frequency co-movements or on long-term/low frequency comovements. For example, if one is interested in examining long term co-movements, then it is more informative to look at co-movements between the levels of a variables. In particular, when the variables are non-stationary, it is well known that the co-movements between the levels of the variables can be used to investigate the presence of a co-integrating relationship which is precisely the long-term relationship between the variables. In contrast, if one is more interested in short term/high frequency co-movements, then it is more informative to look at co-movements between detrended variables or variables in first difference. It is this difference between short-term/high frequency and long-term/low frequency co-movements which we believe

[37] Murphy, Romer and Riddell (1998) provide estimates of this equations based on pooled data for both the US and Canada. There estimates are The estimates of $\gamma_1 = -.81(.16)$ and $\gamma_2 = .035(.007)$.

is central to understanding the difference between our results and those of Katz & Murphy. In effect, we see our results as reflecting trend movements–since our econometric analysis uses data in levels– while we view Katz & Murphy's analysis as emphasizing more short term/high frequency movements– since it focuses upon deviations from trend.

To see precisely the relationship between our results and that of Katz & Murphy, in terms of the difference in high and low frequency co-movements in the data, consider the following equation which is obtained by taking the difference between equations (6) and (7).

$$\log(\frac{w^s}{w^u}) = (\alpha_0 - \beta_0) + (\alpha_1 - \beta_2)\log(\frac{S_t\theta_t^s}{K_t}) + (\alpha_2 - \beta_1)\log(\frac{U_t\theta_t^u}{K_t}) + \epsilon_{3,t}$$

The first row of Table 10 reports results of estimating the above equation using our US data for the case where θ_t^s and θ_t^u are calculated imposing $\lambda = 1$. As can be seen, the estimates of $(\alpha_1 - \beta_2)$ and $(\alpha_2 - \beta_1)$ are consistent with those reported in Table 5, that is, the increase in educational attainment is predicted to increase the returns to education. Hence the results of this regression appear to support our story and conflict with the hypothesis advanced in Katz & Murphy. Consider, however, the effect of linearly detrending the data. The second row of Table 10 reports estimates of the above equation when we perform the regression on linearly detrended variables. The co-movements between relative wages and inputs is now completely different in that an increase in educational attainment now appears associated with a decrease in the returns to inequality, in accord with Katz & Murphy's conclusions. Hence, this pair of results suggest that the low frequency movements in the data tend to support our view that an increase in educational attainement increases wage inequality while the high frequency movements tend to support the opposite view. The obvious remaining question is whether these two pieces of evidence can be reconciled.

To understand how these two pieces of evidence can be explained within our framework, it is helpful to refer back to the model of endogenous technological choice presented in Section 2. In this model, an increase in educational attainment is predicted to increase returns to education through its effect of inducing capital to move from the traditional firms to the modern firms. However, if capital movements are not instantaneous, then the short run response of an increase in educational attainement can be quite different from the long run response. In particular, if capital is immobile in the short run, then an increase in educational attainment is most likely to decrease the returns to education. Hence, we find it reasonable to interpret the high frequencies results suggested by Row

2 of Table 10 as indicating that capital moves slowly and therefore that our hypothesis regarding the effects of endogenous techical choice only applies for lower frequency movements in the data. In other words, we do not disagree with the view proposed by Katz and Murphy whereby much of the decline in the returns to education observed in the US over the seventies may have been driven by the increase in relative supply of skilled labor; we do, however, disagree that this was the final effect of the increase. In fact, we believe that the increase in relative supply placed presure on capital to move from traditional type organisations toward organisations that use more skilled labour, and that this mode of adjustment took until well into the eigthies to be completed.

5 Conclusion

This paper argues that recent trend movements in wages reflect mainly skill-biased technological choice as opposed to skilled biased technical change. We compare the merits of these two theories by estimating an aggregate production function which does not restrict the patterns of input substitutability. Our main finding is that the estimated patterns of input substitutability fit with the predictions of the endogenous technological choice model. Moreover, we find that observed movements in factor quantities can explain most of the variation in wage data in the US and Canada over the 1971-95 period the need to invoke a ongoing skill biased technical change. We believe that the distinction between exogenous technical change and endogenous choice of technique is of prime importance since it implies a very different view of the likely effects of policy on the wage structure. For example, if the technological choice hypothesis is correct, then policies designed to increase education levels in the population can be argued to be good for growth, but policy makers should be aware that they may have negative effects on between group inequality. In contrast, our model suggests that increased capital accumulation may be good for both promoting growth and reducing inequality.[38] We used data from two very similar countries in our investigation, in part because we believe that large scale forces such as those contained in both the exogenous technical change and endogenous technical choice models should show up in similar ways in more than one country. In this sense, using data from multiple countries poses a harder test for competing theories to meet. Future research should use data from countries other than Canada or the US to further confront these theories.

[38]This observation may help explain some of the puzzles set out in Blanchard (1997).

Appendix 1

In order to verify Proposition 1 through 3, it is easiest to start from the equilibrium conditions stated in their dual form. To this end, let $c^T(w^u, w^s, r)$ and $c^M(w^u, w^s, r)$ represent the unit cost functions associated with the traditional and modern organisations. The equilibrium conditions for our problem can then be expressed by the following 5 equations:

$$c^T(w^u, w^s, r) = 1, \quad (1A)$$

$$c^M(w^u, w^s, r) = 1, \quad (2A)$$

$$Y^T c_1^T(w^u, w^s, r) + Y^M c_1^M(w^u, w^s, r) = U, \quad (3A)$$

$$Y^T c_2^T(w^u, w^s, r) + Y^M c_2^M(w^u, w^s, r) = S, \quad (4A)$$

$$Y^T c_3^T(w^u, w^s, r) + Y^M c_3^M(w^u, w^s, r) = K, \quad (5A)$$

In the above equations, Y^T and Y^M are the quantities of output produced by the traditional and modern organisations respectively, and C_j^i is the derivative of the cost function with respect to its jth argument. Equations (1A) and (2A) are the goods market equilibrium conditions in that the unit cost for each organisation must be equal to the price of the produced good (which is normalized to 1). Equations (3A), (4A) and (5A) are the factor market equilibrium conditions.

The effects of factor supplies on factor prices can be derived by totally differentiating the above system, that is, by solving the system of equation given below:

$$\begin{pmatrix} c_1^T & c_2^T & c_3^T & 0 & 0 \\ c_1^M & c_2^M & c_3^M & 0 & 0 \\ Y^T c_{1,1}^T + Y^M c_{1,1}^M & Y^T c_{1,2}^T + Y^M c_{1,2}^M & Y^T c_{1,3}^T + Y^M c_{1,3}^M & c_1^T & c_1^M \\ Y^T c_{2,1}^T + Y^M c_{2,1}^M & Y^T c_{2,2}^T + Y^M c_{2,2}^M & Y^T c_{2,3}^T + Y^M c_{2,3}^M & c_2^T & c_2^M \\ Y^T c_{3,1}^T + Y^M c_{3,1}^M & Y^T c_{3,2}^T + Y^M c_{3,2}^M & Y^T c_{3,3}^T + Y^M c_{3,3}^M & c_3^T & c_3^M \end{pmatrix} * \begin{pmatrix} dw^u \\ dw^s \\ dr \\ dY^T \\ dY^M \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ dU \\ dS \\ dK \end{pmatrix} \quad (5.1)$$

For example, from the above system, the change in the unskilled wage induced by a change in the supply of skilled labor is given by

$$\frac{\partial w^u}{\partial S} = \frac{(c_1^T c_2^M - c_2^T c_3^M) * (c_1^T c_3^M - c_3^T c_1^M)}{D}$$

where D is the determinant of the left hand side matrix. Since concavity of technologies implies that D is negative (see Diewert and Woodland (1977)), $\frac{\partial w^u}{\partial S}$ is negative if $(c_1^T c_2^M - c_2^T c_3^M) > 0$ and $(c_1^T c_3^M - c_3^T c_1^M) > 0$. Since by Sherpards Lemma, $c_i^j = X_j^i$, these conditions correspond to the conditions stated in Proposition 1 and hence prove the proposition. The statements of the other propositions can be verified in the same manner. Note that in the case of determining the effects on relative wages, it is useful to exploit the fact that $w^u C_1^i + w^s C_2^i + r C_3^i = 1$.

Appendix 2

Adjustments made for changes in Educational Definitions.

In the SCF, the primary change was that individuals who received post-secondary education but never completed high school were switched from the high school or less education category to the post-secondary education category. This creates a noticeable jump down in total weeks worked by high school or less educated workers and a jump up in weeks worked by post secondary (not BA) workers in 1989. Other smaller definition changes, cause a jump down in the university worker weeks worked measure at the same time. Plotting three education group quantity series, one notices that the definition changes appear to change the levels but not the trends in each. Taking this into account, we regress the high school educated quantity series on a time trend and a dummy variable representing the post-1989 period. We then add the coefficient on the post-1989 dummy variable to the post-1989 high school quantity values. We repeat this exercise for the university educated. For the post-secondary (not BA) series subtract the sum of the high school and university educated post-1989 dummy coefficients from all post-1989 observations. This ensures that we do not create extra supply of any kind through our adjustment process. For the CPS, in 1992 questions on educational categories replaced questions on years of schooling taken and completed. This potentially allows more exact allocation of quantities into the sorts of education categories we wish to use but also generated jumps in the quantity series at the time of the definitional change. We corrected for these jumps using the same methodology as for the SCF. [39] The resulting, corrected series are substantially smoother than the initial, uncorrected series.

