DEPARTMENT OF ECONOMICS WORKING PAPER SERIES

Neutral Technical Progress and the Measure of Value: along the Kaldor-Kennedy line

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Working Paper No: 2018-05

August 2018

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Abstract

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Keywords: Neutral balanced growth, Capital controversy, Growth and distribution
JEL Classification: B22, O33, E12

Acknowledgements: I am grateful to Codrina Rada, Cihan Bilginsoy, Neal Wilson, two anonymous referees, friends and colleagues in Utah and Colorado for their comments, suggestions and most importantly supports.

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In this paper, I investigate the question of "the effect of progress upon distribution" based on the analyses of Hicks, Robinson, Harrod, Salter, Kaldor, Samuelson, and Kennedy. The paper aims to address a neglected and controversial theoretical argument on neutral technical progress related to the measure of value that preceded and then continued to the period of the Cambridge Capital Theory Controversy. I focus on Kennedy's writings and his solutions to the complications between the measure of value and technical progress. Important intuitions behind the measure of value are crucial to the formulation of neutral technical progress in both the post-Keynesian and the neoclassical-Keynesian endogenous growth models. The paper concludes with mathematical illustrations of neutral technical progress theories.

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1. Introduction

The foundation of value theories in the growth and distribution literature is not rigorous, with inconsistencies in the mathematical formation of growth models regarding the measure of factors of production. The most renowned modern incident was the Cambridge Capital Theory Controversy (Harcourt, 1972; Harcourt and Cohen, 2003). The controversy came to the attention of the public when Joan Robinson initiated a conversation questioning the validity of the neoclassical production function (1953-54). The public debate was summed up by Paul Samuelson (1966), who acknowledged the reswitching and capital-reversing theory. The controversy covered a large body of literature, including value theory, price theory, capital theory, growth theory, and methodology. Harcourt "found it impossible to disentangle them and… not being able to do so is no bad thing anyway" (2015a, p. 243).

More importantly, the framework of the Cambridge Capital Theory Controversy questions the contentious foundation of the growth and distribution literature. The controversy has direct implications for the discussion of inequality between capital and labor raised recently by Thomas Piketty in *Capital in the Twenty-First Century*.[1] This topic, the relationship between capital and labor, was discussed by the Keynesian economists even prior to the formal debate of the Cambridge Capital Theory Controversy. In their attempt to expand Keynes's ideas to the growth and distribution theory of classical political economy, post-Keynesian and neoclassical-Keynesian economists had disputed the measure of the effect of technical progress on the distribution of income. They argued over the dynamic nature of the wage share and the profit share, which depends on the measure of value. The theoretical dispute was the origin of economic tools and terminologies of modern endogenous growth models that we use today in the discussion of the inequality between capital and labor.

This theoretical dispute about technical progress and the measure of value that preceded and then continued to the period of the formal Cambridge Capital Theory Controversy has been, however, overlooked as a peripheral theoretical issue. Hicks, Robinson, and Harrod argued about the theoretical formulation of technical progress in the early 1930s. The issue then resurfaced again almost two decades later in the writings of Salter, Kaldor, Kennedy, and Samuelson. The Keynesians focused on the effect of technical progress on income distribution because it was not clear how to measure and determine the value of the sources of the factors of production.

Above all, neutral technical progress and the measure of value provide a critical connection between post-Keynesian economics and neoclassical-Keynesian economics.

Robinson's objections to the neoclassical production function attracted MIT's attention due to her use of linear models. "Samuelson and Solow believed that they understood because it related directly to their recent work" (Backhouse, 2014, p. 256). They were focusing on linear-programming models, which exhibit a "balanced growth" path.[2] Solow recalled that when he was in England enduring Joan Robinson's repetitive metaphysic, he finally forced her to admit that "a constant capital-output ratio will do" (2007, p. 4). A constant capital/output ratio implied a long-period neutral position, which was their mutual hypothesis. The neoclassical concept of balanced growth was analogous to Kaldor's stylized facts and Robinson's golden age.[3] After the publication of Piero Sraffa's *Production of Commodities by Means of Commodities*, the issue of linearity became even more relevant. Samuelson considered the problem of the measure of value as his lifelong quest. Toward the end of his life, he engaged in discussions with the neo-Ricardians regarding the implicit assumption of constant returns in Sraffa's system (Samuelson, 2000a; 2000b; Garegnani, 2007).

In contrast to Piketty's inequality conclusion, the two Cambridges focused on the neutrality of wage share and profit share. This paper emphasizes the relation between the measure of value and the existence of neutral technical progress in the framework of the Cambridge Capital Theory Controversy. The goal here is to address the foundation of endogenous growth models of both the post-Keynesians and the neoclassical-Keynesians.[4]

1.1. Outline of the debate on neutral technical progress and the measure of value

Sir John Hicks introduced the question of "the effect of progress upon distribution" to modern economics (Hicks, 1932, p. 112). Hicks's writings were the origin of the controversial neoclassical aspect of the "elasticity of substitution." He used the neoclassical

marginal productivity theory, which implies price substitution to determine the effect of technical progress on the value of capital and labor. Neutral progress that increases the income of capital and labor in the same proportion requires an elasticity of substitution equal to one. Joan Robinson followed Hicks's framework in her analysis of the question of technical progress in *Essays on the Theory of Employment* (Robinson, 1937). However, her approach received a negative response from Sir Roy Harrod, who criticized Robinson's handling of the elasticity of substitution because it implied a controversy regarding the measurement of capital and the interest rate. This period was the beginning of modern economic analysis of the growth and distribution theory. At the time, the theoretical differences between post-Keynesian and neoclassical-Keynesian economics were still not clearly understood.

