Note on the Role of Embodied, Neutral and Investment Specific Technical Change in the New Economy

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Abstract

In a seminal paper, Jeremy Greenwood and al. (1997) have claimed that the growth accounting framework that they ascribe to Dale Jorgenson and Zvi Griliches (1996) is flawed and severely understates the role of technological change embodied in new capital goods in explaining United States (hereafter US) growth. They develop an alternative framework centred round the concepts of neutral technical and investment specific technical change to determine what proportion is due to investment specific technical change, ie what is the importance of embodied technical change. The main purpose of this paper is to survey the literature surrounding the ongoing debate of the nature of technical change, ie what are the relationships between embodied, neutral and investment technical change. In this paper, we show that, contrary to Jeremy Greenwood and al. (1997)'s claim, on the one hand, embodied technical change and investment specific technical change are two distinct concepts and on the other hand, Jeremy Greenwood and al. (1997)'s and Nicholas Oulton (2004)'s model can be a special case of the two sector vintage capital growth model.

Keywords : Investment-specific technological change, embodiment, TFP, growth accounting

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1. Introduction

A quick look of the major innovations of the century, ie electricity, automobiles, clearly shows that innovation was necessary to increase prosperity and economic standard of living. This is not news to economists who have long known that innovation is a key source of long-term economic growth. Indeed, using a well known growth accounting methodology, Robert Solow (1957) in a seminal paper estimated that nearly 90% of the increase in United States (hereafter US) output per person in the first half of the 20th century was attributable to technical progress. Robert Solow (1957) defines the technical change as the residual growth of output not explained by the change in factors. Technology hits the economy in a Hicks neutral way because it does not modify the marginal substitution rate of inputs. Consequently, the technical change is disembodied[2]. This analytical framework will be extended by Dale Jorgenson and Zvi Griliches (1996). Finally, Hicks neutral technical change neglects the fact that the economy develops only when it invests on new vintages of capital goods incorporating innovations. To explain this fact, Robert Solow (1960) proposes an alternative framework in which embodied technical change is used. Contrary to Robert Solow (1960), Dale Jorgenson (1996) argues that the growth accounting is not able to solve the embodiment controversy because there is a one to one correspondence between this two technical change.

More recently, some economists have spent considerable effort on understanding the role of innovation in the revival of US output growth and productivity growth in late 1990s which called by some people “New Economy”. The rapid advancement of information and communication technologies (hereafter ICT) has been identified as critical driving force of the improved economic performance and a growing body of research links ICT to the recent productivity gains. Indeed, the main empirical studies (Robert Gordon (1999), (2002), Dale Jorgenson (2001), Dale Jorgenson and al. (2003), Dale Jorgenson and Kevin Stiroh (1995), (2000), Stephen Oliner and Daniel Sichel (1994), (2000), (2003), Karl Whelan (2003)) outline the strong productivity growth in the computer sector. Most of these analyses have a common methodology. Indeed, they use data from the National Income and Products Account (hereafter NIPA) and methodology from the Bureau of Economic Analysis (hereafter BEA) which based on a well-known Dale Jorgenson and Zvi Griliches (1996)’s methodology. However, another economists, Jeremy Greenwood and al. (1997) develop in a seminal paper an alternative point of view based on an alternative methodology. Indeed, they think that the

[2] See Charles Hulten (2000) for an excellent survey about total factor productivity.

Jorgensionian growth accounting framework is flawed at least for the purposes of productivity analysis. They develop a framework centred round the concepts of neutral technical change and embodied technical change to evaluate the impact of embodied technical change on productivity and growth. In using this methodology, the debate on the nature of the technical progress which called "Embodiment Controversy[3]" re-emerges. In conclusion of their work, they find that the investment specific technical change is the most important in value of the two concepts of technical change. Consequently, it seems to be very important to define precisely the nature of the technical progress to better understand the links between innovation or technical progress and economic standard of living.

The main purpose of this paper is to survey the literature surrounding the ongoing debate of the nature of technical change, ie what are the relationships between embodied, neutral and investment technical change.

