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The Economic Impact of Telecommunications Diffusion on UK Productivity Growth

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ABSTRACT

This paper investigates the relationship between telecommunications infrastructure competition, investment and productivity. Using econometric modelling and input-output economics, the analysis examines and measures the extent to which telecommunications has contributed to national and sectoral productivity performance. The main findings from this paper suggests that most industries have benefited from the incorporation of advances of telecommunications technology, which might have, amongst other things, emanated from encouraging infrastructure investment, in their production processes. Thus the analysis demonstrates that U.K. government policies on telecommunications and its investment incentives may have wide-reaching consequences for not only the telecommunications industry but also the economy as a whole.

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1. Introduction

Economists have long observed concomitant trends in growth rates of publicly owned infrastructure investment and productivity and these growth rates and measures of international competitiveness e.g. Ashauer (1989), De Long, Bradford and Summers (1991, 1995). Whilst the extent of the relationship is inconclusive, most agree that infrastructure plays a positive role in total factor productivity. Furthermore, studies - see Jipp (1963), Hardy (1980), Cronin, Parker, Colleran and Gold (1991, 1993) - have found that highly developed national economies are correlated with highly developed telecommunications infrastructure. However, no study in the UK has examined and measured the extent to which telecommunications and its diffusion have contributed to productivity performance at economy-wide and sectoral levels. To do this the relationship between telecommunications infrastructure investment and a measure of economic growth is investigated, using an alternative analytical approach comprising econometric modelling and input-output economics.

Using these different techniques, (as discussed below) the main findings from the analysis in this paper suggests that, from a historical basis, most industries have benefited from the incorporation of advances in telecommunications technology, which might have, amongst other things, emanated from encouraging infrastructure investment, in their production processes. Thus this paper demonstrates that U.K. government policies on telecommunications and its investment incentives may have wide-reaching consequences for not only the telecommunications industry but also the economy as a whole.

The structure of the paper is as follows: Section 2 provides a brief outline of the main studies investigating the extent of the relationship between telecommunications infrastructure investment and economic growth. Section 3 outlines the methodology undertaken in this study for measuring the impact of telecommunications infrastructure investment on national and sectoral productivity. Section 4 discusses the data relating to Section 3. Section 5 then examines the extent of this relationship and provides an estimate of the relative impact of telecommunications infrastructure investment on national and sectoral productivity. Finally in Section 6, we conclude with a summary of the results and their public policy implications.

2. Previous Related Research

The relationship between telecommunications investment and economic development has been the topic of several studies – see Norton (1992), Greenstein and Spiller (1995, 1996), Sakurai, Papaconstantinou and Ioannidis (1997) and Röller and Waverman (2001). Most of these have assessed the effect of telecommunications investment or R&D at the macroeconomic level i.e. country- or county-level using traditional econometric analysis. This has usually consisted of a macroeconomic structural model (often with only one equation embodying some causal relation). The results of these studies generally suggest that there is a strong positive relationship between telecommunications investment and economic activity.

Such methods, although valuable, are however subject to important limitations. The results are highly dependent on the variables utilised and the model specification. The relationship between telecommunications investment and economic activity is far too complex to be captured by a single equation model with only one or a few independent variables. The large aggregation of factors involved in the variables and the aggregated nature of the data means that by definition, exercises of this type might well obscure most of the links reflecting unbalanced development in technology and productivity across sectors and countries.

Given the above, this paper will contribute to the telecommunications literature by examining and measuring the extent to which U.K telecommunications contributes to national and sectoral productivity by employing an alternative analytical approach comprising econometric modelling and input-output economics. In addition, the data that is utilised also differs substantially from other studies in that it is cross-checked against individual company accounts. This ensures that all U.K. infrastructure providers are included in the analysis.

Cronin, Colleran, Herbert and Lewitsky (Dec. 1993) have conducted some comparable work for the U.S. market using input-output economics covering the period 1963 – 1991. Their empirical findings suggest that telecommunications investment is causally related to the nation's total factor productivity and that telecommunication contributions to aggregate and sectoral productivity growth rates are both quantifiable and substantial (of the order of 21.5% for economy-wide productivity). Their study contains however no real methodological observation, so a detailed comparison with the approach employed in this paper cannot be made. It is possible to say, nonetheless, that their study covers a substantial time-span which no doubt contained large dynamic effects. These appear however not to be included in the analysis and so their study should be viewed with caution. The detail of the different approach undertaken in this paper forms the basis of discussion of the following section.

3. The Methodology For Measuring The Impact Of Telecommunications Investment On National And Sectoral Productivity

There is considerable evidence that improvements in performance associated with technological progress could result not only from within industry progress but also from external industry progress which is embodied in intermediate goods purchased by sectors (e.g. Schmookler 1966, Scherer 1982). Given the need to study linkages between the telecommunications sector and other economic sectors, it was decided that use should be made of inter-industry data series or inter-industry social accounting matrices. The disaggregation of the production account within the social accounting matrix is of particular importance for our analysis as it provides us with a direct means to ascertain the link between industrial sectors and commodity accounts and therefore enables us to assess how sectors have changed their production techniques over time. It also ensures that the indirect effects of technical advance, through the provision of cheaper inputs to other industries, are incorporated in the study[1].

The basic method employed involves trying to measure the relative impact on productivity of telecommunications infrastructure investment. To do this analysis, we use the counterfactual of what would happen had telecommunications infrastructure investment during the period 1991 – 1996 not occurred. This approach maximises transparency in the links between the variables and allows us to investigate which industries have benefited the most from telecommunications because we calculate the impact of telecommunications infrastructure investment on both a sectoral and economy-wide basis.

To compute an estimate of the economic impact of telecommunications investment, a measure of actual productivity is formulated (see sub-section 3.1) and then compared with a measure of hypothetical productivity where telecommunications technology has been constrained to a period 0 level (see sub-section 3.2). This hypothetical productivity measure, which is described in more detail below, starts off with the use of a price model derived from the primal input-output model. This is used to compute the intermediate good price effect of constraining telecommunications technology to a period 0 level. Using a model such as this, in which all coefficients are constant, to calculate a hypothetical productivity measure, is valid, however, only if all price changes are accepted without substitution. In practice, we know that producers react to changes in relative prices by substituting some inputs for others. Price

1. This is important for the analysis as it allows us to separate the movements along

elasticities of demand thus need to be estimated and employed in deriving the hypothetical productivity measure.

Within the framework of inter-industry economics, the Peterson Index of Direct and Indirect Productivity Gains $(d\log v)$ and $(d\log V)$ was chosen as the measure of productivity to be used in the analysis (Peterson, 1979). Using standard input-output techniques (Miller and Blair, 1995), this index measures for a given time period the movement in direct and indirect inputs required by each industry so that the economy can produce its actual level and mix of GDP in the last year of the time period. Direct inputs are those purchases that an industry makes in order to produce its goods and services. Indirect inputs, in contrast, are those purchases that are required by an industry's suppliers, suppliers' suppliers, and so on, in order that they can satisfy the production needs of an industry/supplier.