[39]The only difference is that the quantity series do not appear to follow the same linear trend before and after 1992 in the CPS data. Thus, we regress the quantity series on both time and time squared, as well as a post-1992 dummy variable.

Table 1: Estimates of Equation (6) and (7) Based on Pooled Data

	λ Free Estimates	Std. Err.	$\lambda = 1$ Estimates	Std. Err.	$\lambda = 0$ Estimates	Std. Err.
β_1	-.38	(.32)	-.23	(.19)	.46	(.10)
β_2	-.86	(.19)	-.72	(.06)	.02	(.04)
α_1	-.46	(.11)	-.53	(0.05)	-.97	(.06)
α_2	-.42	(.12)	-.50	(0.11)	-.86	(.11)
λ_c	1.76	(.89)	-	-	-	-
λ_u	.82	(.53)	-	-	-	-
T1	-.19	(.14)	-.24	(.11)	-.42	(.07)
T2	3.11		5.04		55.57	
T3	-.66	(.15)	-.60	(.07)	-.22	(.03)
T4	-.24	(.08)	-.27	(.05)	-.52	(.04)
T5	-.42	(.20)	-.33	(.08)	.31	(.05)
T6	.35	(.62)	-.08	(.28)	-2.31	(.21)

Coefficient estimates corresponding to the constants in the two log wage equations as well as coefficients on a Canada specific dummy variable in each equation were obtained but are not reported.

T1 corresponds to a test of the concavity of the production function. The first column entry corresponds to the estimate of $(\beta_1 * \alpha_1 - \beta_2 * \alpha_2)$. If this term is significantly negative, then it indicates that concavity is rejected.The second column contains its standard error.

T2 reports the Wald statistic corresponding to a test of whether $\beta_2 = S/U^* \alpha_2$, i.e., whether the underlying production function satisfies symmetry. The square root of this statistic follows a t-distribution.

T3 reports the estimate $(\beta_2 - S/U * \beta_1)$ and its standard error. If this entity is negative then an increase in educational attainment, holding the total amount of labour constant, causes a decline in the unskilled wage.

T4 reports the estimate of $\alpha_1 - S/U * \alpha_2$ and its standard error. If this entity is negative then an increase in educational attainment, holding the total amount of labour constant, causes a decline in the skilled wage.

T5 provides an estimate of $(\beta_2 - \alpha_1) - (S/U) * (\beta_1 - \alpha_2)$ and its standard error. If this term is negative then increasing the educational attainment of the population while holding total labour constant yields an increase in the differential between high and low skilled wages.

T6 reports a statistic showing the impact of an increase in the capital stock on the relative wages of low and high skilled workers. The actual statistic reported equals $(\alpha_1 + \alpha_2 - \beta_1 - \beta_2)$. If this statistic is positive it indicates tha an increase in capital accumulation decreases the differential between high and low skilled workers.

Table 2: Changes in Actual and Fitted Log Wages

United States	All Variables Free	TFP Fixed
Change in Low Skilled Log Wage		
True	-.243	
Fitted	-.258	-.227
Change in High Skilled Log Wage		
True	-.034	
Fitted	-.008	-.026
Change in Log Ratio		
True	.209	
Fitted	.250	.201
Canada	**All Variables Free**	**TFP Fixed**
Change in Low Skilled Log Wage		
True	-.134	
Fitted	-.158	-.202
Change in High Skilled Log Wage		
True	-.033	
Fitted	.008	.044
Change in Log Ratio		
True	.101	
Fitted	.166	.246

Fitted wages are fit using coefficient estimates from column 1 of Table 1 and observed labour and capital quantities and TFP. We use the average of the first three fitted log wages and the last three in calculating the table entries.

Table 3: Robustness of Estimates of Equations (6) and (7): λ free

	Double TFP Estimates	Std. Err.	1980-95 Estimates	Std. Err.	0-10 Exp Estimates	Std. Err.
β_1	-.41	(.21)	-.21	(.21)	-.23	(.14)
β_2	-.84	(.17)	-.75	(.26)	-.66	(.13)
α_1	-.43	(.12)	-.60	(.16)	-.33	(.10)
α_2	-.42	(.12)	-.51	(.13)	-.28	(.13)
λ_c	1.53	(.72)	.88	(.65)	1.80	(.74)
λ_u	1.05	(.55)	.54	(.47)	0.88	(.53)
T1	-.20	(.09)	-.25	(.09)	-.09	(.07)
T2	2.64		.60		3.71	
T3	-.63	(.12)	-.63	(.17)	-.54	(.09)
T4	-.20	(.08)	-.33	(.12)	-.19	(.06)
T5	-.43	(.18)	-.29	(.28)	-.35	(.13)
T6	.36	(.57)	-0.15	(.71)	.30	(.45)
See notes of Table 1						

Table 4: Robustness of Estimates of Equations (6) and (7): $\lambda = 1$

	Double TFP Estimates	Std. Err.	1980-95 Estimates	Std. Err.	0-10 Exp Estimates	Std. Err.
β_1	-.26	(.13)	-.28	(.12)	-.13	(.11)
β_2	-.73	(.03)	-0.86	(.08)	-.55	(.05)
α_1	-.52	(.03)	-0.54	(.06)	-.41	(.05)
α_2	-.52	(.07)	-0.46	(.09)	-.32	(.10)
T1	-.24	(.10)	-0.24	(.10)	-.12	(.06)
T2	10.92		12.90		6.39	
T3	-.59	(.09)	-.71	(.08)	-.48	(.04)
T4	-.25	(.05)	-.30	(.07)	-.24	(.04)
T5	-.34	(.10)	-.41	(.11)	-.23	(.06)
T6	-.05	(.14)	.14	(.21)	-.04	(.22)
See notes of Table 1						

Table 5: Estimates of Equation (6) and (7) Based on US Data

	λ Free Estimates	Std. Err.	$\lambda = 1$ Estimates	Std. Err.	$\lambda = 0$ Estimates	Std. Err.
β_1	-.74	(.57)	-.20	(.21)	.64	(.21)
β_2	-1.23	(.49)	-0.76	(.11)	-.00	(.12)
α_1	.01	(.32)	-.29	(.12)	-.84	(.15)
α_2	.06	(.40)	-.30	(.23)	-.96	(.25)
λ_u	5.94	(17.27)	-	-	-	-
T1	.07	(.30)	-.16	(.16)	-.54	(.13)
T2	2.05		2.28		11.97	
T3	-.80	(.19)	-.64	(.07)	-.37	(.05)
T4	-.02	(.12)	-.12	(.06)	-.28	(.05)
T5	-.78	(.29)	-.51	(.09)	-.08	(.07)
T6	2.06	(1.74)	0.37	(.47)	-2.45	(.52)
See notes of Table 1						

Table 6: Estimates Based on US Data with 0-10 Years of Experience

	λ Free Estimates	Std. Err.	$\lambda = 1$ Estimates	Std. Err.	$\lambda = 0$ Estimates	Std. Err.
β_1	-.49	(.28)	-.21	(.09)	.59	(.09)
β_2	-.95	(.22)	-.70	(.04)	.02	(.05)
α_1	-.08	(.18)	-.25	(.11)	-.81	(.14)
α_2	-.03	(.24)	-.23	(.19)	-.91	(.23)
λ_u	2.27	(1.96)	-	-	-	-
T1	.01	(.16)	-.11	(.11)	-.46	(.09)
T2	4.00		4.03		15.43	
T3	-.66	(.08)	-.58	(.04)	-.33	(.03)
T4	-.06	(.07)	-.12	(.05)	-.28	(.05)
T5	-.60	(.13)	-.46	(.06)	-.05	(.06)
T6	1.33	(.85)	0.42	(.32)	-2.33	(.40)
See notes of Table 1						

Table 7: Estimates of Equation (6) and (7) Based on Canadian Data

	λ Free Estimates	Std. Err.	$\lambda = 1$ Estimates	Std. Err.	$\lambda = 0$ Estimates	Std. Err.
β_1	-.28	(.43)	-.25	(.37)	.36	(.15)
β_2	-.73	(.28)	-0.69	(.11)	-.02	(.06)
α_1	-.59	(.14)	-0.61	(.04)	-.99	(.04)
α_2	-.49	(.12)	-0.51	(.09)	-.75	(.09)
λ_c	1.10	(.78)	-	-	-	-
T1	-.19	(.20)	-0.19	(.20)	-.34	(.11)
T2	1.09		1.62		43.97	
T3	-.60	(.20)	-.57	(.11)	-.13	(.04)
T4	-.36	(.11)	-.38	(.04)	-.65	(.02)
T5	-.23	(.30)	-.20	(.11)	.52	(.05)
T6	-0.07	(.82)	-0.17	(.47)	-2.14	(.25)
See notes of Table 1						