Decades later, the effect of technical progress reemerged as a subject of interest due to its neutral characteristic between wage and profit. Nicholas Kaldor argued that the stylized facts of constancies in the distributive share, the profit rate, and the capital/output ratio are inexplicable in the neoclassical production function. With capital deepening, the neoclassical assumption of diminishing returns implies that the profit rate will fall. Neoclassical economics found a solution to the stylized facts only when Paul Samuelson (1965) adapted Charles Kennedy's "Induced Bias in Innovation and the Theory of Distribution" (1964) to neoclassical theories. However, Kennedy disapproved of Samuelson's approach. Kennedy was well aware of the complications in the measurement of value and the production function. He had "hoped that the innovation-possibility frontier might be able, so to speak, to swallow up the traditional production function and replace it altogether" (Kennedy, 1966, p. 442).

Prior to Kennedy and Samuelson's argument on production function, W. E. G. Salter (1960) had developed a best-practice productivity movements model through price substitution that explained the dominance of labor-saving invention via the cheapening of the price of capital goods. In disagreement, Kennedy countered with a theory that avoided price substitution, instead describing neutral technical progress through bias in innovation from the relative share of capital and labor. Kennedy was indebted to Hicks for the development of his theory.[5] At first, Kennedy's primary concern (Kennedy, 1961; Kennedy, 1962a; Kennedy, 1962b) was the measure of value from innovations in the factors of production. He questioned whether new investment is needed under technical progress: the value of existing capital has to rise, or it requires an accumulation of new machines. His question is fundamental to the argument that Robinson and Harrod had earlier. Kennedy seemed to suggest the possibility of a consistent measure of value. He drew a curious conclusion that Hicks's neoclassical definition of neutral technical progress and Harrod's definition of neutral technical progress were equivalent. It should be noted that Kennedy's conclusion about the Hicks and Harrod neutral equivalency would likely come as a surprise to modern growth theorists. Notice here that Kennedy had not relied on the neoclassical production function or the restrictive assumption of constant elasticity of substitution.

We now have two concerns about technical progress: the measure of value and the neutrality of wage and profit in growth models. The two concerns are usually analyzed separately. This paper will analyze both concerns, starting with the history of economic thought method. The goal here is to clarify the complications in the measurement of value concerning technical progress that engaged our predecessors. Questions regarding the

measure of value and the existence of neutral technical progress should receive more consideration. I then describe the mathematical formulations of neutral technical progress and provide intuitions for the consistent measure of value suggested by Kennedy. The second section discusses concerns regarding the measure of value and technical progress. The third section analyzes neutral technical progress in growth models and the stylized facts. The fourth section provides intuitions behind the mathematical assumptions of the Kaldor and Kennedy theories.

2. Technical progress and the measure of factors of production

> "…to have labour measure. It implies that the average of money rewards paid to workers never rises… Is it not a little sadistic to seek to deprive men of this increment of pleasure, for the sake of —what? —a mere academic preference." (Harrod, 1948, p. 29)

The measure of factors of production was crucial to determine the change in the distributive share due to technical progress. Harrod was well aware of this complication, and he refused to use labor as the measure of value. This section sets out the difficulties faced by our Keynesian predecessors concerning the two issues of technical progress and the measure of value. It describes, in brief, what the difficulties are and how to resolve them.

Hicks was the first among his contemporaries to raise the question of the effect of progress upon distribution. He coined the term "elasticity of substitution" in his book *The Theory of Wages* (Hicks, 1932; Hicks, 1963) as a criterion to look at income distribution. Hicks was very clear in stating that his analysis was based on the neoclassical marginal

productivity theory of distribution and value. If the elasticity is equal to one, "the increase in one factor will raise the marginal product of all other factors taken together in the same proportion as the total product is raised" (Hicks, 1932, p. 117). The elasticity of substitution determines the change in relative price as affected by the increase in the factor of production. If the elasticity of substitution is biased toward labor, an increase in the supply of capital tends to move the relative share toward labor. However, Hicks's criterion was inadequate because the marginal productivity theory is ambiguous about the notion of capital. The question of how to measure the value of capital remained.

Furthermore, a more serious difficulty in Hicks' theory concerned the characteristics of invention. Technical progress is a term applied to the whole system, whereas invention relates specifically to a particular sector. An invention implies two separate effects: a saving of the volume of factor input needed in production and an increase in the value of its marginal product. First, an invention increases the efficiency of production by saving the amount of input factor used in production. The invention can be labor-saving, capital-saving, or neutral if it affects labor and capital in the same proportion. Second, in addition to the saving efficiency aspect, Hicks also defined bias-saving innovation as an increase in the unequal amount of each factor's marginal productivity. A contradiction was raised because in the former, saving invention refers to an existing volume of factors' input, whereas in the latter an increase in the marginal productivity assumes a rise in the value of factors' input. There is no problem identifying the amount of labor from the marginal product of labor. However, for capital, it is not clear how to determine the measure of capital. For example, the amount of capital stock might stay the same, but the price of it has to increase with the marginal product from an invention. If the

volume of capital stock increases simultaneously with the invention, we need Hicks's criterion of elasticity of substitution to determine its effect on distribution, assuming that we know the exact measure of capital. On the post-Keynesian side, Robinson and Harrod argued about the same theoretical problem in the measure of value.