3.1 ACTUAL ECONOMY PRODUCTIVITY GAINS

In this sub-section, a formal algebraic statement of the theoretical basis for the estimates reported in this paper is provided. The first part outlines the theory underpinning the derivation of the conventional economy and within-industry productivity growth measures from input-output databases. The second part then proceeds to set out the relationship between the economy and conventional within-industry productivity growth rates and gains in the efficiency with which commodities are delivered to final demand i.e. the Peterson Index of Direct and Indirect Productivity Gains. Both these parts are derived, however, under the assumption that time can be treated as a continuous variable whereas in reality, data is available only for discrete time periods. Given this, the third part thus identifies the discrete time equivalent used to estimate rates of economy and within-industry productivity growth.

the production function from the shifts in the production function.

3.1.1 CONVENTIONAL MEASURES OF PRODUCTIVITY GROWTH IN AN INPUT-OUTPUT SYSTEM

The standard Leontief input-output system for a closed economy can be expressed by a three equation system. Gross outputs depend on intermediate inputs (AX) and final demands (Y) such that:

$$X = AX + Y$$
or (1)
$$X = [I - A]^{-1} Y$$

Primary input requirements depend on gross outputs:

$$Z = BX \qquad (2)$$

and prices depend on intermediate and primary input payments:

$$p' = p'A + w'B = w'B[I - A]^{-1} \qquad (3)$$

where X = n-vector of gross outputs;
Y = n-vector of final demands,
Z = m-vector of primary inputs;
A = $[a_{ij}]$ = (n x n) matrix of inter-industry technical coefficients;
B = $[b_{jk}]$ = (m x n) matrix of primary technical coefficients;
p = n-vector of output prices;
w = m-vector of primary input prices.

Total factor productivity is defined as the change in final output per unit of combined labour, capital and material inputs. Growth in total factor productivity implies that a given level of output can be produced with a smaller quantity of inputs or that a given amount of inputs can produce a greater quantity of output.

Within the input-output framework, the Hicksian rate of growth of total factor productivity for the economy can be measured as a weighted net reduction in input-output coefficients where prices are given constants (see Peterson, 1979):

$$d\log T = -(p'Y)^{-1}[p'dA + w'dB]X \tag{4}$$

This is equivalent to the conventional growth accounting definition of total factor productivity as a ratio of Divisia indices (see Jorgenson and Grilliches, 1967) and is a continuous time analogue of Leontief's index of structural change (See below).

Likewise, the conventional Hicksian measure of productivity growth for the kth industry can be written in terms of changes in input-output coefficients, at given prices, as:

$$d\log t_k = -\left[\sum_i^n p_i da_{ik} + \sum_j^m w_j db_{jk}\right] p_k^{-1} \tag{5}$$

where $d\log t_k$ is the efficiency gain for the kth industry. Technical change in an input-output framework manifests itself through changes in the technical coefficients over time. Unambiguous technical progress thus requires da_{ik}, db_{jk} ≤ 0 for all i; strict Hicksian neutral technical change requires da_{ik}, db_{jk} $= c$ for all i; and a necessary condition for technical progress is da_{ik}, db_{jk} < 0 for some i. In reality, however, simultaneous input substitution means that da_{ik}, db_{jk} > 0 for some i, and therefore a sufficient condition for technical progress is that a weighted average of the changes in the technical coefficients is negative.

In conducting a multi-sectoral analysis, a potentially desirable feature is that a suitable weighted sum of the industry total factor productivity estimates equates with the economy-wide estimate. Aggregation of industry level estimates in (5) so as to achieve consistency with the overall estimate in (4) requires the weighting of the industry estimates by the ratio of industry gross output to total final demand. Specifically:

$$d\log T = \sum_k^n \left(\frac{p_k x_k}{p'Y}\right) d\log t_k \tag{6}$$

Noticeably the weights in (6) sum to a total greater than one. The explanation of this (Domar 1961) is that within-industry productivity growth facilitates an increase in the efficiency with which products are delivered to both final demand and intermediate demand. Thus it is possible to define the contribution of each industry to overall productivity growth as:

$$d\log\tilde{t}_k = \left(\frac{x_k}{y_k}\right) d\log t_k \tag{7}$$

and using (7), overall productivity growth can then be defined as the final demand share weighted sum of the industry contributions:

$$d\log T = \sum_k^n \left(\frac{p_k y_k}{p'Y}\right) d\log\tilde{t}_k \tag{8}$$

3.1.2 THE PETERSON INDEX OF DIRECT AND INDIRECT PRODUCTIVITY GAINS AND ITS RELATIONSHIP WITH THE ECONOMY AND CONVENTIONAL WITHIN-INDUSTRY PRODUCTIVITY GROWTH RATES

As Peterson (1979) has shown the conventional within-industry measures as outlined above, do not distinguish between productivity growth as it affects deliveries to final demand and productivity growth as it affects deliveries to intermediate demand[2]. Peterson (1979) therefore established an alternative measure of productivity growth by redefining the underlying technology of the

2. The importance of the insights this can provide should not be underestimated. The literature on productivity growth has highlighted the importance of distinguishing between productivity growth originating within an industry and the impact of productivity upon an industry (e.g. Hulten 1978). The *within* sector element seeks to identify and quantify the change in the quantities of inputs required by an industry to produce a unit of output while the *upon* a sector element seeks to identify and quantify the effects of efficiency changes in the various intermediate input industries. In terms of a cost dual, the objective is therefore to distinguish between the unit cost reducing contributions of a technological change that reduces the physical quantities of inputs required (and thereby the cost reductions at constant prices) and the effects of input price reductions arising from changing efficiency in the intermediate input industries.

input-output system in terms of vertically integrated sectors (VIS). This means that, in effect, each sector produces only final output, making use only of primary inputs to do so.

Using the three equation system outlined above (equations 1 – 3), we obtain:

$$Z = B[I - A]^{-1} Y = MY \qquad (9)$$

$$p' = w'B[I - A]^{-1} = w'M \qquad (10)$$

Equation (9) is obtained by substituting for X in $Z = BX$ from $X = [I - A]^{-1} Y$ and M is a (m x n) matrix defined as $M = B[I - A]^{-1}$. The elements m_{jk} of the matrix M refer to the average quantity of primary input j employed directly and indirectly in the production of a unit of output from sector k.

Starting from the social accounting identity and employing the growth accounting methodology, Peterson (1979) derived a vertically integrated estimate of total factor productivity for the economy $(d \log V)$ equivalent to the expression derived from the conventional input-output framework in (4)[3] and an expression for sectoral efficiency gain $(d \log v_k)$:

$$d \log V = -(p'Y)^{-1} [w'dMY] \qquad (11)$$

$$d \log v_k = -\left[\sum_{j}^{m} w_j dm_{jk} \right] p_k^{-1} \qquad (12)$$

Thus, a necessary, but not sufficient condition for a change in total factor

3. We can show that (11) is equivalent to (4) by using M=B[I-A]$^{-1}$. Totally differentiating the matrix M, dM = dB[I-A]$^{-1}$+B[I-A]$^{-1}$dA[I-A]$^{-1}$ = [dB+MdA][I-A]$^{-1}$. Inserting this expression for dM in the numerator of equation (11), w'dMY =[w'dB+ w'MdA][I-A]$^{-1}$Y =[w'dB+ p'dA]X which is the same as the numerator in (4).

productivity growth is a change in the coefficients matrix M which results from changes in A and B.