Table 8: IV Estimates of Equation (6) and (7) Based on Pooled Data

	λ Free Estimates	Std. Err.	$\lambda = 1$ Estimates	Std. Err.	$\lambda = 0$ Estimates	Std. Err.
β_1	-.70	(.19)	-.43	(.16)	.43	(.17)
β_2	-1.08	(.15)	-.84	(.09)	.02	(.10)
α_1	-.33	(.13)	-.52	(.09)	-1.09	(.06)
α_2	-.34	(.16)	-.47	(0.16)	-.92	(.11)
λ_c	2.77	(1.26)	-	-	-	-
λ_u	1.47	(1.09)	-	-	-	-
T1	-.14	(.12)	-.18	(.12)	-.45	(.12)
T2	9.44		4.54		30.14	
T3	-.68	(.11)	-.59	(.06)	-.22	(.04)
T4	-.14	(.08)	-.25	(.05)	-.56	(.05)
T5	-.54	(.16)	-.35	(.08)	.33	(.06)
T6	1.11	(.49)	.27	(.33)	-2.48	(.34)
See notes of Table 1						

Table 9: Katz and Murphy(1992) Regression

	γ_1	Std. Error	γ_2	Std. Error
(1)	-0.16	(.22)	0.020	(.009)
(2)	-0.89	(.48)	0.057	(.023)
(3)	-0.71	(.21)	0.039	(.011)

Table 9 reports estimates of the following equation:

$$\log(\frac{w^s}{w^u}) = \gamma_0 + \gamma_1 \log(\frac{S_t}{U_t}) + \gamma_2 t + \mu_t,$$

The first row corresponds to estimate using US data over the sample 1971 to 1994, where wages are for men with 0 to 5 years of experience. The second row corresponds to same data except the sample is changed to the 1971 to 1987 period. The third row corresponds to estimates using the US data over the period 1971-1987, where wages are for men aged between 20 and 60.

Table 10: Clarifying the effects of Detrending

	$\alpha_1 - \beta_2$	Std. Err.	$\alpha_2 - \beta_1$	Std. Dev
(1)	0.47	(.12)	-0.09	(.22)
(2)	-0.13	(.34)	0.17	(.25)

Table 10 reports estimates for the following equation.

$$\log(\frac{w^s}{w^u}) = (\alpha_0 - \beta_0) + (\alpha_1 - \beta_2)\log(\frac{S_t\theta_t^s}{K_t}) + (\alpha_2 - \beta_1)\log(\frac{U_t\theta_t^u}{K_t}) + \epsilon_{3,t}$$

The estimates are based on US data over the period 1971 to 1994, where wage are for men with 0 to 5 years of experience. The first row corresponds to estimates from running the regression on non-transformed variables, while the second row correspond to estimates based on linearly detrended data.

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Fig.1: Real Weekly Earnings FYFT Young US Men No-Post Secondary

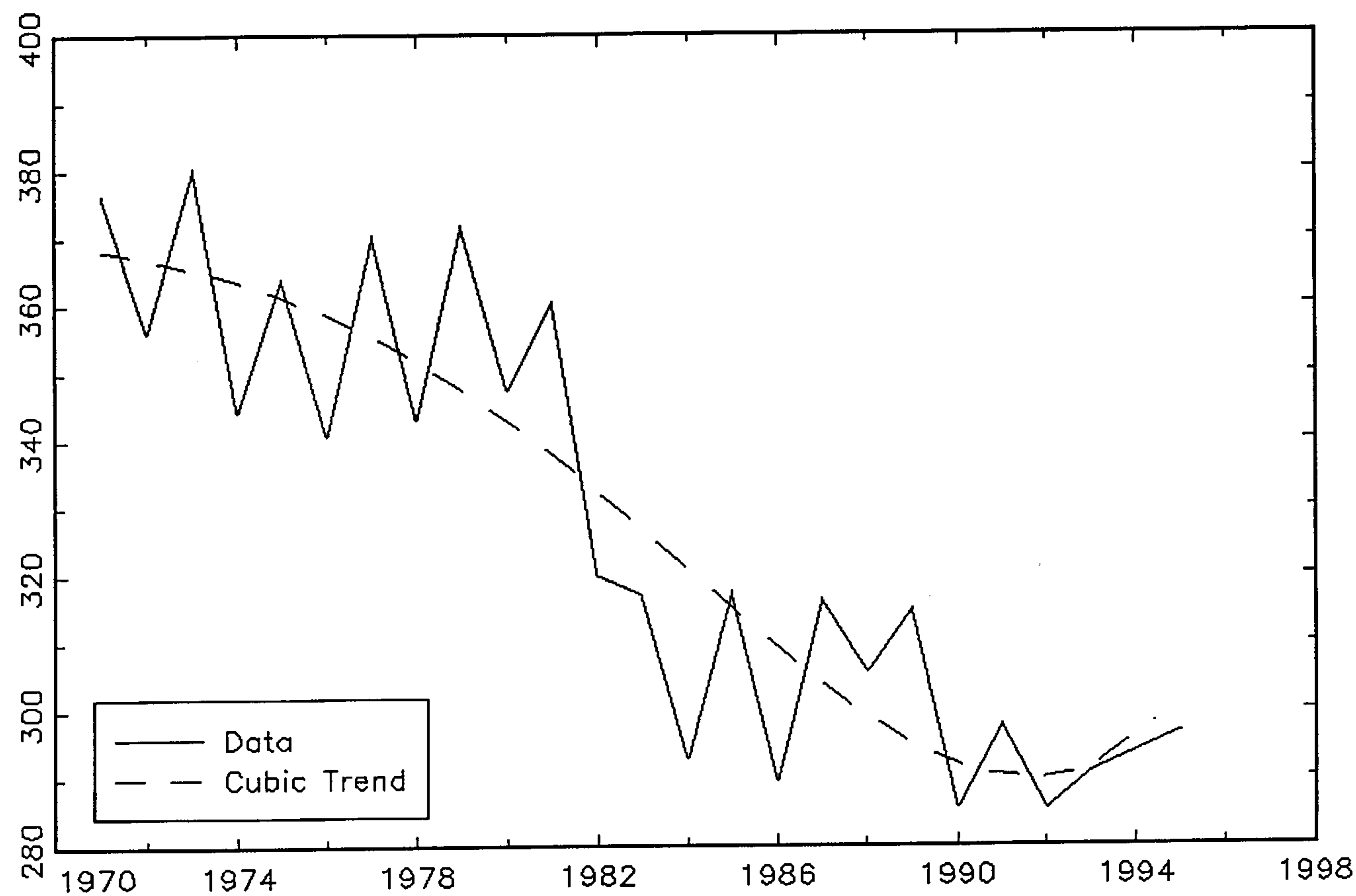

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Fig.2: Real Weekly Earnings FYFT Young US Men College Grads