In what follows, in a section 2, I analyse different ways to measure the embodied technical change. In a section 3, I define the relationships between embodied, neutral and investment specific technical change. In a section 4, I develop a more general model in using a two sector vintage capital growth model to demonstrate that Jeremy Greenwood and al. (1997)'s and Nicholas Oulton (2004)'s models are special case of this more general model. Finally, I conclude in a section 5.

2. Embodied technical change : measurement[4].

Embodied technological change[5] refers to improvements in the quality of investment goods. Consequently, investment is required in order to diffuse the changes in technology.

[3] Zvi Hercowitz (1998) describes the 1960s controversy in the context of contemporary models of investment specific technology.

[4] The ratio of price index is not the only way to measure embodied technical change. Indeed, there exists two another different way. First, some economists have estimated embodied technical change by using a production function. This way is followed by Byong-Hyong Bahk and Michael Gort (1993) and Plutarchos Sakellaris and Daniel Wilson (2001), (2004). Byong-Hyong Bahk and Michael Gort (1993) provide estimates using Richard Nelson (1964) variant of Robert Solow (1960)'s model. Plutarchos Sakellaris and Daniel Wilson (2001), (2004) implement a more direct approach. Second, another economists have estimated embodied technical change by using a structural model. This way is followed by Bart Hobijn (2001) and Bart Hobijn and al. (2002). Bart Hobijn (2001) measures embodied technical change by fitting a simple stochastic vintage capital model to aggregate US data. Bart Hobijn and al. (2002) modify the neoclassical model of investment with convex adjustment costs to include embodied technical change.

[5] Embodied technological change and quality improvements are very related concepts. Quality improvements refer to an economic process in which new goods have higher and higher quality. The best example of this economic process is may be the personal computer. Indeed, new processors have characteristics which quality is improved. The importance of quality improvements in the growth process has been recently stressed by Philippe Aghion and Peter Howitt (1998) and Gene Grossman and Elhanan Helpman (1991) among others. However,

The purpose of economists is to measure the service of new and old capital in terms of efficiency units (e.g. computing power) rather than natural or physical units (e.g. number of computers). Following Huw Lloyd-Ellis (2001), the simplest way to represent efficiency units is to define it as

$$e_t = q_t i_t \qquad (1.1)$$

where q_t is a quality index and i_t denotes real investment in natural units. To be coherent, the nominal value of investment goods measure in terms of efficiency or physical units must be the same

$$p_{et} e_t = p_{it} i_t \qquad (1.2)$$

where p_{et} is an hedonic[6] price index for efficiency units of capital and p_{it} is a market price index for natural units.

Substituting the equation (1.1) into the equation (1.2) for e_t, we obtain the following equation

$$q_t = \frac{p_{it}}{p_{et}} \qquad (1.3)$$

Finally, the quality of capital goods must be measured by the ratio of a hedonic price index and a market price index.

Now, the difficulty to measure the embodied technical change is to compute the hedonic price index. A hedonic price index which attempts to measure the quantity of utility derived from a particular good is a statistical technique that adjusts the price of an item to reflect improvement in quality. To do this hedonic regression, we need knowledge of the large amount of information on characteristics of the unit of capital. However, much of which is unavailable. Thus, any estimated price index is subject to different critics like for example : omitted characteristics bias. In spite of difficulties, some economists try to evaluate hedonic price index.

Robert Gordon (1990) finds a substantial impact of quality improvement in a wide range of producers' durable equipment prices. To find this result, he compiled a data set of more than 25.000 price observations. Using a number of methodologies including traditional matching methods hedonic price index construction and price comparisons for used capital equipment, he compiled the data into quality adjusted price indexes for 105 different product

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embodied technical change and quality improvement are different concepts. Indeed, new technologies can also be more efficient by producing exactly the same good with a smaller amount of resources.

[6] The use of hedonic methodology to quantify the quality is not a particularly new idea. Indeed, in the 30's, economists used this methodology to compare the automobile quality across model. Jack Triplett (1986) attributes the origin of hedonic terminology to Andrew Court (1939).

categories. Then, he aggregated the data and compared this aggregate price index to the official NIPA price index.

Charles Hulten (1992) is the first to use Robert Gordon (1990)'s hedonic price index in order to compute the growth rate of embodied technical change q_t. He constructs a single aggregate index from Robert Gordon (1990)'s index and he compares this one to the corresponding price index published by Bureau of Labor Statistics (hereafter BLS). Finally, he finds that the rate of embodied technical change averaged 3.44% per year from 1949 to 1983.