An aggregation of industry level estimates in (12) so as to achieve consistency with the overall estimate in (11) and (4) then requires the weighting of the industry estimates by the ratio of industry final demand to total final demand. Specifically:

$$d\log V = d\log T = \sum_{j}^{m}\left(\frac{p_k y_k}{p'Y}\right) d\log v_k \tag{13}$$

We note that $d\log v_k$ can be derived from the conventional within-industry measures as simple substitution demonstrates. Inserting for dm in (12) using the details of footnote (3) gives[4,5]:

$$v' = t'\hat{p}[I-A]^{-1}\hat{p}^{-1} \tag{14}$$

where a carat indicates a vector transformed into a square matrix, the elements of the vector being placed on the principal diagonal, v is a vector of elements $d\log v_k$ and t is a vector of elements $d\log t_k$.

4 It should be noted that this expression is different from that given by Peterson (1979). In his paper, the expression provided for the relationship between the conventional within-industry productivity growth rate and the VIS productivity growth rate was: $v' = t'[I-A]^{-1}$. Operationally, the difference in the two expressions is unimportant because when evaluated at or close to base prices $\hat{p}\ \hat{p}^{-1}$ essentially becomes equivalent to an identity matrix.

5. Ignoring $\hat{p}$ and $\hat{p}^{-1}$ for simplicity purposes, equation (14) can also be written as *d*log*v* = *d*log*t* + ?aik.*d*log*v* - aik is the i, k element of the inter-industry matrix. The interpretation of this expression is that the efficiency with which the k[th] Vertically Integrated Sector delivers products to final demand is the sum of the weighted reduction in inputs per unit of output arising from productivity growth generated *within* the k[th] Vertically Integrated Sector plus the weighted sum of the total Vertically Integrated Sector efficiency gains transmitted to the k[th] Vertically Integrated Sector through the intermediate inputs.

3.1.3 LEONTIEF INDEX OF STRUCTURAL CHANGE

Now as discussed above, the measures $d\log t$ and $d\log T$ are a continuous time analogue of the Leontief index of structural change. Given the fact that data is available only for discrete time periods, the Leontief index is therefore required to estimate within-industry and economy-wide productivity growth and from this, we can then calculate the Peterson Index of Direct and Indirect Productivity Gains.

As outlined above, technical change in an input-output framework manifests itself through changes in some or all of the technical coefficients over time, and this is the focus of attention in the Leontief index. Following Leontief (1953, pp27-28), and the clarification provided by Domar (1961, p727), the proportionate change in the coefficient for an input i to industry k in discrete time can be defined as:

$$\hat{\alpha}_{ik} = \frac{\left(\alpha_{ik}^{1} - \alpha_{ik}^{0}\right)}{\left(\alpha_{ik}^{1} + \alpha_{ik}^{0}\right)/2} \tag{15}$$

where the superscripts refer to time periods and the technical coefficients α_{ik} refer to <u>both</u> intermediate and primary inputs. To determine the net effect of technical changes on the kth industry, Leontief uses the standard index number principle of weighting inputs according to their relative importance. More specifically, Leontief (1953 pp28) measured relative importance by the '...total values (prices times quantities) of the inputs'. Thus the discrete time weights, $\hat{\upsilon}_{ik}$ can be expressed as:

$$\hat{\upsilon}_{ik} = \frac{\left[\left(\upsilon_{ik}^{1} + \upsilon_{ik}^{0}\right)/2\right]}{\sum_{i}^{m+n}\left[\left(\upsilon_{ik}^{1} + \upsilon_{ik}^{0}\right)/2\right]} \tag{16}$$

where the elements are input value shares and the superscripts identify time periods. Estimation of the Leontief index for the kth industry which is the discrete time equivalent to (5) thus involves the following calculation:

$$LI_k = \sum_i^{m+n} \hat{v}_{ik}\hat{\alpha}_{ik} \tag{17}$$

and weighting the industry estimates (17), as discussed above in (6), and as proved by Domar (1961), by the ratio of industry gross output to total final demand gives the overall economy efficiency gain which is the discrete time equivalent of (4):

$$LI = \sum_k^n \left(\frac{p_k x_k}{p'Y} \right) LI_k \tag{18}$$

Using equations (17) and (18), within-industry and economy-wide productivity growth estimates can thus be derived and then from these estimates, the Peterson index of actual direct and indirect productivity gains can be obtained using equations (13) and (14) above.

3.2 HYPOTHETICAL ECONOMY PRODUCTIVITY GAINS

Once actual direct and indirect productivity gains have been quantified, equations (13) and (14) for a hypothetical economy in which telecommunications technology has been constrained to a certain time period can then be calculated. This latter computation involves three stages of analysis. These are described in more detail below.

Very briefly, using the notation given previously, the basic methodology for calculating efficiency gains for a hypothetical economy involves constructing hypothetical factor input matrices (M). In what follows, the term 'technology' refers to the production frontier whilst the term 'technique' refers to the input-output coefficients chosen by the VIS so as to optimise for given prices. Starting with actual inputs in period 1, we can write:

$$M_1 = M(p_1, T_1^{All}, T_1^{Tel}) \tag{19}$$

Equation (19) states that actual M is a function of actual prices (p), actual technology of all industries except telecommunications (T^{All}) and actual telecommunications technology (T^{Tel}). The subscripts identify time periods. Similarly, actual prices:

$$p_1 = p(M_1) \tag{20}$$

are a function of the actual factor input matrix (M_1). Equation (21) then gives us our equilibrium hypothetical factor input matrix (a carat (^) refers to the hypothetical situation and the subscript ($_e$) indicates that this is an equilibrium state):

$$\hat{M}_{1,e} = M(\hat{p}_{1,e}, T_1^{All}, T_0^{Tel}) \tag{21}$$

in which T^{Tel} is constrained to period 0 and allowance is made for consequential changes so as to reach an equilibrium in prices:

$$\text{where } \hat{p}_{1,e} = p(\hat{M}_{1,e}) \tag{22}$$

To arrive at this equilibrium solution, we first replace the actual period 1 telecommunications technique (A_1^{Tel}, B_1^{Tel}) with the period 0 telecommunications technique (A_0^{Tel}, B_0^{Tel}) where (A^{Tel}, B^{Tel}) denote the intermediate and primary coefficients for the telecommunications industry. This gives:

$$M_1^0 = B_1^0\left[I - A_1^0\right]^{-1} \quad \text{where} \quad B_1^0 = \begin{vmatrix} B_1^{All} \\ B_0^{Tel} \end{vmatrix} \quad \text{and} \quad A_1^0 = \begin{vmatrix} A_1^{All,All} & A_0^{All,Tel} \\ A_1^{Tel,All} & A_0^{Tel,Tel} \end{vmatrix} \tag{23}$$

There is however now an inconsistency between prices and inputs because the telecommunications industry is making its decisions given (p_0) whilst other industries are making their decisions given (p_1). Compromised prices will therefore arise such that:

$$p_1^0 = p(M_1^0) \tag{24}$$

Equation (24) tells us how the output prices of all industries (comprising the telecommunications and other sectors) would have been affected had telecommunications techniques and technology been constrained to period 0.