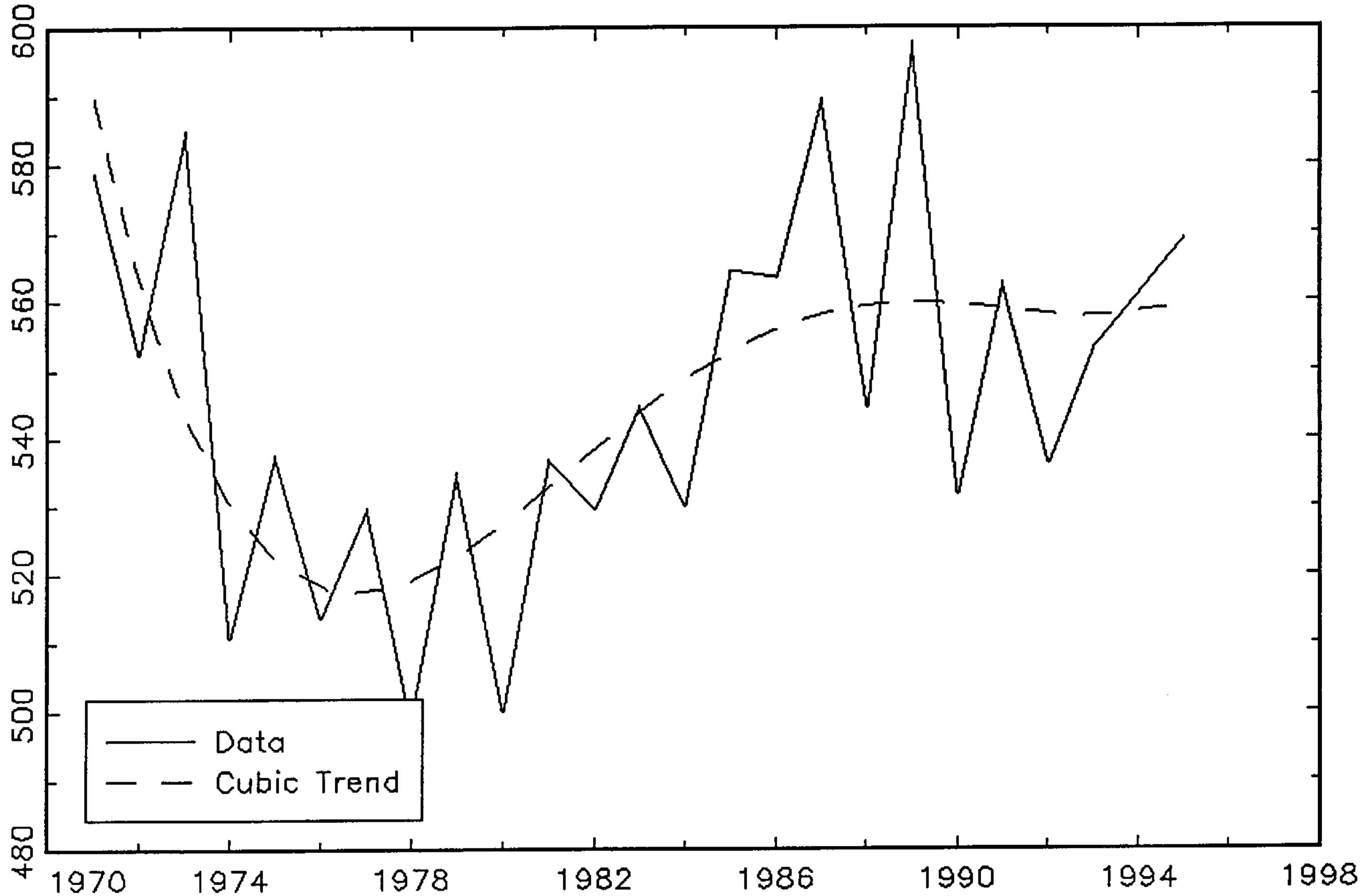

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Fig.3: Real Weekly Earnings FYFT Young Can. Men No-Post Secondary

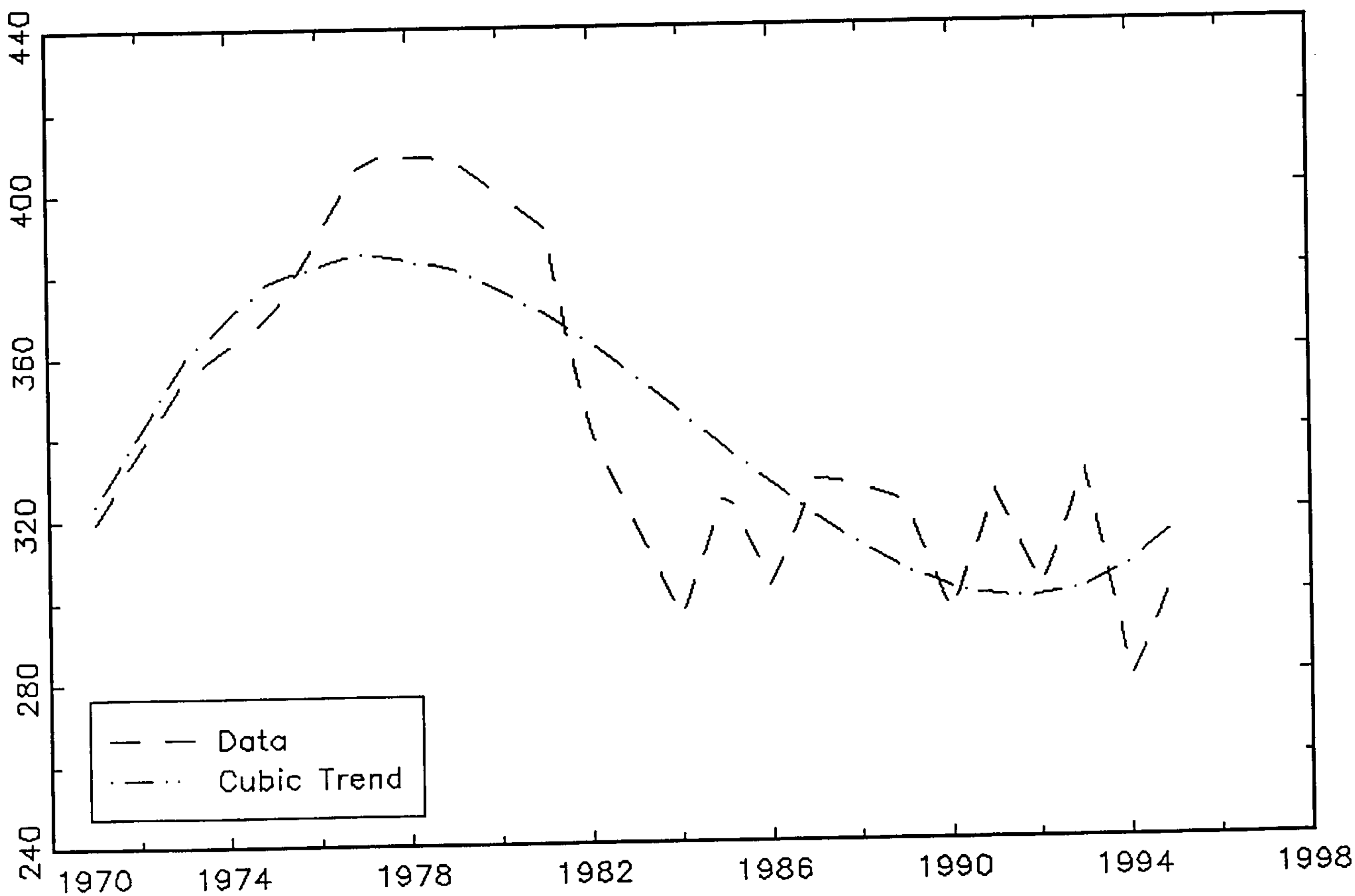

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Fig.4: Real Weekly Earnings FYFT Young Can. Men College Grads

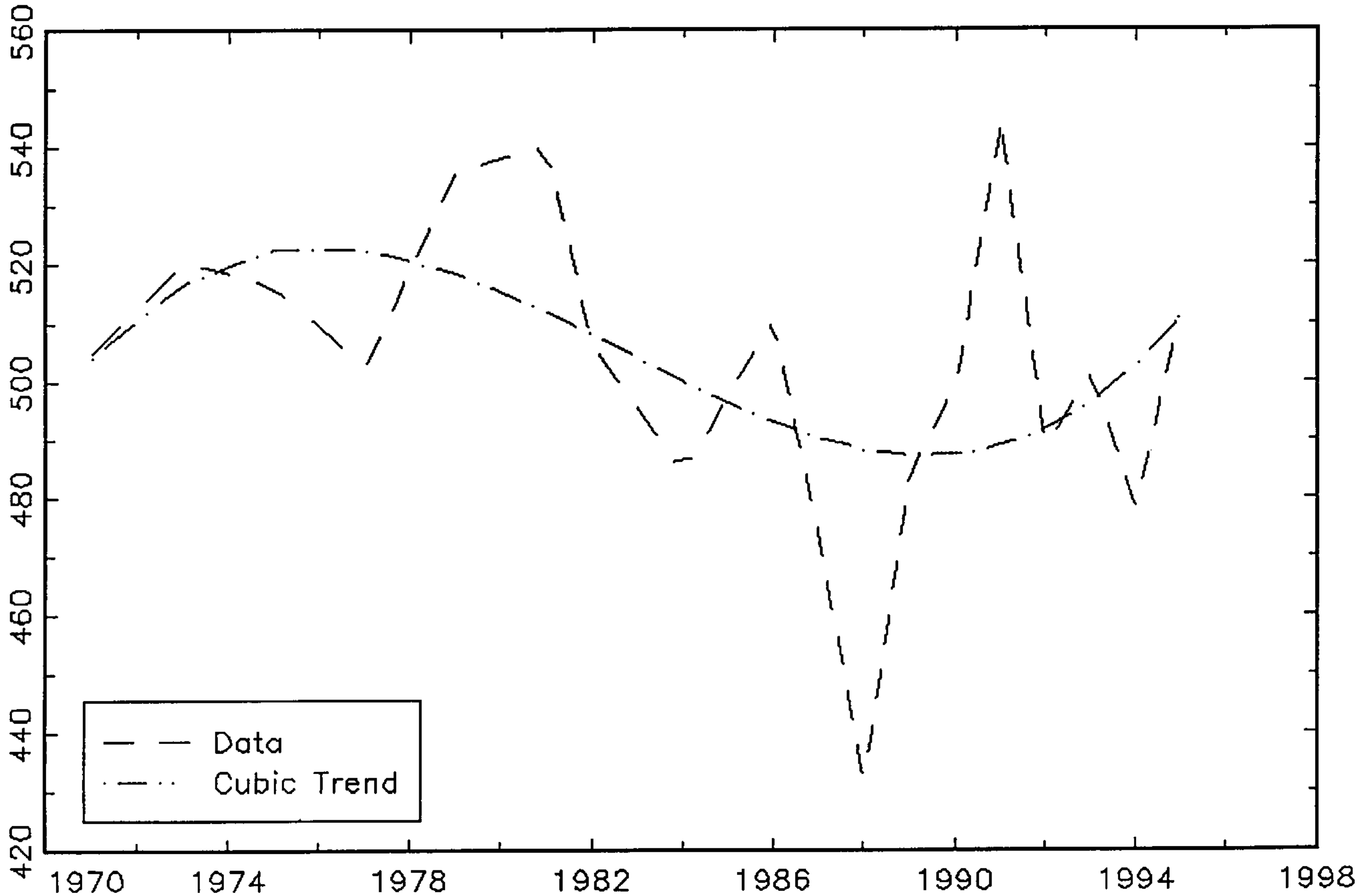

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Figure 5: Growth Patterns in US