Some economists have followed Charles Hulten (1992) in using Robert Gordon (1990)'s data but differed in the methodology employed. Jason Cummins and Gianluca Violante (2002) have updated the Robert Gordon (1990)'s work to 2000. They extrapole these asset specific price indexes using a time series forecasting technique for the quality adjustment for each of the capital assets in the Robert Gordon (1990)'s study.

However, there exists an alternative way in the economic literature to measure the embodied technical change. This way consists to use a growth model to try to measure this technical change.

We begin with the basic one sector model framework[7] outlined in Jeremy Greenwood and al. (1997) and Zvi Hercowitz (1998)[8].

$$y_t = z_t f(k_t, l_t) = c_t + i_t + R(z_t, q_t; x_t) \tag{1.4}$$

$$e_t = i_t q_t \tag{1.5}$$

$$k_{t+1} = k_t(1-\delta) + e_t \tag{1.6}$$

Equation (1.4) is the aggregate production function that has only Hicks-neutral technical change, where constant returns to scale have been imposed. The index of technology z_t, is separable from k_t and l_t, and reflects the standard concept of total factor productivity. q_t represents embodied technical change. To produce quality level q_t and technology z_t at time t, there is a resource requirement R. Output y_t, which can be used for consumption c_t, investment i_t or resources R, is produced with the aid of capital k_t and labor l_t. Equation

[7] For simplicity, we focus on the private production side of the economy and ignore the government. Similarly, we do not dwell on the utility maximization problem of the household. We do that for all model presented in this paper.

[8] The model of Zvi Hercowitz (1998) is identical to the one. The model of Jeremy Greenwood and al. (1997) and Jeremy Greenwood and al. (2000) is more complicated since it has two capital goods sectors, structures and equipment. But these complications are not relevant for the issue discussed in this paper.

(1.5) measures investment goods in efficiency units e_t . Finally, equation (1.6) describes the evolution of the capital stock when measured in efficiency units.

Equation (1.5) can be reformulated to give a total consumption cost function of e_t efficiency units of investment

$$TC(e_t) = i_t = \frac{e_t}{q_t} \tag{1.7}$$

Then, the marginal cost of an efficiency unit of investment is $\frac{1}{q_t}$. Hence, in competitive equilibrium, we have equality between the marginal cost and the relative price of investment goods

$$p_t = \frac{1}{q_t} = \frac{p_{et}}{p_{ct}} \tag{1.8}$$

Finally, the conclusion to the analysis of Jeremy Greenwood and al. (1997) and Zvi Hercowitz (1998) is to propose to identify embodied technical change by examining the relative price of quality adjusted investment goods and consumption goods. Using a quality adjusted producers' durable goods deflator based on Robert Gordon (1990) for p_{et} and the NIPA deflator for non durables and services for p_{ct}, Zvi Hercowitz (1998) estimates that relative prices fell 2.8% per year for 1947-94 and Jeremy Greenwood and al. (1997) estimates 3.2% for 1954-90.

Now, following Karl Whelan (2003), Jeremy Greenwood and al. (1997) and Mun Ho and Kevin Stiroh (2001)[9], we demonstrate that there are implicitly in the Jeremy Greenwood and al. (1997) and Zvi Hercowitz (1998) model two final goods sectors, one producing consumption goods and an other producing investment goods.

3. Relationship between embodied technical change and investment specific technical change.

Investment specific technical change[10] refers to productivity improvements in the production of new efficiency units of investment goods, relative to consumption goods. To

[9] They use a two sector growth model to criticize the one sector growth model used by Jeremy Greenwood and al. (1997).