Robinson (1937) wrote about technical progress in her chapter titled a "Long Period Theory of Employment" in the *Essays in the Theory of Employment*. Her book was an attempt to expand Keynes's ideas to various branches of economics. However, Harrod reviewed her chapter on technical progress with skepticism. Robinson used terminologies and theories laid down earlier by Hicks to determine the effect of progress on growth and distribution theory in the long-period equilibrium. The tangled relationship between the elasticity of substitution and invention described earlier made her analysis incoherent. Robinson retracted many of her propositions in her second edition (Robinson, 1947) as a result of her exchange with Harrod.

The definition of neutral invention was the focus of the exchange between Robinson and Harrod. With Hicks's definition, a neutral invention was an increase in the marginal product of capital and labor in the same proportion. Robinson applied Hicks's neoclassical foundation to analyze the long-period equilibrium and stated, "thus if a neutral invention occurs in conjunction with an elasticity of substitution equal to unity, the relative share of labour is unchanged" (Robinson, 1937, p. 133). A unity(one) of the elasticity of substitution implies that the price of labor relative to the price of capital is unchanged when there is a change in the supply of labor or capital. With a neutral invention that increases both the marginal product of capital and labor in the same proportion, the distributive share

will be constant in the long period. Once again, Robinson's experiment with marginal productivity theory implied that we can determine the exact measure of capital.

Harrod (1937) criticized Robinson based on the issue of the measurement of capital. He suggested instead an alternative definition to characterize inventions that is more general. Harrod proposed to "divide inventions into those which *at a given interest rate*, and an infinitely elastic supply of capital at that rate, increase, leave unchanged or diminish the length of the productive process" (Harrod, 1937, p. 329). Invention is characterized according to the length of the productive process to bypass the theoretical difficulties in value. Harrod made two assumptions. The first concerned the interest rate and an infinitely elastic supply of capital. He claimed that an infinitely elastic supply of capital is in agreement with Keynes's optimism. A horizontal supply will guarantee the existence of a constant interest rate. Second, Harrod asserted that the length of the productive process "is the most fundamental concept in defining the quantum of capital" (Harrod, 1961, p. 300). He chose to leave the interest rate and the measure of capital untouched. In effect, he did not have to consider the change in relative price from the elasticity of substitution. A neutral invention by Harrod's definition was summarized as an invention that "at a constant rate of interest, does not disturb the value of the capital coefficient" (the capital/output ratio) (Harrod, 1948, p. 23).

Joan Robinson responded in defense of her position with "Classification of Inventions" (Robinson, 1938). She accepted Harrod's criticism of the measurement of capital, but she insisted on using Hicks's conceptual framework. She illustrated graphically that an invention classified by Harrod as neutral is identical to an increase in the supply of labor with an unchanged technique. Neutral technical progress is an overall increase in the

efficiency of labor. In response to Harrod's criticism, Robinson argued that her illustration did not contradict her former analysis by using Hicks's classification.

> "Consider, for instance, the case in which an invention raises the average productivity curve of capital iso-elastically (so that the invention is neutral in Mr. Harrod's sense). In this case (with a constant rate of interest) the relative share of capital in the total product is unchanged by the invention: it follows from my former analysis that if, in this case, the elasticity of substitution with the new technique is equal to unity, then the invention must be neutral in Mr. Hicks's sense, while if the elasticity of substitution is less or greater than unity, the invention must be capital-saving or labour-saving, to a corresponding extent, in Mr. Hicks's sense." (Robinson, 1938, p. 141)

The Hicks neutral and Harrod neutral did have some congruities. In effect, Robinson jeopardized the argument even more because she asserted that both Harrod's method and Hicks's method were compatible as a classification of inventions.

This early debate among Hicks, Robinson, and Harrod has the same implications for the measure of value as the Cambridge Capital Theory Controversy. They were arguing over the measure of value in the growth and distribution framework. Harrod noticed the theoretical inconsistencies in the neoclassical foundation of the theory of distribution and value. Robinson, however, introduced a creative procedure different from those of her contemporaries. After Robinson's Classification of Inventions, interest in the theoretical formulation of technical progress concerning the measure of value died down, leaving many unanswered questions.

Years later, Joan Robinson raised the problematic issue of the measure of value again in her famous paper "The Production Function and the Theory of Capital" (1953-54) and her book *The Accumulation of Capital* (1956). She questioned the concept of a unit measure of capital and introduced "real capital", which marked the starting point of the formal Cambridge Capital Theory Controversy. Robinson's real capital, "reckoned in terms of labour time" (Robinson, 1956, p. 123), shows that the change in the distribution of income creates "perverse" relationships among the techniques of production. Robinson's measure of real capital was one of the appealing aspects of her argument in the Cambridge Capital Theory Controversy. However, in contrast to the earlier dispute, Robinson's focus was not on technical progress. She was skeptical about the neutral characteristic of invention in relation to capital accumulation. The prospect of neutrality in the measure of real capital "depends also upon how much accumulation took place while the technical change was being made. As we have seen, for the factor ratio to remain unchanged, when the inventions have been neutral, capital must have increased in the same proportion as output" (Robinson, 1953-54, p. 102). Robinson subsequently chose to focus on other problems more important than the neutrality of progress.