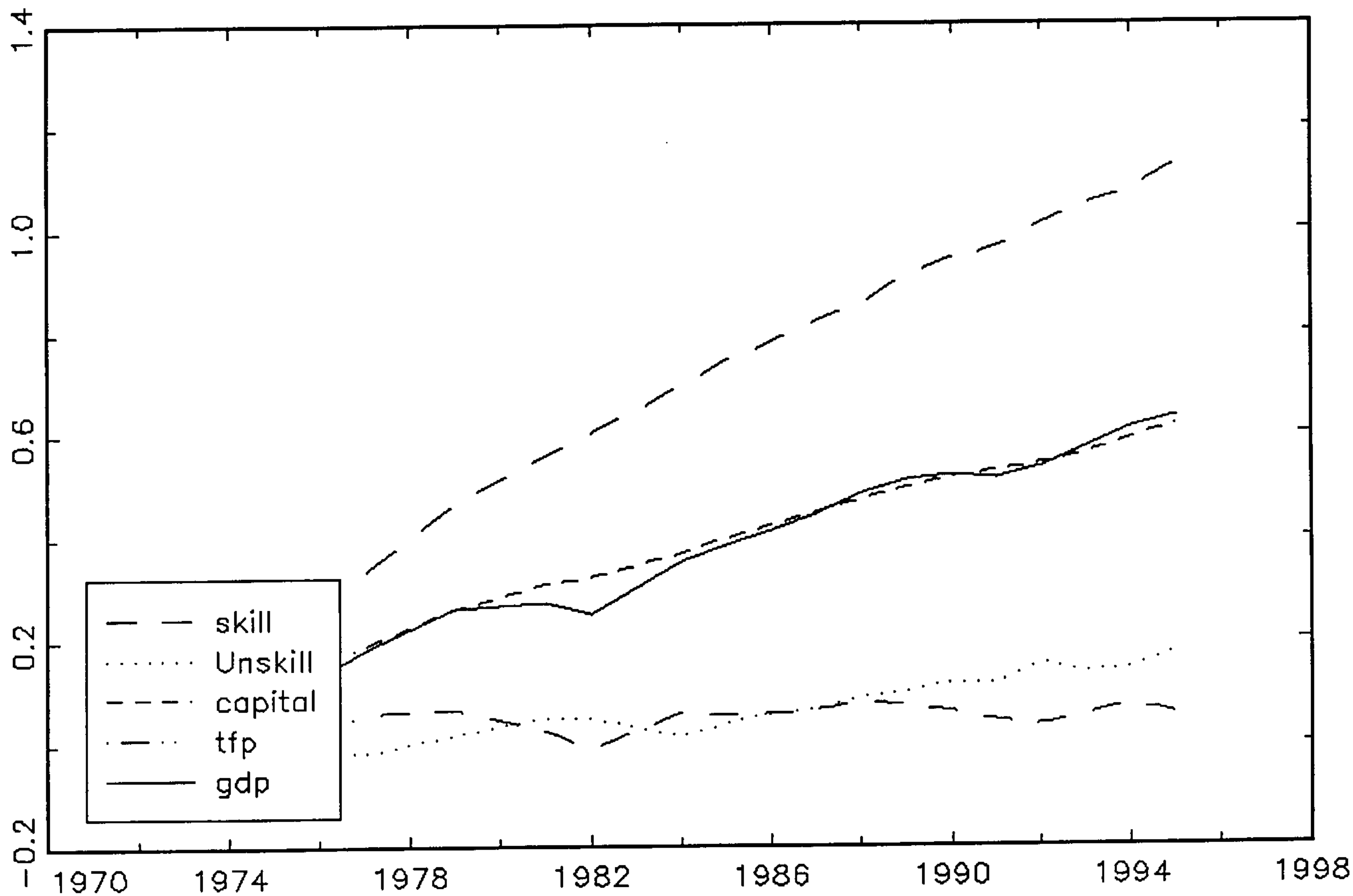

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Figure 5b. Productivity in US

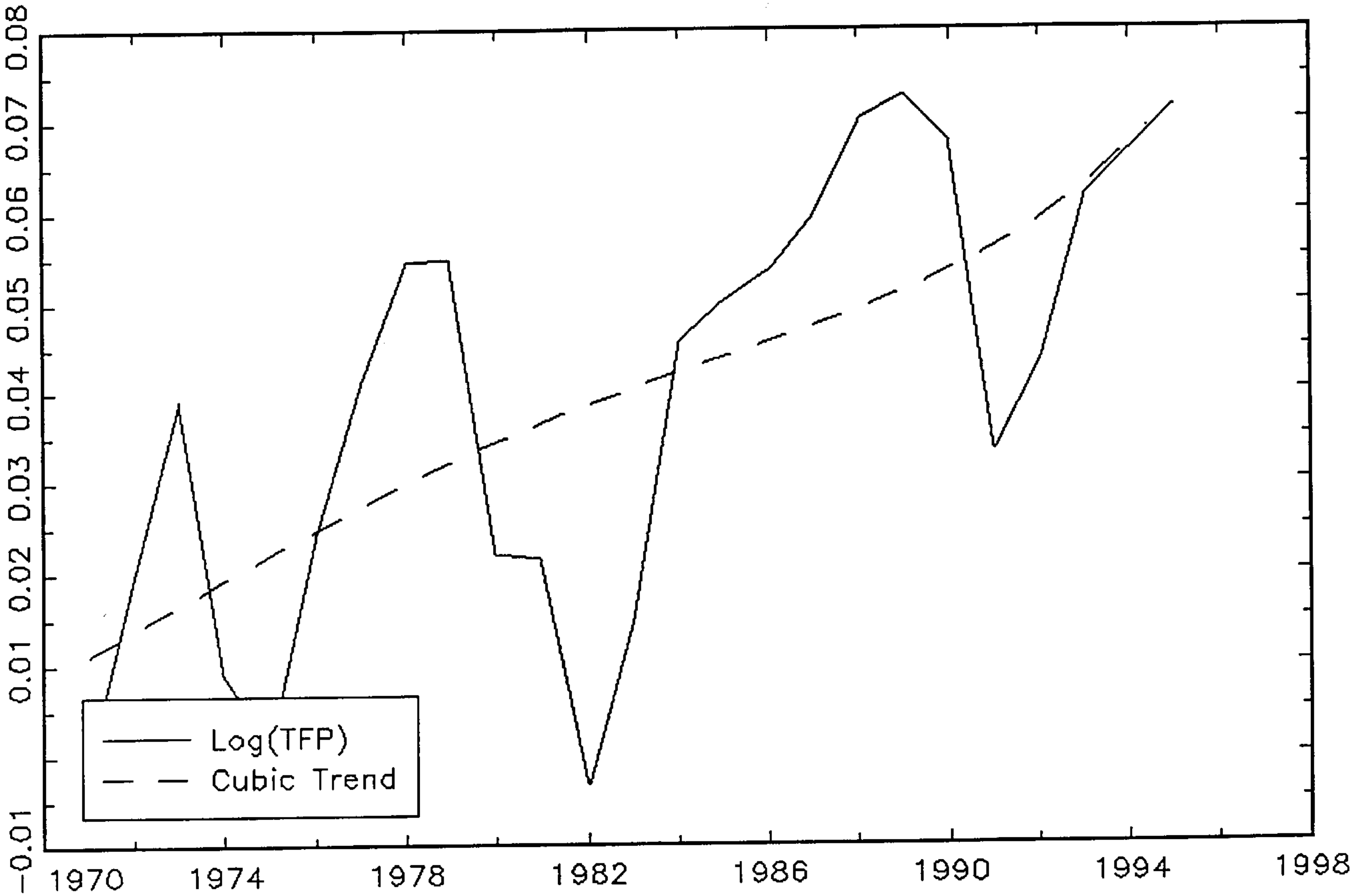

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Figure 6: Growth Patterns in Canada