These equations do not however tell us how industry techniques would have evolved between period 0 and period 1 had telecommunications technology been constrained to period 0 levels. Had telecommunications technology been held fixed in period 0, techniques during the transition stage to period 1 (due to differences in prices) would have evolved differently (from actual reality) for fixed period 1 final demands. To obtain these modified industry techniques, we must therefore start from the industry input mixes expressed in (23) and adjust them to what they would be, had telecommunications technology been at (T_0^{Tel}) and prices been at (p_1^0). To do this, we use price elasticities of demand and prices (p_0), (p_1) and (p_1^0) such that for all sectors except telecommunications:

$$\hat{A}_1^{;All} = A_1^{;All} + \frac{\partial A_1^{;All}}{\partial p}\left(p_1^0 - p_1\right), \qquad \hat{B}_1^{All} = B_1^{All} + \frac{\partial B_1^{All}}{\partial p}\left(p_1^0 - p_1\right) \tag{25}$$

and for the telecommunications sector:

$$\hat{A}_0^{;Tel} = A_0^{;Tel} + \frac{\partial A_0^{;Tel}}{\partial p}\left(p_1^0 - p_0\right), \qquad \hat{B}_0^{Tel} = B_0^{Tel} + \frac{\partial B_0^{Tel}}{\partial p}\left(p_1^0 - p_0\right) \tag{26}$$

These calculations ensure that all industries (comprising telecommunications and others) are facing prices (p_1^0) and technologies (T_0^{Tel}) and (T_1^{All}). In equations (25) and (26), $\frac{\partial A}{\partial p}$ and $\frac{\partial B}{\partial p}$ can be interpreted in terms of the relevant elasticities of demand applicable for each industry. Applying this adjustment to all sectors gives:

$$\hat{M}_1 = M(\hat{p}_1, T_1^{All}, T_0^{Tel}) \quad (27)$$

The adjustment in techniques in response to (p_1^0) will however result in a new set of prices $(\hat{p}_1)$:

$$\text{where } \hat{p}_1 = p(\hat{M}_1) \quad (28)$$

Simultaneous input substitution will therefore result in all industries for given period 1 final outputs. To incorporate these effects, input mixes for all sectors will thus again need to be adjusted for the new prices $(\hat{p}_1)$ i.e. $\hat{\hat{M}}_1 = \hat{M}_1 + \partial\hat{M}_1/\partial p\,(\hat{p}_1 - p_1^0)$

Repeating this adjustment process until prices have stabilised and $\Delta p \approx 0$ eventually gives the equilibrium equations (21) and (22).

In light of the basic methodology outlined above, the first stage below, gives the methodology for calculating prices from the primal input-output model and specifically sets out the method for computing p_1 and p_1^0. The second stage then proceeds to detail the method undertaken in the analysis to estimate price elasticities of demand i.e $\partial M/\partial p$. Finally, the third stage outlines in more detail the adjustment process undertaken so that the hypothetical input-output matrices and $\hat{p}_{1,e}$, $\hat{M}_{1,e}$ can be calculated.

3.2.1 FIRST STAGE

Imposing the condition that the value of total sectoral purchases for inter-industry inputs plus total payments for primary factors is equal to the value of sales of sectoral output gives equation (29). It should be noted that this is equivalent to previous equations (3) and (10), discussed above:

$$p = A'p + B'w = [I - A']^{-1} B'w = M'w \qquad (29)$$

Equation (29) states that the price received per unit of output must equal the inter-industry purchases of inputs required for the production of a unit of output plus the primary factor payment per unit of sectoral output.

To conduct an analysis of technical change, the equations expressed in (30) are then used to obtain a vector of prices (p_1) and (p_0) for the actual economy for the periods under analysis[6] i.e. periods 1 and 0.

$$\begin{aligned} p(M_1) &= p_1 = M_1' w_1 \\ p(M_0) &= p_0 = M_0' w_0 \end{aligned} \qquad (30)$$

Taking the input-output table for period 1, the input coefficients comprising technical and primary coefficients for the telecommunications sector are replaced by the period 0 coefficients. M_1^0 thus represents a matrix of technical coefficients in which period 1 telecommunications inputs have been replaced by period 0 telecommunications inputs i.e. A_1^{Tel} and B_1^{Tel} are replaced by A_0^{Tel} and B_0^{Tel}. This gives:

$$p(M_1^0) = p_1^0 = M_1'^0 w_1^0 \qquad (31)$$

The calculation of (31) and a comparison with the equations expressed in (30) - as per the basic methodology above - gives the proportional difference in sectoral prices (hereafter referred to as ($p_1^0 - p_1$) for all sectors excluding telecommunications and ($p_1^0 - p_0$) for the telecommunications sector) had telecommunications technology been constrained to period 0 levels whilst all other industries production processes and technologies advanced at their actual historical rates.

6. It should be noted that the prices implied by the input-output tables do not necessarily refer to the price indices used in the analysis.

3.2.2 SECOND STAGE

Having derived the price differentials as outlined above, the second stage then involves the estimation of price elasticities of demand i.e. $\partial M / \partial p$ hereafter referred to as (ε). There are several ways that this can be done but in the present analysis, use was made of the Cobb-Douglas cost function[7]. It is normally specified as:

$$C = Kp_i^{\alpha_i} p_j^{\alpha_j} p_k^{\alpha_k} Y \qquad (32)$$

where p_i, p_j and p_k are input prices, α_i, α_j and α_k represent the value shares of inputs (X_i, X_j, X_k) in the value of output and Y is output and is given by the expression: $Y = AX_i^{\alpha_i} X_j^{\alpha_j} X_k^{\alpha_k}$. A convenient feature of this specification is that price elasticities of demand are equal to:

$$\begin{array}{lll} \varepsilon_{ii} = \alpha_i - 1, & \varepsilon_{ji} = \alpha_i, & \varepsilon_{ki} = \alpha_i \\ \varepsilon_{ij} = \alpha_j, & \varepsilon_{jj} = \alpha_j - 1 & \varepsilon_{kj} = \alpha_j \\ \varepsilon_{ik} = \alpha_k, & \varepsilon_{jk} = \alpha_k & \varepsilon_{kk} = \alpha_k - 1 \end{array} \qquad (33)$$

which are just the value shares of inputs in the value of outputs. These can thus be directly obtained from the input-output tables.

3.2.3 THIRD STAGE

These price elasticities of demand (ε) can then be used in association with the price differentials derived in stage one, to estimate how each industry's input requirements would have changed had telecommunications technology been

7. It was hoped that the translog specification could be used because it does not impose any restrictions on the data. Input-output data on a long time-series basis is not however available because these tables were generally only computed to coincide with Census years. Estimation with this data would thus be difficult (i.e. lack of degrees of freedom) and any data extrapolation would lead to biased estimates.

constrained to period 0 levels, whilst all other production processes and technologies had advanced at their actual historical rates.

Starting with the matrix M_1^0 expressed in (23) and (31) and using the equations from (25) and (26), the observed input mix for all industries (comprising telecommunications and others) is replaced by the input mix that would have been selected had telecommunications been constrained to period 0 technology levels and prices been at p_1^0.