It was Charles Kennedy who attempted to reconcile this issue of technical progress and the measurement of new accumulated capital stock. In "Technical Progress and Investment" (Kennedy, 1961), he asked whether a new investment is needed for technical progress. The question, he noted, depends on the standard of measure of capital. "If a labour standard of value is chosen, no new saving is required: if, on the other hand, a good standard is chosen, as Harrod himself prefers, an increase in the capital stock is necessary"

(Kennedy, 1961, p. 232-233). Kennedy perceived a possible solution to the problem of capital accumulation in the labor standard of measure.

If the labor standard is chosen, there is no need for a change in the volume of capital. Kennedy illustrated this by using Joan Robinson's measure of real capital and her diagram (Robinson, 1953-54; Robinson, 1956): see figure 1 below. The horizontal axis represents real capital, and the vertical axis measures output. A shift due to an invention will raise the overall output: line NQ shifts to NQ'. Output per worker increases from OP to OP'. The wage follows through from W to W'. Furthermore, a higher wage increases the value of capital when multiplied by real capital. The volume of capital (OR, real capital) can stay the same, but the aggregate value of capital will rise because of the growth of wage from invention. In effect, we have a rise in the value of capital with a rise in wage that leaves the interest rate constant, which is the definition of neutral technical progress.[6]

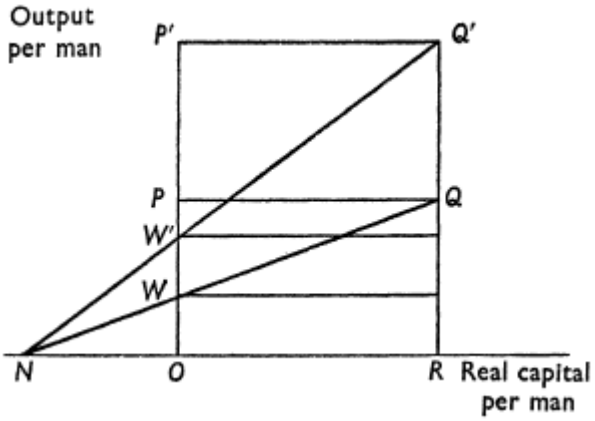

Figure 1 Kennedy's (1962a) adaptation of Robinson's real capital under neutral technical progress

This question about the new accumulation of capital stock for neutral technical progress was crucial to the measure of capital. Prior to Kennedy's formulation, Kaldor had expressed his skepticism about separating the movement along the production function

from the shift of the production function curve. Movement along the production function referred to an increase in capital stock, whereas the shift of the curve was an effect of technical progress. He noted that the distinction was "artificial and arbitrary" (Kaldor, 1957, p. 596). For this reason, Kaldor avoided the use of the unit measure of capital. In contrast, Kennedy questioned Kaldor's method and suggested that the measure of real capital can cope with both the movement and the shift effects.

In his second paper, "The Character of Improvements and of Technical Progress" (Kennedy, 1962), Kennedy expanded his theory to a multisector model to address the problem of accumulation. Kennedy suggested comparing the new accumulated machine to the old machine in labor cost (wage-unit). "For example, if the old machine is taken as standard, and the new machine costs x times as much as the old machine in terms of wage-units, then the quantity of capital embodied in the new machine can be said to be x standard "machines""(Kennedy, 1962a, p. 908). By specifically situating invention in the investment sectors, an improvement from invention will lower the labor cost of a machine, which will lead to an accumulation of more machines per worker. If the improvement is neutral, real capital (labor cost multiplied by the number of machines) will be unchanged. The aggregate real capital in terms of labor embodied stays the same as a reduction in the labor cost in capital production is offset by a new accumulation in the number of machines. Kennedy used this complex counting procedure to clarify the ambiguity of capital accumulation under technical progress.

Output increases through invention. The value of capital increases through a rise in wage. The rate of growth of the value of capital and wage will be the same. With unchanged real capital, the capital/output ratio stays constant. Kennedy summarized his accounting

among the number of machines, labor(wage-unit) cost, and real capital in the following passage:

> "The relationship between these three measures of capital is straightforward. If we multiply the number of machines by the cost of a machine in terms of wage-units, we obtain Mrs. Robinson's real capital. If we multiply real capital by the real wage, we obtain the value of capital in terms of the product." (Kennedy, 1962a, p. 903)

Neutral technical progress leaves real capital per worker unchanged, but the value of capital increases with the wage. Capital in terms of machines in the investment sector accumulates, but the aggregate real capital remains unchanged. Kennedy later used this mechanism to address Samuelson's objection to his accumulation scheme.

Kennedy's labor measure in real capital attracted Harrod's attention. Harrod had analyzed this issue before in his dialogue with Robinson, as discussed earlier. Harrod (1961) wrote an article in response to Kennedy's and reiterated his definition of neutral technical progress, stressing his view on the measurement of capital. In a rejoinder, Kennedy (1962b) pointed out that Harrod in fact had shown that the Harrod definitions of neutral technical progress and those of Hicks are equivalent. According to Kennedy's analysis, neutral technical progress implies that real capital per worker will remain unchanged. With a constant interest rate, Harrod neutral technical progress leaves the capital/output ratio unchanged. An increase in the wage leads to a rise in the value of aggregate capital. Kennedy asserted that this narrative of Harrod neutral technical progress can be translated into a rise in the marginal product of both capital and labor in the same proportion, which is Hicks's neoclassical definition of neutral technical progress. The

controversy over the two competing definitions was created because of the "lack of care in the measurement of capital" (Kennedy, 1962b, p. 250).