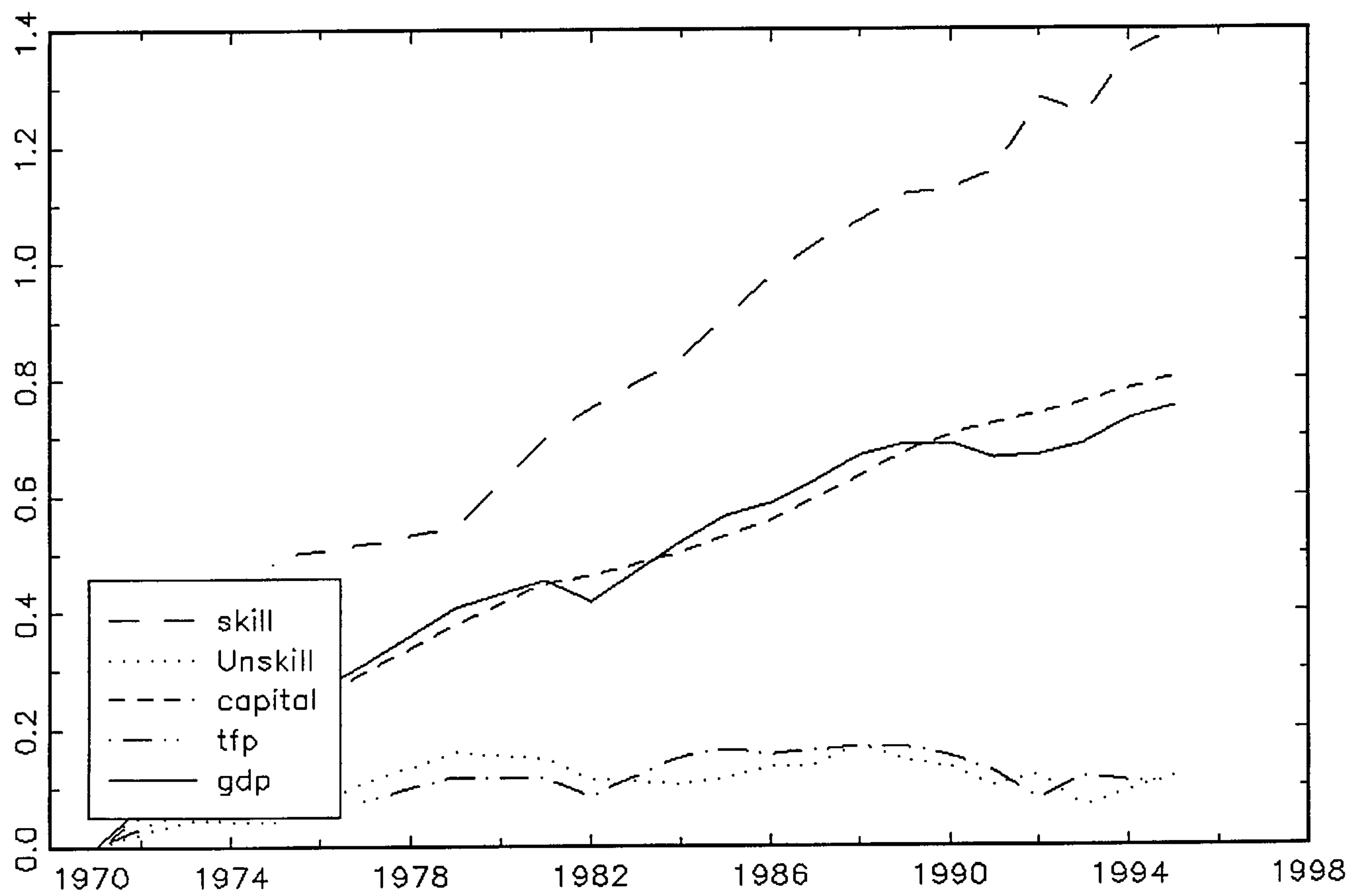

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Figure 6b. Productivity in Canada

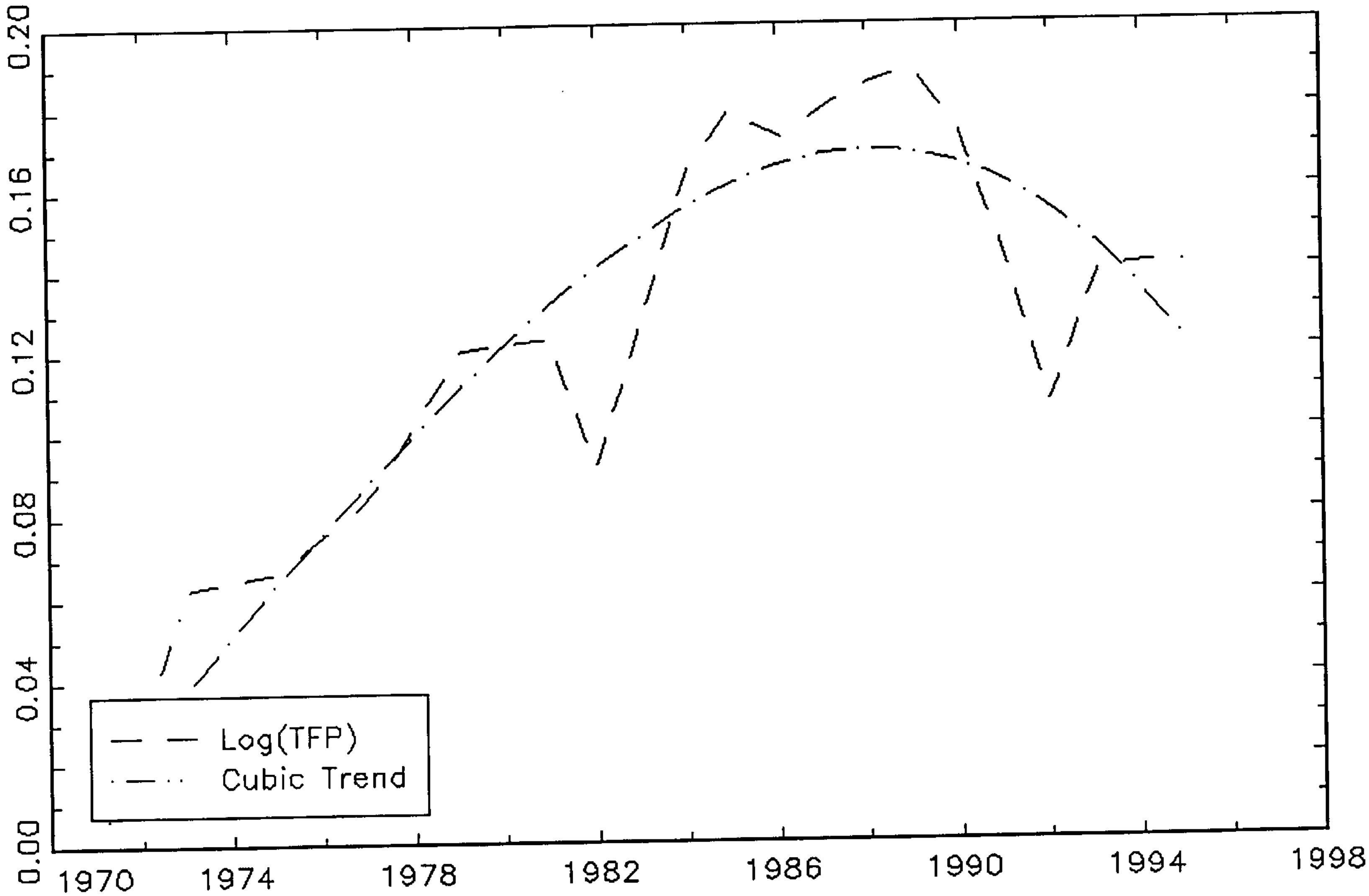

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Figure 7: Pattern of Earnings for US Experience Groups, No Post Sec