This adjustment in techniques in response to p_1^0 will however result in a new set of prices $(\hat{p}_1)$. There will therefore be an inconsistency between inputs and prices so that simultaneous input substitution from these new $(\hat{p}_1)$ will again result in all sectors so as to maintain actual period 1 final output. To incorporate this effect, we thus start with the modified factor input matrix $(\hat{M}_1)$ and using equation (34):

$$\hat{\hat{M}}_1 = \hat{M}_1 + \frac{\partial \hat{M}_1}{\partial p}\left(\hat{p}_1 - p_1^0\right) \tag{34}$$

the input mix for each industry is replaced by the input mix that would have been selected had prices been $\hat{p}_1$. This results in a new set of prices $(\hat{\hat{p}}_1)$ which will again induce further substitution of inputs by industries. Repeating the adjustment process, as described above, until hypothetical prices have stabilised and the substitution bias has been eliminated i.e. $\Delta p \approx 0$, eventually results in a new/hypothetical factor input matrix (35) being built.

$$\hat{M}_{1,e} = M(\hat{p}_{1,e}, T_1^{All}, T_0^{Tel}) = w_e' B_e [I - A_e]^{-1} \tag{35}$$

Using B_e and $(I - A_e)$ - the equilibrium hypothetical factor inputs - equations (13) and (14) can then be re-calculated at an industry level as well as at an economy level so that we can evaluate the hypothetical change in direct and indirect inputs that would be required at a sectoral and national level so that the actual economy period 1 final demands can be produced.

3.2.4 THE IMPACT OF TELECOMMUNICATIONS INVESTMENT ON NATIONAL/SECTORAL PRODUCTIVITY

The difference between the actual VIS productivity gains in the economy and the hypothetical VIS productivity gains should then provide us with an indication as to how direct telecommunications investment in infrastructure and acquired telecommunications infrastructure investment embodied in purchased products has impacted economy-wide and sectoral productivity levels.

4. The Data

Section 5 below investigates the productivity gains due to telecommunications infrastructure investment using the methodology outlined in the previous section. The analysis is performed in constant value terms and focuses on the years 1963, 1984, 1991 and 1996. These years have been specifically chosen because they cover most of the important phases in U.K. telecommunications' history. They should hence allow us to directly compare the impact of different telecommunication regulatory policies on not only the telecommunications industry itself but also on other sectors[8].

Data for inter-industry purchases, final sales, wages and capital investment were obtained for the 2-digit industry SIC codes and were collected from the CSO Input-Output tables. Cross-checks were made against telecommunications company accounts so as to ensure that the telecommunications input-output data pertained solely to telecommunications operators who own infrastructure or are infrastructure providers.

8. These years were also chosen as there were constraints on the availability of input-output data. Specifically, the input-output tables have generally only been computed to coincide with Census years.

The time-span covered by the input-output analysis is extensive and the classification of industries and commodities has undergone significant change. In the earlier matrices, 73 domestic industries and domestically produced commodities were distinguished. This classification has since, however, been expanded and there are now 124 industries and 123 domestically produced commodities. Given this, work was needed to reconcile the original data so that it could be brought together under the two-digit 1992-based industry and commodity classification used within this study[9]. Although, the two-digit industry SIC code classification is not ideal, there is no choice but to work within this context.

The figures in the input-output tables were re-valued into constant value terms so as to allow for comparisons between actual production technologies in different periods. Using sector-specific investment goods deflators, wage indices and wholesale price indices, compiled from the Census of Production, Annual Abstract of Statistics, Digest of U.K. Energy Statistics, Employment Gazette and The Blue Book, all goods, services, labour and capital in the tables were re-expressed into 1995 prices. For the telecommunications industry, however, separate output, wage and capital price indices were estimated using BT industry data derived from annual accounts[10].

Table 4.1, below, presents the real inputs of telecommunications production per real unit of telecommunications gross output for the years 1963, 1984, 1991 and

9. The relationships between the 12 industry level SIC(92) based classification used in the study and the input-output groups used in the various input-output tables can be obtained from the author on request.

10. This is the normal accepted procedure in telecommunications regulation for the purposes of the price cap. It could be argued, however, that it does not take into account the rapid quality improvements in communication technology. Sensitivity analysis with regard to this issue has recently been carried out by the U.K. Office for National Statistics (See Vaze, 2001) on an aggregate index for information and communication technology (ICT). The results showed that the U.K. producer price index did not change significantly.

1996. Although capital inputs over the years have varied quite considerably, it does appear that the quantity of total inputs required to produce a unit of telecommunications output has consistently fallen over all sub-periods. It suggests therefore that telecommunications production processes have experienced significant efficiency gains. In fact, comparing the telecommunications efficiency gains for the period 1963-1996 with other sectors suggests that telecommunications is ranked first in productivity improvements on a gross output basis[11].

Table 4.1 Real factor inputs of telecommunications production per unit of telecommunications output

	1963	1984	1991	1996	%Δ 1963-84	%Δ 1984-91	%Δ 1991-96	%Δ 1963-96
Materials	0.91	0.61	0.43	0.28	-32%	-29%	-36%	-69%
Labour	5.17	2.25	0.77	0.29	-57%	-66%	-62%	-94%
Capital	0.22	0.32	0.09	0.18	44%	-71%	101%	-18%
Total Inputs	6.31	3.18	1.30	0.76	-50%	-59%	-41%	-88%

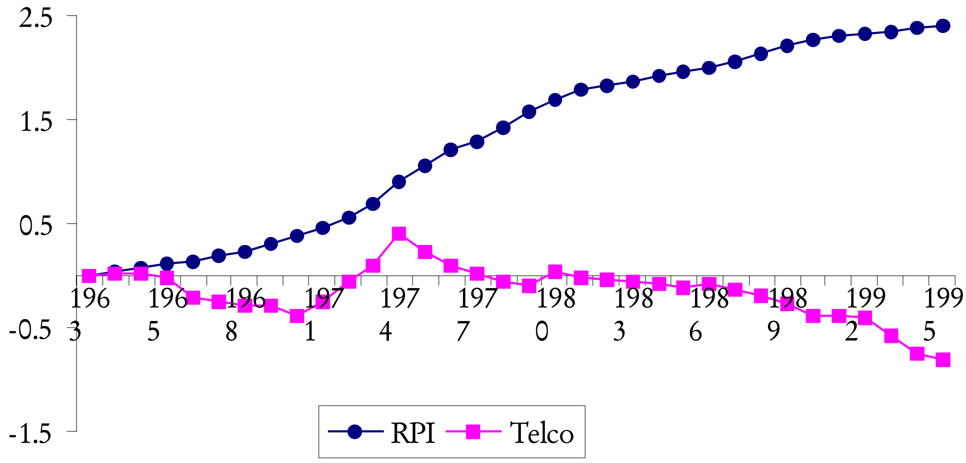
The impact of these efficiency gains undoubtedly means that the telecommunications industry has been able to lower its prices relative to the prices of other goods and services. This statement is borne out by Figure 4.1 which shows that the telecommunication industry's prices relative to the retail price index has fallen considerably since 1980.

Given this significant decrease in prices, it is therefore not surprising to discover that other sectors have responded to these reductions and have increased their consumption of telecommunications. Table 4.2 illustrates the

11. It should be noted that the figures in Table 4.1 are based on total inputs and are not weighted. As such the results presented will not be the same as the efficiency gains calculated in Section 5 and should thus be used only for descriptive purposes.

telecommunications intensity figures, valued at 1995 prices, for the years 1963, 1984, 1991 and 1996.