Kennedy had provided an alternative measure for capital in Robinson's concept of real capital. However, Kennedy warned that "because of the very restrictive assumptions made, too great claims should not be made" (Kennedy, 1962a, p.909). The analysis in this section has set out the difficulties in measuring value and technical progress. The problem at the center of the debate was to find a consistent measure of value to explain the neutrality in the distribution of income. This overlooked theoretical debate merits further consideration.

3. Stylized facts and the existence of neutral technical progress

The third part of this paper describes the intuitions behind the modifications of the definition of neutral technical progress in growth and distribution models. The focus of this section concerns the existence of the neutral technical progress conditions. Our Keynesian predecessors were arguing about the mechanism that explained this neutrality. We have two theories describing the existence of neutral technical progress. The first theory was from Nicholas Kaldor, who introduced the technical progress function that fits his economic stylized facts. For the second theory, Charles Kennedy provided a different treatment of neutral technical progress by using the biased character of invention. Neoclassical economics failed to replicate the neutral results when the elasticity of substitution was less than one until Samuelson adopted Kennedy's method. However, Samuelson's use of the production function started a dispute with Kennedy because of the complications in the measurement of value described earlier. Toward the end of this

section, the paper discusses Salter and Kaldor's vintage method, which focuses on net investment due to the complication on the measure of capital. This section aims to provide a clearer picture of the neutral technical progress theoretical puzzle. It is crucial to define our question first as some assertions are not consistent with the current literature (e.g., on the equivalence of Hicks and Harrod neutral technical progress).

The last section started with a quote by Harrod in which he refused to use labor as the measure of value. Perhaps Harrod forgot about the more important aspect of technical progress: that it explains a rise in labor productivity and the wage. If technical progress is neutral, the economy moves to a higher stage with constancies in the distributive share, the rate of profit, and the output/capital ratio. The wage is predetermined to rise along with economic growth. Neutral technical progress is a win-win for both capital and labor. Labor-saving inventions are acknowledged as dominant forces in the economy. However, the empirical outcomes of this mechanism were implicit in the analyses of Hicks, Harrod, and Robinson. It was Kaldor's narrative of stylized facts that emphasized these properties and attracted a wider audience.

In contrast to his Keynesian contemporaries, the previously implicit properties of technical progress were explicit in Kaldor's writings. He suggested that economists should build a model that conformed to economic stylized facts of constancies in the distributive share, the capital/output ratio, and the rate of profit. Kaldor proposed the technical progress function that fits the narrative and explains the interdependencies among economic variables. As a result, Kaldor provided the first endogenous growth model of neutral technical progress that conforms to the stylized facts and shows the irrelevancy of the neoclassical production function.

Kaldor (1957, 1961) stressed that the neoclassical production function was incompatible with the stylized facts. The production function "is assumed to be a unique relationship between capital and output, which conforms to the general hypothesis of diminishing productivity, but this relationship is constantly shifting with the passage of time" (Kaldor, 1961, p. 203-4). Kaldor asserted that technical progress is treated as a simple exogenous shift of the production function. The existing capital stock represents the optimal state on the production curve, but it has to separate the effect of technical progress from new accumulation. Technical progress in neoclassical theory becomes a circular determination from the shift in the production function and the move along the production function. Marginal productivity theory cannot guarantee that factor rewards will be paid since the shift in the production function and movement along the production function blur the concept of the factor of production. Kaldor concluded that "any sharp or clear-cut distinction between the movement *along* a 'production function' with a given state of knowledge, and a shift in the 'production function' caused by a change in the state of knowledge is arbitrary and artificial" (Kaldor, 1957, p. 959).

Kaldor proposed instead the "'technical progress function' which postulates a relationship between the rate of increase of capital and the rate of increase in output and which embodied the effect of constantly improving knowledge and know-how, as well as the effect of increasing capital per man, without any attempt to isolate the one from the other" (Kaldor, 1961, p. 207). In effect, Kaldor had integrated both a shift in the production function and a movement along the production function into one postulate of his technical progress function. The capital/output ratio is constant because of the equal rate of growth for both capital and output. With full employment, technical progress will be neutral, with

constancy in the distributive share. Kaldor's technical progress function conforms to his previous observation on the stylized facts.

However, according to Kennedy, Kaldor's model was a theoretical description of the stylized facts, not an explanation. The technical progress function did not set out an adequate mechanism to explain why the rate of growth of capital should equal the rate of growth of output.[7] Instead of using the nature of invention as did his contemporaries, Kaldor relied on assumptions of entrepreneurial investment behavior. Entrepreneurs will invest according to a prospective rate of profit that has adjusted to maintain a constant output/capital ratio. Kaldor provided a lengthy comment on the nature of entrepreneurs' expectations. In the case that the rate of accumulation is less than the rate of growth of output, the output/capital ratio is higher than the equilibrium rate. As a result, entrepreneurs will see the prospect of higher profits. They will increase the accumulation rate to adjust to equilibrium. Invention will appear to be labor-saving or capital-saving according to the adjustment of the rate of accumulation to the technical progress function. The capital/output ratio will adjust to the same rate. However, the adjustment mechanism of Kaldor's technical progress function had weaknesses. Kaldor relied on the behavior of the representative firm in the investment function instead of the nature of invention. Kennedy commented that in Kaldor's formulation, the output/capital ratio was assumed constant a priori. The deficiency of Kaldor's technical progress function was that "Mr. Kaldor had already assumed what he was trying to prove" (Kennedy, 1962a, p. 910).