[10] Finally, investment specific technical change refers to productivity improvements in the production of new efficiency units of investment goods relative to consumption goods. We will demonstrate that the investment specific technical change may be either embodied technical change or disembodied technical change.

illustrate the concept of investment specific technical change, we need a two sector model where one produces consumption goods c_t and the other produces efficiency units of investment goods e_t . Each good is produced using capital k_t and labor l_t as inputs according to the following production functions

$$c_t = A_t k_{ct}^{\alpha} l_{ct}^{1-\alpha} \tag{1.9}$$

$$e_t = z_t A_t k_{et}^{\alpha} l_{et}^{1-\alpha} \tag{1.10}$$

where A_t is an index of technology representing Hicks neutral technological change that is common to both sectors whereas z_t reflects increments in the technical efficiency of the investment goods sector relative to the consumption goods sector. This is what Jeremy Greenwood and al. (1997) refer to as investment specific technical change. Note that for simplicity the capital share α is assumed to be the same in both sectors[11]. Moreover, if we assume that factors are mobile across sectors and there is perfect competition[12], then the capital labor ratio in each sector are equal. Since the marginal product of each factor will be equalized across sectors, we have the following relationship $p_{ct} = p_{et} z_t$. Thus, the investment specific technical change could be measured as the decline in the relative price of efficiency units of investment goods

$$z_t = \frac{p_{ct}}{p_{et}} \tag{1.11}$$

Note that the estimation of the investment specific technical change in the two sector growth model is equal to the estimation of the embodied technical change in a one sector. Indeed, the equation (1.11) is identical to the equation (1.3). Consequently, Jeremy Greenwood and al. (1997) identify investment specific technical change and embodied technical change.

Whereas Jeremy Greenwood and al. (1997) relate embodied technical change and investment specific technical change, if we compare the equation (1.3) and equation (1.11), we see that there are a difference between this two technical change concepts. Indeed, following Huw Lloyd-Ellis (2001), under certain circumstances, like for example if the growth rate of consumption goods price is equal to the growth rate of investment goods price, there can have an identity between embodied technical change and investment specific

[11] Andreas Hornstein and Per Krusell (1996) show the implications of allowing α to vary across sectors.

[12] The assumption of perfect competition seems not to be the best assumption. Indeed, the existence of markups implies a difference between price and marginal costs that create a biais if you evaluate the embodied technical change by the decline in relative prices of the two goods. However, as long as there is no trend in the ratio of the markups in the two sectors, the measurement error generated would not be important.

technical change. But if a difference exists between the growth rate of consumption goods price and the growth rate of investment goods price, then the embodied technical change and the investment specific technical change are not equivalent.

However, following Nicholas Oulton (2004), we can do another interpretation of the Jeremy Greenwood and al. (1997)'s model. Indeed, contrary to Jeremy Greenwood and al. (1997), we can relate the decline of the relative price of investment goods to the Hicks neutral technical change. Do demonstrate that, we assume that each sector's technical change can be described by a production exhibiting constant returns to scale and unbiased technical change.

$$c_t = A_{ct} k_{ct}^{\alpha} l_{ct}^{1-\alpha} \tag{1.12}$$

$$e_t = A_{et} k_{et}^{\alpha} l_{et}^{1-\alpha} \tag{1.13}$$

where k_t and l_t are capital and labor inputs and A_{ct} an index of technology representing Hicks neutral technological change in the consumption goods sector and A_{et} is an index of technology representing Hicks neutral technological change in the investment goods sector.

Now, we can estimate the neutral technical change by using the price side. Indeed, under constant returns, there exists a unit cost function in each sector, which is dual to the production function. Following Dale Jorgenson and Zvi Griliches (1996) and Robert Barro (1999), if input prices stay constant then the growth rate of neutral technical change equals the rate at which unit cost would fall over time. Under the assumptions of perfect competition and constant returns to scale, price equals unit cost. These assumptions imply that input shares and input ratios will be the same in the two sectors. Then, we obtain the following relationship

$$\frac{p_{ct}}{p_{et}} = \frac{A_{et}}{A_{ct}} \tag{1.14}$$

Finally, contrary to Jeremy Greenwood and al. (1997) which identify investment specific technical change to embodied technical change, we find that investment specific technical change is equal to the ratio of the neutral technical change.