Figure 4.1
The Log of the Telecoms Price Index against the Log of the Retail Price Index (RPI)



Whilst the average industry (Total) in 1963 purchased £9.58 of telecommunications to produce a £100 worth of final output, in 1996, this figure increased to £10.44. This represents a 8% increase in telecommunications usage or a 0.26% compound annual growth rate. If, however, we exclude telecommunications from the average industry intensity figures, one can observe that telecommunications usage by other industries has increased over the period 1963 to 1996 by 57% or alternatively by 2.50% on a compound annual growth basis[12].

It is further worthwhile noting from Table 4.2 that the compound annual growth figures indicate that for the average industry (Total), the largest increase in usage occurred during the period 1984 – 1991. The next largest increase then

12. Comparing this 1963 – 1996 increase in usage with other sectoral usage figures for this period, shows that only construction and agriculture had similar increases of usage whilst for the period 1991 to 1996, only financial intermediation and construction had similar increases in usage as telecommunications.

Table 4.2

The consumption of telecommunications services as a percentage of industry final output

Industry	1963	1984	1991	1996	Compound annual growth rate			
					1963-84	1984-91	1991-96	1963-96
Agriculture, Hunting, Forestry, & Fishing	1.083	1.067	0.746	1.100	-0.07	-4.36	6.67	0.05
Mining & Quarrying	0.675	0.384	0.489	0.316	-2.53	3.08	-7.04	-2.21
Manufacturing	0.780	0.951	0.645	0.757	0.90	-4.73	2.70	-0.09
Electricity, Gas & Water Supply	1.198	1.130	1.278	2.121	-0.26	1.55	8.81	1.69
Construction	1.103	1.126	1.452	1.257	0.10	3.22	-2.37	0.39
Wholesale & Retail trade	0.717	1.173	3.040	4.445	2.26	12.64	6.54	5.51
Transport	0.299	0.763	1.465	1.059	4.36	8.49	-5.26	3.79
Communication	106.9	109.9	108.1	106.9	0.12	-0.22	-0.18	0.00
Financial Intermediation[13]	-	1.526	2.309	1.984	-	5.31	-2.49	-
Public Administration[36]	-	-	3.520	2.411	-	-	-6.11	-
Education & Health	0.636	0.592	0.516	1.201	-0.33	-1.69	15.11	1.89
Other Services	1.451	2.373	0.833	1.754	2.26	-12.27	13.22	0.56
Average Industry (Total)	9.577	10.09	10.36	10.44	0.24	0.34	0.13	0.25
Average Industry (Excl. Communications)	0.662	0.924	1.358	1.534	1.53	4.93	2.05	2.50

occurred in 1963 – 1984 and lastly the period 1991 – 1996 encountered a 0.15% increase in telecommunications usage. Given that change in intensity is due to (i) changes in technology, reflecting changes in the ways inputs generate output, and (ii) changes in prices that induce substitutions of cheaper inputs, this pattern of growth should not be surprising, in light of the history of telecommunications in the U.K.. 1963 – 1984 marked the start of the period of

13. Note that in 1963, for financial intermediation and public administration, no intermediate data was available for these sectors. The data was wholly attributed to final demand.

modernisation of U.K. telecommunications in terms of new network capabilities. Substantial technological changes occurred during this period which impacted network costs and hence output prices. The increase in telecommunications usage during this period could thus have directly resulted from these technical changes. The liberalisation process, in contrast, could be argued to be the main driver during the period 1984 – 1991. Regulation coupled with increased competitive activity has meant that considerable inefficiencies may have been removed from the incumbent's operations. This would no doubt have had a strong upward impact on telecommunications productivity (Note Table 4.1 indicates that the largest decrease in inputs required to produce a unit of output in telecommunications occurred during 1984 – 1991) and a consequent downward impact on prices (see Haskel and Symanski, 1993). It can be argued therefore that this sizeable increase in telecommunications usage and efficiency during this period might have ensued from this inefficiency shedding process. As inefficiencies have been eliminated, however, one would have expected the rates of change in usage and efficiency figures to have levelled out or even to decline. Surprisingly, however, the period 1991 – 1996 shows that efficiency gains and usage growth were still substantial. One explanation for this could be because the period 1991-1996 was characterised by the termination of the duopoly period and the start of infrastructure competition as a policy objective[14]. With the duopoly period ended and infrastructure competition encouraged, coupled with the increased diffusion of telecommunications from the liberalisation process during 1984-

14. In 1984, British Telecommunications (BT) was privatised and Mercury Communications (MCL) was licensed for national and international services. To introduce competition into the market, the Government adopted a seven year Duopoly policy which meant that only BT and MCL operated in the market. The reason for this was to allow BT to get accustomed to its new privatised surroundings and to give MCL time to develop its network etc. so that it could become an effective competitor to BT. In 1990/91, however, the Government terminated the Duopoly policy and adopted a policy of licensing fixed networks without formal limit. The idea, therefore, was to encourage competing networks in the marketplace so that dynamic competition would prevail.

1991, an increased number of firms have competed to meet the needs of customers. Innovation may thus have been essential if firms were to remain financially viable in the long run[15].

This appears to be confirmed by Figure 4.1 and Table 4.2. Prices have decreased substantially and in response to this, many sectors have increased their usage of telecommunications inputs relative to other inputs. They may have hence indirectly benefited from significant cost savings, thereby improving the effectiveness of their own production processes. The extent, however, to which improvements have been made due to telecommunications forms the basis of discussion of the next section.

5. The Impact Of Telecommunications Infrastructure Investment

This section investigates explicitly whether and by how much telecommunications infrastructure investment influences national and sectoral productivity. Table 5.1 sets out the average annual Peterson growth rates of productivity[16] given existing investment structures and production methods in all sectors, using equations (15) and (16)[17]. One can observe that over the

15. Note the increase in capital inputs during the period 1991 – 1996 in Table 4.1. This might be due to the policy of infrastructure competition which meant that networks were having to invest in infrastructure so as to provide more innovative value-added services to customers. The previous emphasis on being the lowest cost operator may thus have been replaced by network operator product and process differentiation and innovation.

16. It should be noted that because the productivity measures calculated in this study rely on input-output data, quality changes in labour and capital inputs cannot be differentiated amongst the various sectors as this data is unavailable. For this reason, these estimates may be subject to negative bias. (Note the apparent negative productivity estimates for wholesale and retail).

17. Comparing the productivity figures above with other studies shows that the figures do appear comparable. In particular, McDonald et al. (1991) derive a figure of 4% for the agricultural sector for the period 1979-1984. Sakurai et al. (1997) quote economy-wide productivity figures of 1.68% for the period 1984-1990 and

complete sample period and sub-periods, telecommunications productivity has not only far outpaced the economy-wide productivity level but it has also outpaced other sectoral productivity rates.