The existence of neutral technical progress was the more important question. Hicks had previously commented on the dominance of labor-saving inventions in the real economy. He suggested that labor-saving inventions are a predictable outcome because the

cost of labor is high compared to the cost of capital. Capitalists will choose to develop an invention that saves the cost of labor. Hicks's theory of bias in innovation relied on the assumption that we know the factor price substitution between labor and capital. In the last section, we discussed this difficulty. Salter (1960; 1966) put forward his argument on technical progress based on Hicks's framework of the elasticity of substitution, but he argued that entrepreneurs are interested in reducing total cost, and so there should not be an induced bias toward labor-saving inventions. Neutral technical progress is seemingly a result of price substitution from cheaper capital.[8] Salter assumed an ex-ante neoclassical production function in his theory of investment decision-making. In each successive period, new technical knowledge changes the shape of the production function. "Parallel with the improving technical knowledge are changing relative factor prices. Both combine to determine the nature of the flow of new techniques coming into use—best-practice techniques" (Salter, 1966, p. 23). The two components—new technical knowledge and factor prices— determines the character of technical progress. If labor-saving invention is not already inherent in the new technical knowledge, there is no reason invention will be labor-saving. Hence, in contrast to Hicks's theory of induced invention, Salter asserted that it could only be the cheaper price of capital that substitutes for labor, thus resulting in labor-saving bias.

Kennedy noticed the defects in Salter's argument concerning price substitution. Kennedy's theory was an accumulation of his previous inquiries. He was hoping to retain some of Hicks's intuitions and provide a concise theoretical foundation for neutral technical progress that did not have to use price substitution and the production function as in Salter's theory. Kennedy made use of his analyses of the value of capital and the equivalency of

Hicks and Harrod neutral technical change to build a model of biases in innovation. He asserted that "changes in relative factor price are not essential for a theory of induced bias in innovation" (Kennedy, 1964, p. 542).

In Kennedy's formulation, the constancy of the distributive share from neutral technical progress is the result of an adjustment of unit cost reduction constraint on the condition of innovation. Kennedy considered the share, instead of factor price, in the cost of production as a whole. The system chooses bias in innovation, which affects the share of labor cost and capital cost: $\lambda p + \gamma q = reduction\ in\ unit\ cost$, where λ is labor cost share, γ is capital cost share, and p and q are labor and capital saving improvement, respectively. The reduction in unit cost depends on the interaction of labor (p) and capital (q) saving improvement with their share in the cost of production. Furthermore, the reduction in the unit cost constraint adjusts according to the feasibility of invention. The "innovation possibility frontier" between labor-saving innovation and capital-saving innovation is concave, $\emptyset(p, q) = 0$. "If the labour costs are high relative to capital costs ($\lambda > \gamma$) he will search, *ceteris paribus*, for a labour-saving innovation. If capital costs are high relative to labour costs he will search for a capital-saving innovation" (Kennedy, 1964, p. 543). The reduction in unit cost is subjected to a trade-off between labor and capital improvement. Kennedy structured his theory as a straightforward optimization of the reduction in unit cost constraint ($\lambda p + \gamma q = reduction\ in\ unit\ cost$) to the concave innovation possibility frontier ($\emptyset(p, q) = 0$).

If $p \neq q$, there will be an adjustment with bias in innovation. An improvement will alter the cost share according to the innovation possibility frontier. The system will adjust until $p = q$, when there will be no change in the distributive cost share (λ, γ). At

equilibrium, the distributive share will not alter in the next period. The system exhibits Hicks neutral technical change, where there is the same rate of labor-saving and capital-saving innovations. Moreover, the equilibrium tangent determines the distributive share between capital and labor. Kennedy asserted that "in the long run the equilibrium values of the distributive shares will be determined by the characteristics of the purely technological innovation possibility function" (Kennedy, 1964, p. 545). Notice here that the distributive share does not change in the next period only when $p = q$ with Hicks's definition of neutral technical progress.

Furthermore, in the second part of his paper, Kennedy went beyond his previous assumption of no capital accumulation. If improvement occurs in the investment sector, Kennedy assumed that there will be accumulation of new machines, which will leave the real capital unchanged due to the fall in capital cost with the same amount of labor. The improvement in the investment sector disturbs the previous equilibrium when $p = q$. The system adjusts to maintain equilibrium by focusing on endogenous labor-saving inventions. More machines will be augmented to the previous equilibrium condition of Hicks neutral technical progress. The system adjusts to Harrod's neutral technical progress with a labor-saving invention bias. Kennedy asserted that Kaldor's stylized facts "are to be explained by the neutrality of technical progress for the economy as a whole, a neutrality in which the generally labour-saving character of individual improvements is balanced by the fact that some of the improvements take place in the capital sector" (Kennedy, 1962a, p .911). Kennedy came to the conclusion that Hicks neutral technical progress is equivalent to Harrod neutral technical progress as discussed in the last section.

Without considering the complications in the measurement of value, Samuelson (1965, 1966) adapted Kennedy's innovation possibility frontier for the neoclassical production function when the elasticity of substitution is less than one to answer the question posed by Kaldor's stylized facts. However, Samuelson significantly deviated from Kennedy's formulation. Samuelson insisted on using factor price theory derived from the production function. In effect, he neglected the complex structure of value from capital to labor and did not consider the equivalency of Hicks and Harrod neutral technical progress. Samuelson's forceful introduction of factor price changed the previous assumption about the cost share of the factor of production. According to marginal productivity theory, price is determined by factor scarcity. Hence, Samuelson's distributive share is determined in the competitive market, which is in sharp contrast to Kennedy's endogenous determination of the distributive share on the innovation possibility frontier.