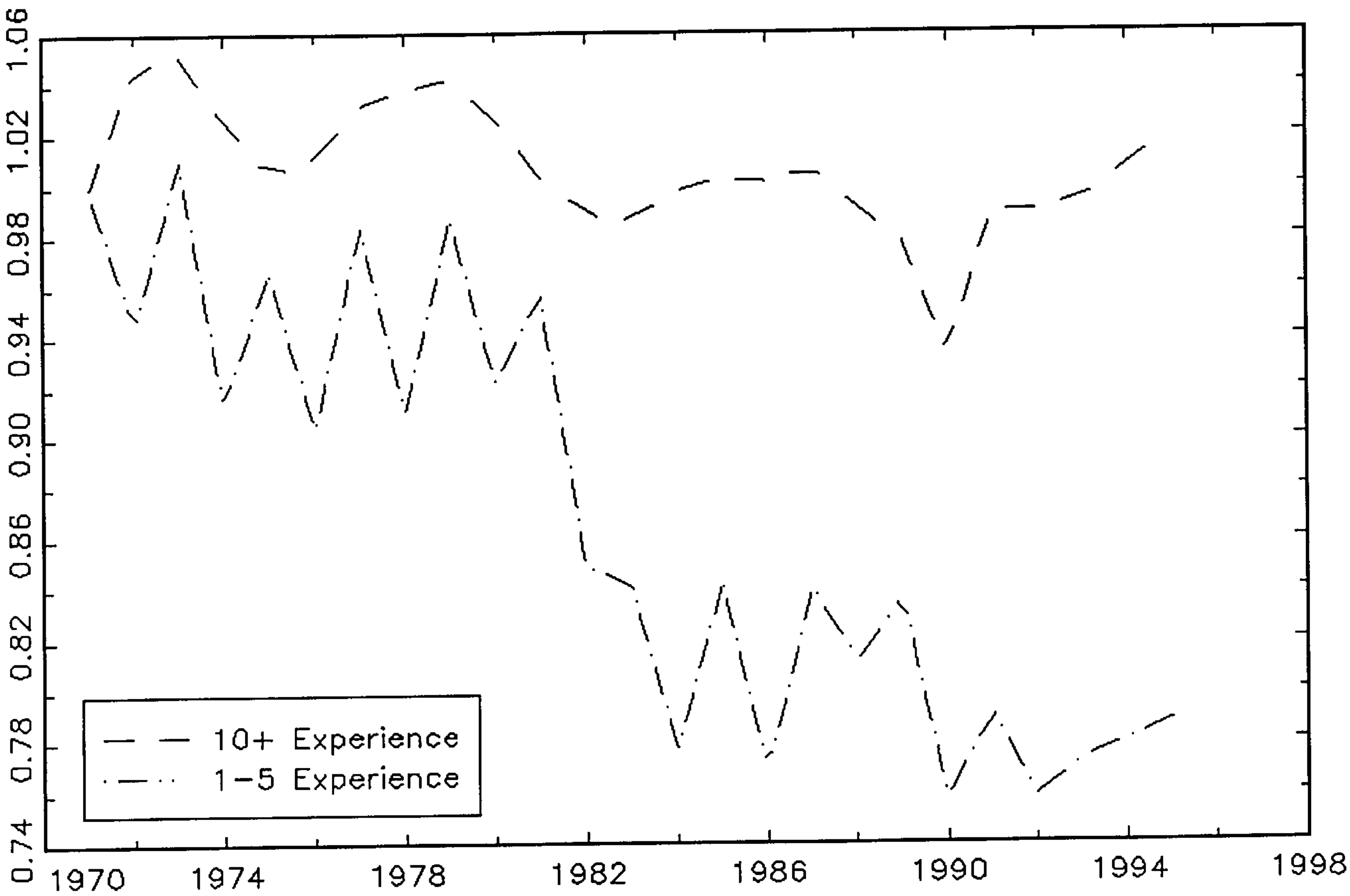

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Figure 8: Pattern of Earnings for Can. Experience Groups, No Post-Sec.