Table 5.1
Actual Peterson Index of Productivity

	1963-1984	1984-1991	1991-1996	1963-1996
Agriculture, Hunting, Forestry, & Fishing	4.3%	5.6%	1.8%	2.8%
Mining & Quarrying	1.1%	0.0%	5.9%	1.5%
Manufacturing	2.5%	2.4%	1.5%	1.6%
Electricity, Gas & Water Supply	0.8%	0.5%	3.5%	0.5%
Construction	2.8%	2.3%	3.0%	1.7%
Wholesale & Retail trade	-1.6%	-7.3%	-1.3%	-3.5%
Transport	1.5%	1.2%	5.1%	0.0%
Telecommunications	14.4%	21.8%	8.9%	5.8%
Financial Intermediation	2.0%	1.6%	2.7%	-0.8%
Public Administration	3.2%	1.4%	1.1%	1.5%
Education & health	-3.1%	8.6%	1.2%	-1.7%
Other Services	2.8%	2.6%	-0.8%	1.9%
Total Economy	1.7%	1.6%	2.0%	0.7%

Furthermore, as Table 5.2 below indicates, the results presented in Table 5.1 suggests that telecommunications has not only contributed its share of total output more efficiently, but it has additionally contributed to *overall* productivity growth via its influence on other industries. Modifying equation (16) - ignoring $\hat{p}$ and $\hat{p}^{-1}$ for operational purposes - by subtracting t from both sides, gives:

$$v' - t' = i\bar{t}\left\{[I - A]^{-1} - I\right\} \quad (36)$$ [18]

where v is a vector of elements $d\log v_k$ and t is a vector of elements $d\log t_k$ The elements in the kth column of the RHS of the equation give the indirect

1.45% for the period 1979-1984. And from Oulton (1998), one finds that manufacturing had a productivity figure of around 1.8 for the period 1970-1996.

18. A ¯ indicates a vector transformed into a square matrix with the elements of the vector being placed on the principal diagonal .

contributions of within-industry productivity growth across all industries to efficiency gains in the delivery of the k^{th} commodity to final demand. Conversely, and more significant for our purposes, the elements of the g^{th} row of the RHS of the equation weighted by final demand shares, represent the indirect contributions of the g^{th} industry to productivity growth in the economy. Carrying out the above calculation gives Table 5.2 which details sectoral contributions to the economic system as a whole on an average annual basis.

Table 5.2
Sectoral Contributions To The Economic System

	1963-1984	1984-1991	1991-1996	1963-1996
Agriculture, Hunting, Forestry, & Fishing	0.05%	0.10%	0.02%	0.04%
Mining & Quarrying	0.02%	-0.01%	0.11%	0.03%
Manufacturing	0.47%	0.43%	0.23%	0.37%
Electricity, Gas & Water Supply	0.00%	0.00%	0.03%	0.00%
Construction	0.04%	0.03%	0.05%	0.03%
Wholesale & Retail trade	-0.09%	-0.25%	-0.07%	-0.09%
Transport	0.04%	0.06%	0.26%	0.00%
Telecommunications	0.11%	0.25%	0.12%	0.07%
Financial Intermediation	0.10%	0.11%	0.26%	-0.09%
Public Administration	0.00%	0.00%	0.00%	0.00%
Education & health	-0.03%	0.10%	0.02%	-0.06%
Other Services	0.07%	0.03%	-0.02%	0.04%

One can observe that telecommunications has been a strong indirect contributor to the overall economic system as has manufacturing and financial intermediation. Whether the economic system and all the sectors have been able to benefit from the productivity effects or cost savings experienced in telecommunications forms part of the discussion of Table 5.3. This table presents the sectoral price effects had telecommunications technology or investment been constrained[19], and displays the comparison in terms of

19. This is equivalent to $(\hat{p}_{1,e} - p_1)$ as discussed in Section 3 and gives the sectoral price effects had telecommunications experienced no technical change from 1991. Alternatively, it can be regarded as an estimate of the sectoral conventional

percentage increases over the actual period 1 price level. It shows that had telecommunication not undergone technical advances since 1991, then 1996 telecommunications prices would have been more than 84% higher than the actual 1996 price level[20].

Table 5.3 Sectoral Price Effects Had Telecommunications Technology Been Constrained	
	1996/96hyp91
Agriculture, Hunting, Forestry, & Fishing	7.5%
Mining & Quarrying	2.9%
Manufacturing	5.5%
Electricity, Gas & Water Supply	4.4%
Construction	8.6%
Wholesale & Retail trade	8.3%
Transport	12.1%
Telecommunications	84.9%
Financial Intermediation	37.5%
Public Administration	6.9%
Education & health	3.5%
Other Services	8.1%
Total Economy	16.4%

As should be expected, the greatest impact of constraining telecommunications investment or technology would be realised by the telecommunications

measure for TFP ($d \log t_k$) – see Aulin-Ahmavaara (1999). It can be shown that the conventional TFP measure is equivalent to the relative decrease in the production price of the output of sector j when all inputs are treated as exogenous constants. On the assumption that all the input prices in equation (3) are exogenous constants, differentiating it (with respect to time) and multiplying both sides by $-\hat{p}^{-1}$ (a carat indicates a vector transformed into a square matrix, the elements of the vector being placed on the principal diagonal) gives t' where t' is a vector of elements $d \log t_k$. This result means therefore that for the total economy, had telecommunications experienced no technical change from 1991, prices would have been 16.4% higher than they historically were or alternatively, economy-wide productivity would have been 16.4% lower i.e. hypothetical TFP would be 1.7% versus actual TFP of 2% - see Table 5.1.

20. This figure of 84% on telecommunications prices i.e. prices annually being 12% higher than they were historically should not be unexpected. Similar results have been attained in studies of this type (see Cronin et. al, 1992).

industry. Other sectors would however also be affected: the financial intermediation sector, the transport industry, construction and wholesale and retail trade. This is largely due to the fact that these sectors are telecommunications intensive as outlined in Table 4.2.

One can therefore conclude that advances in telecommunications emanating from infrastructure investments have lowered telecommunications prices and have enabled other industries to benefit from these cost savings which has led to price reductions throughout the economy. The link between this and productivity growth, however, has not yet been fully answered. To do this, an understanding of how industries have changed their production processes over the 1991 – 1996 period to take account of these cost benefits must be obtained.

Using equation (33), the Leontief averaging method (1953, pp28) was used for the 1991 and 1996 input-output tables, to estimate price elasticities of demand. These estimates in association with the iterated price differentials, as described in Section 3, were then used to re-calculate the 1996 hypothetical input-output table. Computing equations (13) and (14) for this hypothetical economy allowed us to evaluate the hypothetical change in direct and indirect inputs that would be required at a sectoral and national level so that the actual economy final output could be produced. A comparison of the equilibrium hypothetical productivity gains in the economy with the actual productivity gains provides us with estimates of the impact of telecommunications infrastructure investment given that telecommunications infrastructure investment had not advanced. Expressing this as a percentage of the actual productivity gains made by each sector and the aggregate economy, the results are presented in the table below[21].