Samuelson simulated Kennedy's results using a pure neoclassical method. If the innovation possibility frontier is symmetric and the factor input ratio does not change, Samuelson obtains stable equilibrium results from Hicks neutral technical change and a strange equal dividend of factor share.[9] Samuelson showed that his use of factor price on the innovation possibility frontier can also yield results similar to Kennedy's. The outcomes are due to the restrictions that there is no factor accumulation and the innovation possibility frontier is symmetrically given. However, with steady capital accumulation, Samuelson asserted that Kennedy's results for Hicks neutral technical change were inconsistent.

Samuelson demonstrated his argument by dropping an assumption of a fixed factor ratio and "replacing it by the more realistic recognition that capital is 'deepening relative to labor'" (Samuelson, 1965, p. 348). If the elasticity of substitution is less than unity, labor's

relative share will tend to rise more than capital's relative share. There has to be a bias in invention that offsets diminishing marginal productivity from accumulated capital. Samuelson showed that this scenario happens only under Harrod neutral technical progress with a labor-saving invention. It is impossible to retain Hicks's neutrality as in Kennedy's model. Output will keep up with the constant capital/output ratio with labor-augmented invention and less efficiency for capital. The concept of elasticity of substitution and bias technical change are to remain in neoclassical endogenous growth models (Acemoglu, 2003; León-Ledesma and Satchi, 2015).

Kennedy (1966) objected to Samuelson's use of the production function.[10] He demonstrated that Samuelson's capital accumulation could be reconciled with his theory: "in Kennedy's case, the Harrod-neutral result is not 'supposed to come about,' it *does* come about" (Kennedy, 1966, p. 442). The disagreement between Samuelson and Kennedy echoes the complication of value we discussed in the second section. Because of their different treatments, Samuelson would deny the equivalency between Hicks and Harrod neutral technical progress, whereas Kennedy insisted otherwise. As a result, Samuelson established Harrod's definition instead of Hicks's as the standard exposition of neutral technical progress in the growth and distribution literature. Their disagreement about the theory of neutral technical progress, which aimed to implement the stylized facts, was due to the controversy over the measurement of capital.

Furthermore, Samuelson's solution on bias in innovation was to address the elasticity of substitution less than one. When the production function exhibits constant elasticity of substitution, i.e., the Cobb-Douglas production function, capital accumulation will always be neutral in neoclassical "balanced growth". It can be shown that Kaldor's

technical progress function is just another form of neoclassical production function (Black, 1962). Due to the many criticisms of his linear technical progress function, Kaldor put forward another endogenous growth model: A New Model of Economic Growth (Kaldor and Mirrlees, 1962), which addressed and clarified many of the criticisms of his previous models.

As noted earlier, although Salter relied on neoclassical production function and price substitution, Kaldor, in an attempt to discard any connections to the production function, used the vintage method pioneered by Salter. The Salter process[11] focused on the initial investment in each period due to technical progress. Salter was aware of the complications in measuring capital. He proposed instead to focus on an analysis of obsolescence and scraping of each vintage of machines. Salter (1965) compared his theory to Ricardo's quasi-rents. The investment decision to replace the existing capital stocks depends on the prospect of quasi-rents the capital stocks have in the next period. A new investment is encouraged by the change in conditions, making the quasi-rents of the existing capital stocks go down in each successive period. Focusing on the initial investment, there is no need to measure capital directly. Salter proposed that "by replacing capital in the production function by this less ambiguous concept of investment, we are forced to recognize the time element in technique decisions" (Salter, 1966, p.18).

Kaldor used Salter's concept to modify his technical progress function. Previously, Kaldor had set up the technical progress function between a relation of the rate of growth of output and the rate of growth of capital. In the New Model of Economic Growth, the new technical progress function instead depicts a relation between the rate of growth of productivity per worker and the rate of growth of investment per worker. Notice that it is

the rate of growth of investment that comes from Salter's theory. Kaldor was more explicit in avoiding the measure of capital stock, addressing the previous critique that his technical progress function was just another form of the neoclassical production function.

This section has described the intuitions behind the modifications of neutral technical progress in growth and distribution models. Kaldor made explicit statements about the nature of economic growth and the fact that wage was predetermined to rise. The focus of this section concerns the existence of the neutral technical progress conditions. Kaldor had assumed an automatic process based on the technical progress function. Kennedy relied on the framework of bias in innovation. His modification went back to the complication in the measure of value debated in the early years of the Keynesian revolution. In contrast, Samuelson had fulfilled the task of neoclassical economics by attaching the marginal productivity factor price theory to neutral technical progress. Neoclassical economics had discarded this complication in the measure of value and confined to Samuelson's formulation. On the other hand, Kaldor introduced a vintage method pioneered by Salter that focused only on investment to avoid the use of the measurement of capital. I want to emphasize Kennedy's solution for neutral technical progress and the measure of value. Kennedy's model based on Joan Robinson's real capital did not get the credit it deserved. The next section focuses on the mathematical formulations of neutral technical progress theories.

4. Neutral technical progress along the Kaldor-Kennedy line

The effect of progress upon distribution is a long-period analysis. Both Kaldor and Kennedy made assumptions that the profit rate and employment are constant. Kaldor had

been teased by Samuelson before as "Jean Baptiste Kaldor" (Samuelson, 1964, p. 235) because of these long-period assumptions. The neutral long-period tendency of the effect of technical progress was the central question they had in mind. This section will describe the differences in mathematical assumptions used by Kaldor and Kennedy in income accounting form. Both models provide the same conclusion of neutral technical progress. However, the intuitions are different, as may be shown in the behavior of their variables. At the end of the section, I use the concept of labor measure to provide another intuition on neutral technical progress.