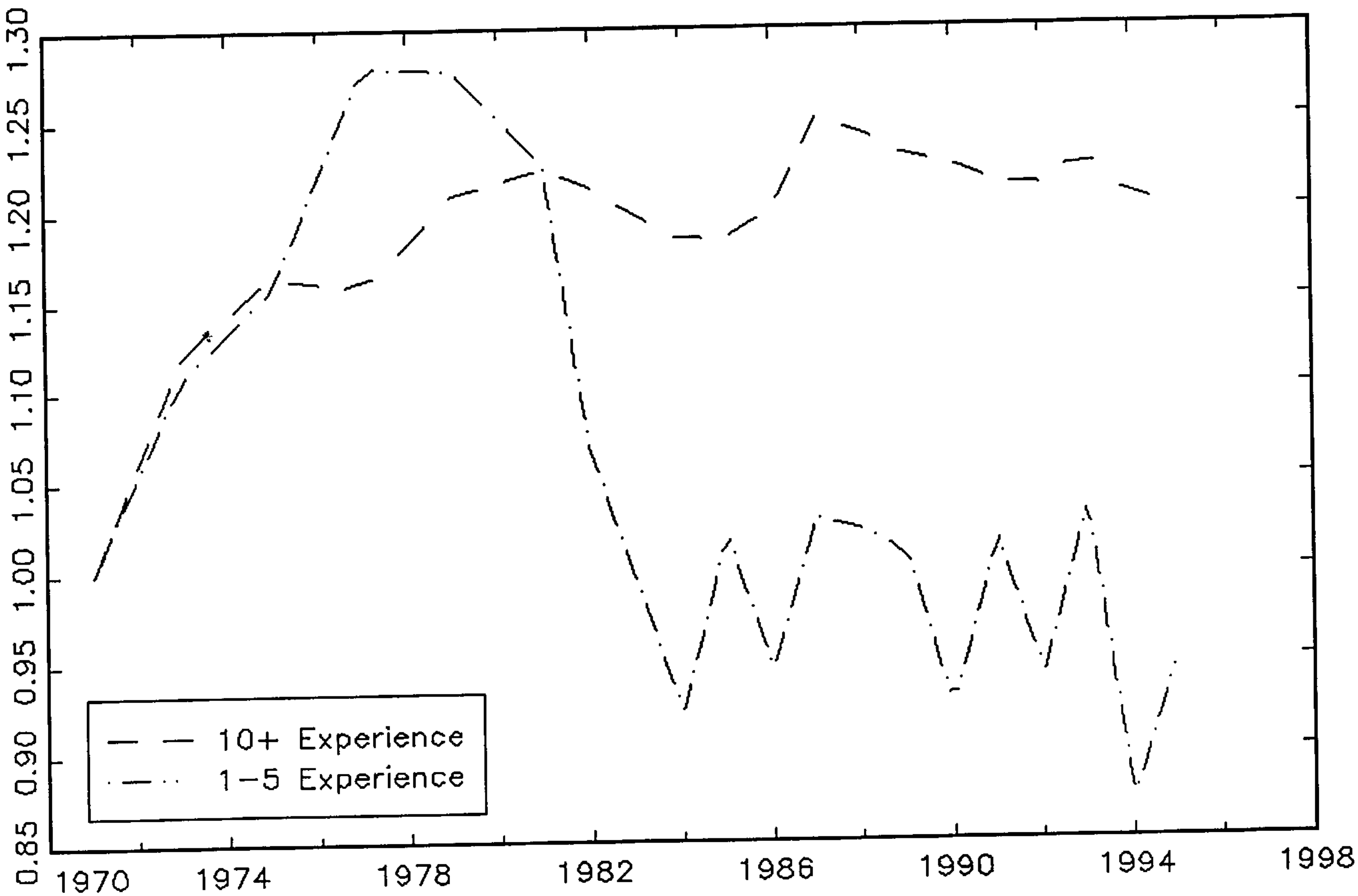

FIGURE 9

FITTED AND ACTUAL LOG WAGES, UNITED STATES

FULL YEAR/FULLL TIME MALES WITH 0-5 YEARS EXPERIENCE

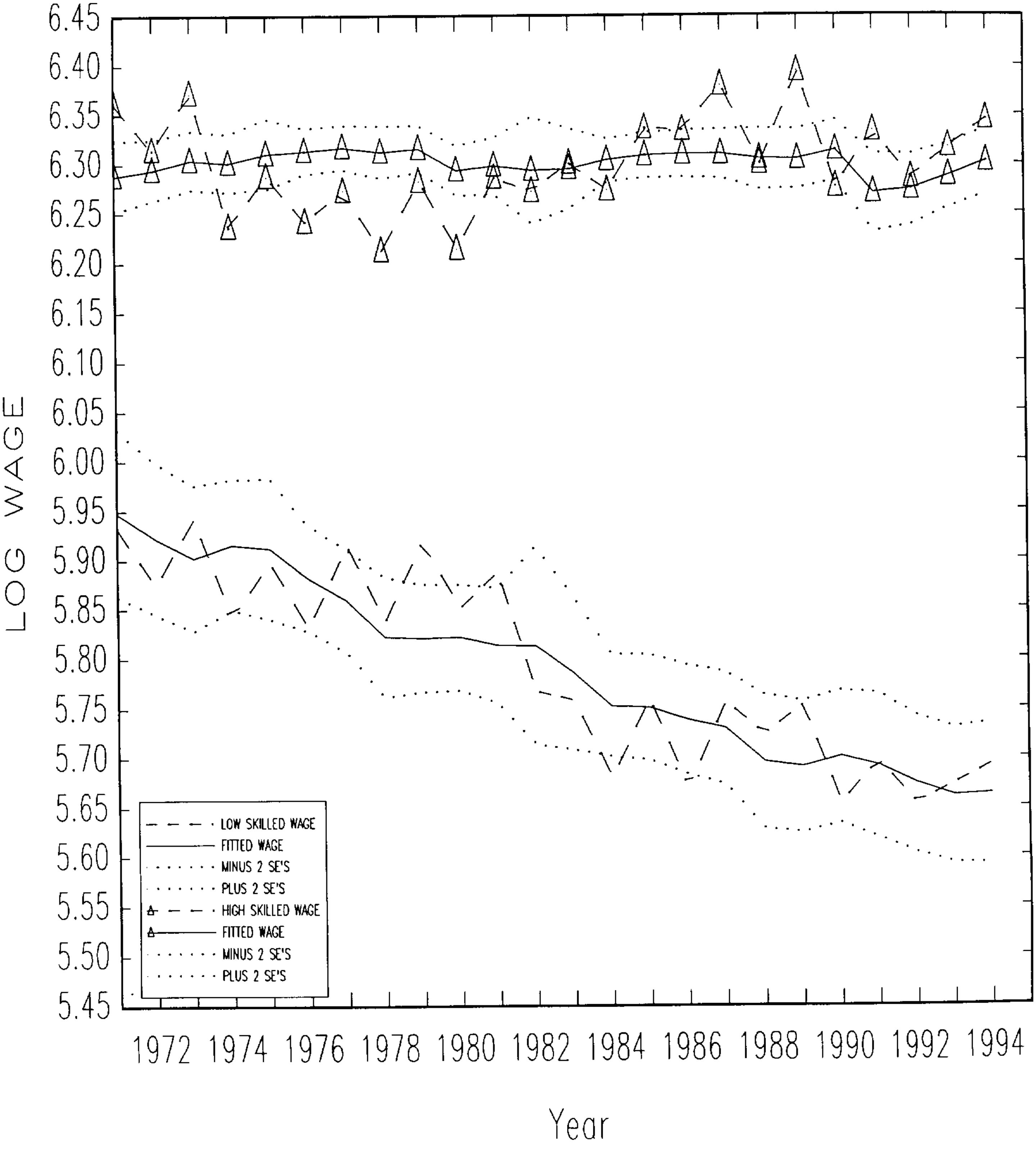

Figure 10

FITTED AND ACTUAL LOG WAGES, CANADA

FULL YEAR/FULLL TIME MALES WITH 0-5 YEARS EXPERIENCE

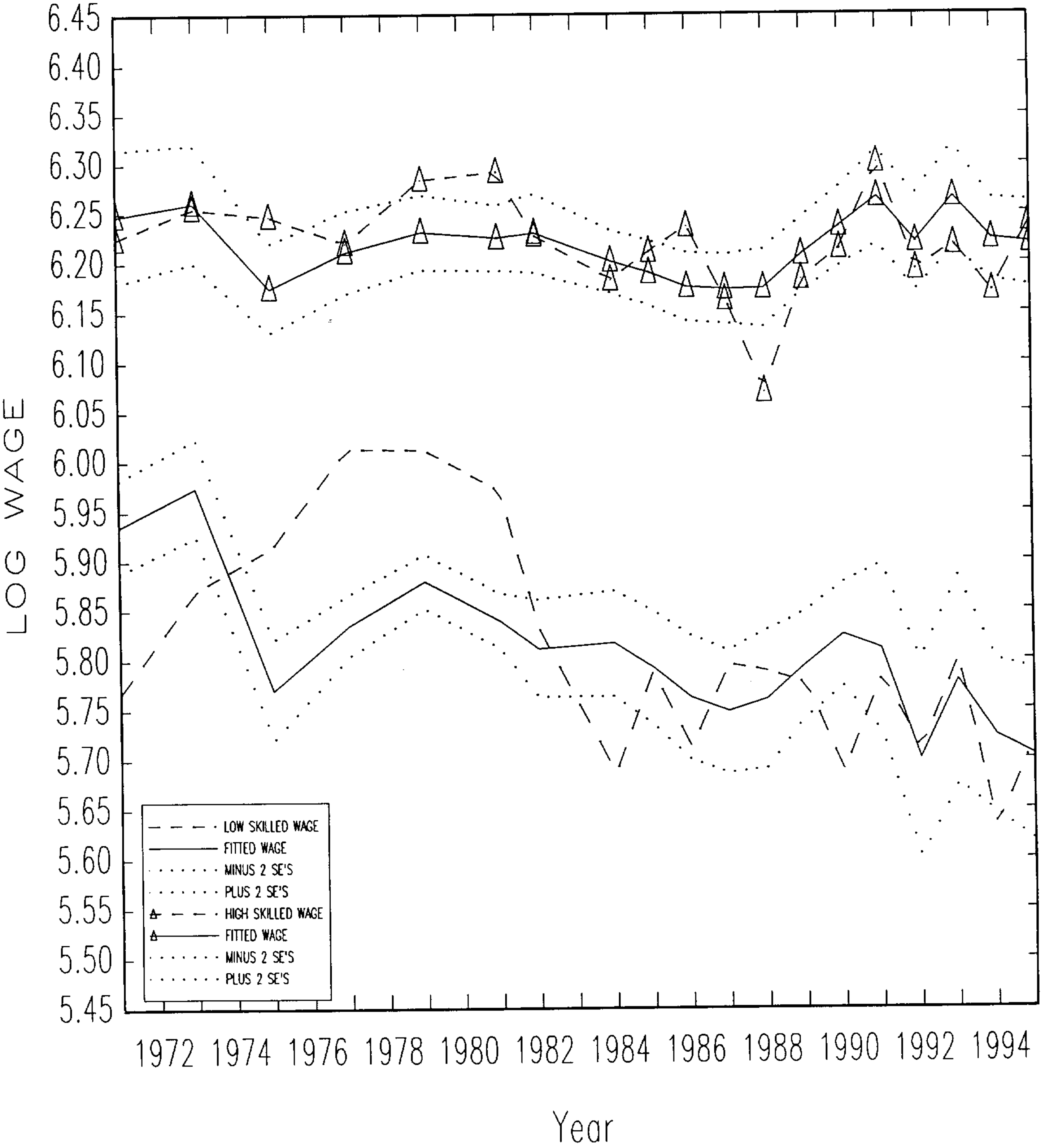

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Fig.11: Relative Weekly Earnings of US College Grads vs No Post–Sec.

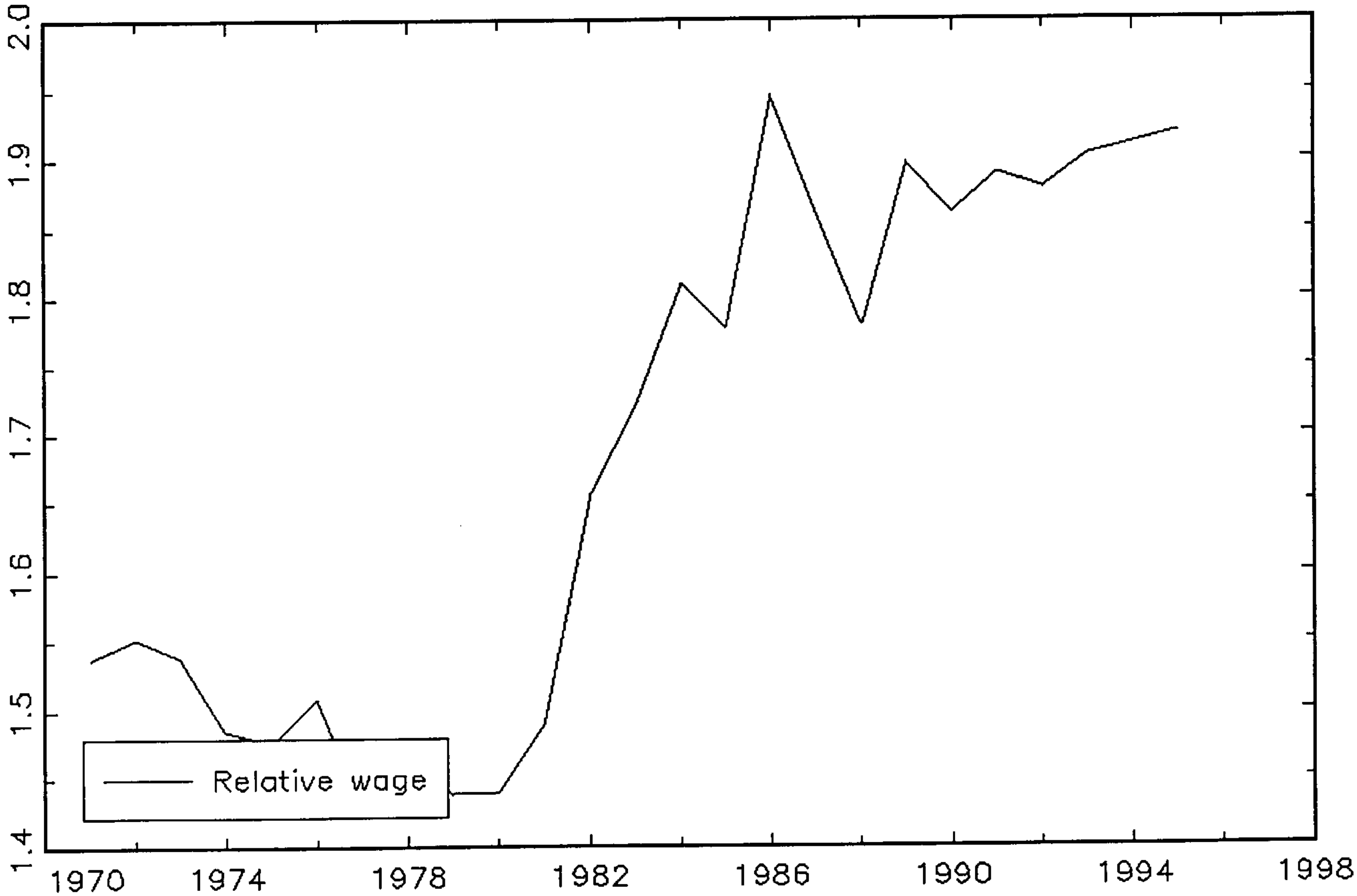

Figure 12

PROPORTION OF 25-29 YEAR OLDS WITH UNIVERSITY EDUCATION

CANADA AND THE US