Now we can demonstrate that another concept used by Jeremy Greenwood and al. (1997), neutral technical change, is identical to total factor productivity. If we measure output in consumption units, we have the following relationship

$$y_t = c_t + i_t = c_t + \frac{e_t}{q_t} = c_t + \left(\frac{A_{ct}}{A_{et}} \right) e_t = A_{ct} k_t^{\alpha} l_t^{1-\alpha} \tag{1.15}$$

Now if we compare the equation (1.15) with the equation (1.4) of the Jeremy Greenwood and al. (1997)'s model, we find that

$$z_t = A_{ct} \tag{1.16}$$

Finally, we can conclude that on the one hand, neutral technological change is equivalent to total factor productivity in the consumption goods sector and one other hand, the concept of embodied technical change or investment specific technical change in the Jeremy Greenwood and al. (1997)'s model is equivalent to the ratio of the total factor productivity between the two sectors. In other words, the Jeremy Greenwood and al. (1997)'s model is very related to the two sector model.

However, we can demonstrate that either the Jeremy Greenwood and al. (1997)'s model or the Nicholas Oulton (2004)'s model are special case of a more general model.

4. A more general approach : a two sector vintage capital model.

Following Robert Solow (1960) and Edmund Phelps (1962), we can construct a two sector vintage capital model[13] with constant returns to scale. However, following Patrick Musso (2004), we extend the previous model by allowing for disembodied technological change and multiple types of capital

$$c_{v,t} = A_{ct} k_{v,ct}^{\alpha} l_{v,ct}^{1-\alpha} \tag{1.17}$$

$$e_{v,t} = A_{et} k_{v,et}^{\alpha} l_{v,et}^{1-\alpha} \tag{1.18}$$

where $k_{v,t}$ and $l_{v,t}$ are capital and labor inputs and A_{ct} an index of technology representing Hicks neutral technological change in the consumption goods sector and A_{et} is an index of technology representing Hicks neutral technological change in the investment goods sector.

Under the assumptions of constant returns to scale and perfect competition, price equals unit cost. Then, we find the following relationship.

$$\frac{p_{et}}{p_{ct}} = \frac{A_{ct}}{q_t A_{et}} \tag{1.19}$$

The relative price of new equipment measured in quality adjusted efficiency units is determined by two factors. First, like Nicholas Oulton (2004), it's determined by the relative level of total factor productivity between the two sectors. Second, like Jeremy Greenwood and

[13] Vintage capital models assume that equipments of different vintages have different performance, implying that the capital age structure is relevant for the determination of the equilibrium. Jess Benhabib and Aldo Rustichini (1991) and Raouf Boucekkine and al. (1997) are recent contributions to this area. However, vintage capital and embodied technical change are also related but different concepts. Indeed, there are some interesting examples of vintage capital models without embodied technical change like for example Jess Benhabib and Aldo Rustichini (1991).

al. (1997), it's determined by the quality improvements of capital or embodied technical change.

Finally, the following table summarizes the restrictions used by Jeremy Greenwood and al. (1997) and Nicholas Oulton (2004) in their respective analysis. Indeed, Nicholas Oulton (2004) in this framework assumes implicitly that the embodied technical change does not exist. Consequently, the relative price index is only determined by the relative total factor productivity. Contrary to this framework, in an opposite sense, Jeremy Greenwood and al. (1997) assumes that the total factor productivity of both sector is identical. Consequently, the relative price index is determined only by the embodied technical change. In reality, the relative price index is may be determined by the two technical change.

Authors	Relative price	Restrictions
Nicholas Oulton (2004)	$\frac{p_{ct}}{p_{et}} = \frac{A_{et}}{A_{ct}}$	$q_t = 1$
Jeremy Greenwood and al. (1997)	$\frac{p_{ct}}{p_{et}} = q_t$	$A_{ct} = A_{et}$

5. Conclusion.

The aim of this paper is to try to clarify the relationships between several concepts like embodied technical change, investment specific technical change and total factor productivity. At this end of this paper, we can conclude that contrary to Jeremy Greenwood and al. (1997) the embodied technical change and the investment specific technical change are two different concepts. Indeed, the embodied technical change is defined by the ratio of the investment goods price index to the quality adjusted investment goods price index while the investment specific technical change is defined by the ratio of consumption goods price index to the quality adjusted investment goods price index. Moreover, contrary to Jeremy Greenwood and al. (1997) and Nicholas Oulton (2004), we have demonstrated that the determinants of the investment specific technical change are either the total facto productivity of each sector or the embodied technical change.

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