21. The estimates in Table 5.3 can be viewed as sectoral conventional measures for TFP ($d\log t_k$). The estimates in Table 5.4, in contrast, refer to the effective rates of sectoral productivity change ($d\log v_k$). In other words, they examine both the direct and indirect effects of productivity change. The economy-wide figures differ

Table 5.4 The Relative Impact Of Telecommunications Infrastructure Investment On Sectoral and Aggregate Productivity (1991 Constrained)			
	1984-96 96hyp91/84	1991-96 96hyp91/91	1963-96 96hyp91/63
Agriculture, Hunting, Forestry, & Fishing	22%	68%	15%
Mining & Quarrying	17%	8%	29%
Manufacturing	31%	51%	16%
Electricity, Gas & Water Supply	45%	27%	69%
Construction	59%	76%	33%
Wholesale & Retail trade	-	-	-
Transport	50%	38%	-
Telecommunications	13%	105%	28%
Financial Intermediation	486%	474%	-
Public Administration	56%	193%	34%
Education & Health	42%	106%	-
Other Services	98%	-	23%
Economy	111%	158%	118%

Table 5.4 presents the percentage of actual observed gains made possible by telecommunications infrastructure investment since 1991[22]. It shows that without advances in telecommunications, the manufacturing sector, over the sample period 1963 to 1996, would have been around 16% worse-off than they were historically. For the period 1984 to 1996, the impact for the telecommunications sector could have been 13% and for the period 1991 to

between the two tables because prices from equation (3) will only equal actual prices on the assumption of a competitive equilibrium. In reality, the productivity gains are likely to be distributed differently because of the weighting procedure used in calculating TFP (see Leontief, 1953, pp27-28). Furthermore, by its very nature, counterfactual analysis is inferential in character (i.e. if sectors were not able to choose their preferred level of telecommunications, what would they select?). The scope in the counterfactual analysis has been limited but it is inevitable that come unreasonable results may have been obtained for the hypothetical situation. This issue is compounded with the well-documented difficulties encountered in productivity measurement exercises especially in service industries. This means that caution should be observed in any precise inference.

22. It should be noted that for those industries where relative impacts have not been calculated, the reason is because the actual productivity for the sector in question is negative, indicating 'decreased' productivity. For these industries, therefore, hypothetical productivity gains would presumably have declined even more had telecommunications not advanced.

1996, productivity losses arising from telecommunications infrastructure investment in the financial intermediation sector could have been 474%[23]. From the above, the service sectors have appeared all to have benefited significantly from telecommunications diffusion. Hence, these results support ideas of unbalanced development in technological and productivity growth across sectors in the economy. The other sector that also appears to have benefited from telecommunications advances is the agricultural sector during the period 1991 – 1996. This should not be surprising since substantial literature on developing countries has shown that the agricultural sector has benefited from telecommunications – the principle reason being because it reduces the cost of acquiring information – see Saunders, Warford and Wellenius (1983).

An interesting observation from the table is that within-sample the aggregate and sectoral economy have benefited the most from telecommunications advances during the period 1991 to 1996 i.e. during the era of infrastructure competition. This observation with regard to 1991-96 does not appear to be too implausible even though at first glance these results do seem to contradict the data given in Table 5.1. A possible historical parallel of this can be found in the writings of Harold Innis (1950, 1951). Innis proposed a three-phase theory of the impact of a new communications technology on economic activity that is compatible with that put forward by David (1990) and Triplett (1999). The first phase involves the market being dominated by a single technology to

23. The estimated relative impacts cited here are not unexpected and appear to be in the same broad band as other studies. In other unrelated studies investigating the productivity impact of R&D and diffusion-based R&D, estimates of these ranges have been obtained. In particular, Mohnen (1994) proposes an average estimate of the excess of the social rate over the private rate of approximately 50% - 100% whilst Sakurai et al. (1997) obtain estimates of embodied R&D ranging between 130% and 190% and of international R&D spillovers ranging between 300% and 450%.

which access is charged at monopoly prices[24]. The high cost of information encourages innovative activity, which if successful, then results in a subsequent phase during which the new technology is diffused widely[25]. It is during this 'phase of balance' where two or more media co-exist that welfare is highest[26]. Evidence of this effect is provided in a study by Haskel and Szymanski (1993). They found that increases in competition significantly increase productivity. In the third and final phase of the cycle, the successful new medium attains a monopoly position and economic progress is then again stifled.

Reviewing the results obtained above in conjunction with the historical development of the telecommunications industry in the U.K. and the three-phase theory put forward by Innis, we know that the period prior to 1991 was characterised by a strong monopoly owned by British Telecom (BT). This could therefore be seen as the first phase in Innis' terminology. The period 1991 to 1996, in contrast, could be perceived as the 'phase of balance' as it marked the start of open competition in most segments of telecommunications and the policy of encouraging infrastructure competition in the market[27]. During this

24. As an example of this first phase and the start of the innovative phase, Innis (1950, pp. 140 - 141) wrote that from the first century B.C., the Romans monopolised the use of papyrus through their control of its production sites in Egypt. They used this mastery to build up a centralised bureaucratic administration that dominated the Mediterranean basin. However, in the early centuries A.D., improvements in the technique for producing parchment, which could be made from animal skins virtually anywhere, broke this monopoly.

25. Again as an example, Innis (1950, pp. 48 – 49) argued that with the fall of Egypt to Islam, papyrus supplies to Europe were cut off. Accordingly, the use of parchment spread to the northern parts of the continent.

26. Innis (1951, pp 53, 64) noted the beneficial effects of coexistence of papyrus and parchment under the Byzantine Empire and the later impact of competition between parchment and paper on trade and urban growth in western Europe.

27. As discussed in Section 4, there were substantial gains made during the period 1984 – 1991. These were however probably more due to the inefficiency shedding process that occurred at this time rather than strong competition. These gains could therefore be viewed as a one-off efficiency step-change or outlier in the dataset.

period, BT still remained dominant but now via increased infrastructure competition, many firms and technologies (even though they may have been focused on low-value applications) co-existed so that there was now increased competitive pressures on players and high welfare gains to be made in all sectors due to significant price and substitution effects.

These high welfare gains during the 'phase of balance' appear to be borne out by the tables above, by the fact that the aggregate and sectoral economy has benefited the most from telecommunications advances during the period 1991 to 1996. Given that this period marked the start of open competition in most segments of telecommunications and the policy of encouraging infrastructure competition in the market, this result might have significant implications for the future development of U.K. telecommunications policy.

6. Conclusions

The research presented in this paper has attempted to establish a link between telecommunications infrastructure investment and economic growth and to assess the specific impacts on the productivity of the economy and 12 industrial sectors. Using improved techniques comprising input-output economics and economic modelling, the results suggest that telecommunications productivity, over a 34 year period, has outpaced the economy-wide productivity level. Furthermore, we found that telecommunications was a strong contributor to the performance of the economic system as a whole. This coupled with the telecommunications productivity rate figures suggests that not only has telecommunications contributed its share of total output more efficiently, but it has also contributed to overall economy-wide productivity growth via its influence on other industries.

Additionally, evidence of the interdependence of telecommunications and other sectors is provided in the research. Indeed the analysis conducted in this paper shows that all industries have benefited from the incorporation of advances in telecommunications technology, which might have, amongst other things, emanated from the policy of encouraging infrastructure investment, in their production processes. It is possible therefore that by pursuing a policy of dynamic competition, thereby encouraging infrastructure competition, organisational performance and productivity within the telecommunications industry has been improved which via the industry's impact on other markets has facilitated the economic development and growth of these other sectors. This paper thus shows that UK government policies on telecommunications and its investment incentives may have wide-reaching consequences for not only the telecommunications industry but also the economy as a whole.

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