Distributive income accounting is shown by

$$1 = w\frac{L^*}{Y} + r^*\frac{K}{Y} \qquad (1)$$

Labor (L^*) and profit (r^*) are assumed constant. The remaining variables are wage (w), capital (K), and output (Y). The neutral technical progress model needs to explain the behavior of these variables to achieve the neutrality result.

Kaldor explained neutral technical progress through the relation between capital (K) and output (Y). His technical progress function depicts an equal rate of growth between capital and output. Kaldor relies on assumptions of entrepreneurial investment behavior. If the rate of capital accumulation is less than the rate of growth of output, entrepreneurs will see the prospect of profitability. A new investment will increase the accumulation rate to adjust to the rate of growth of output. Invention will appear to be labor-saving or capital-saving according to the adjustment of the rate of accumulation that offsets the technical progress function. In effect, the investment behavior of entrepreneurs will maintain the constancy in the capital/output ratio. The distributive income accounting identity will change as shown in equation 2 with a constant capital/output ratio in the parenthesis.

$$1 = w\frac{L^*}{Y} + r^*\left(\frac{K}{Y}\right)^* \qquad (2)$$

With constancy in the capital/output ratio, an increased output will increase capital in the same proportion. Because of the constant profit rate and employment in the income identity, technical progress will leave the profit share of the income identity unchanged. It follows that the wage will increase in the same proportion as a result of an increase in output. Kaldor obtained his stylized facts with the same rate of growth of output, capital, and wage.

In the case of Kennedy, neutral technical progress is a result of bias in innovation. In contrast to Kaldor's investment behavior, Kennedy adopted Hicks's insight on the character of invention to explain the neutrality. The economic system optimizes the cost share between capital and labor to the innovation possibility frontier. An endogenous labor-saving invention is due to an improvement that occurs in the investment sector, thereby disturbing the previous distributive share. Endogenous bias in innovation induced from the disturbance in distributive share will adjust the system to the same distribution. Notice that it is the distributive share that now controls the behavior of the equation. The income accounting identity would change as in equation 3 with constancy in the distributive share in parentheses.

$$1 = \left(w\frac{L^*}{Y}\right)^* + \left(r^*\frac{K}{Y}\right)^* \qquad (3)$$

Technical progress increases the amount of overall output. With Kennedy's bias in innovation, the distributive share is constant. The denominator (Y) increases in both sets of parentheses. Since the distributive share is constant, any increase in output from technical progress will add to the wage share and the profit share in the same proportion. Wage (w) will increase along with the value of aggregate capital (K).

Equations (2) and (3) show the basis of Kaldor's and Kennedy's models for implementing neutral technical progress on the distributive income accounting identity. First, Kaldor used the equal rate of growth of capital and output. Second, Kennedy focused on the character of cost share optimization. Their approaches to neutral technical progress were efforts to overcome the complications in the measure of value, which affected income distribution.

However, Kennedy was more explicit about the measure of value. He suggested using labor as the measure. If capital is a function of labor measure $K = f(w, L^*)$, it follows that the income accounting identity would change as indicated in equation 4.

$$1 = w\frac{L^*}{Y} + r^*\frac{f(w,L^*)}{Y} \qquad (4)$$

The function of the labor measure $K = f(w, L^*)$ has to take a specific form for the effect of technical progress to be neutral. As shown by Kennedy, using Joan Robinson's real capital: $K = wL^*$, the value of capital depends on the wage. Capital will increase only when wage increases because of the behavior of labor measure. With an increase in output, the rate of growth of output will be equal to the rate of growth of capital and the rate of growth of the wage: $g_y = g_k = g_w$. Equation 4 shows that Joan Robinson's labor measure also gives the same result along the Kaldor-Kennedy line of neutral technical progress.[12]

5. Conclusion

"The 100 per cent pseudo labour theory of value is no labour theory of value at all!"

(Samuelson, 1998, p.330)

This paper describes the development of the analysis of the effect of technical progress along the Kaldor-Kennedy neutrality line. Crucial theoretical problems concerning the measurement of capital and the character of technical progress deserve

more attention. Particularly, the effect of technical progress theory is related to the famous Cambridge Capital Theory Controversy. Although overlooked, the intuitions behind the analysis of neutral technical progress are rich and profound. Hicks, Robinson, and Harrod had written about the relation of the measure of value to the effect of technical progress prior to the controversy. Their inquiries led to the establishment of the criteria to distinguish the effects of technical progress on the distributive shares.

Kaldor raised the question again when he put forward the stylized facts of constancies in the distributive share, the profit rate, and the capital/output ratio. Although he was aware of the complications on value, Kaldor proposed the technical progress function, which did not relate to the measure of value pioneered by Salter. In contrast, Kennedy attempted to solve both problems: the measure of value and the neutrality of technical progress. Kennedy suggested that Joan Robinson's measure of real capital was consistent with the neutral technical progress analysis. Kaldor and Kennedy's theories are the foundation of the modern endogenous growth model.

The long-period position of the neutral technical progress theory implies a win-win capitalism. The neoclassical-Keynesian balanced growth theory is analogous to the post-Keynesian neutral technical progress. Although Kaldor later changed his mind to focus on his Mark 2 models (Harcourt, 2006), concentrating on history versus equilibrium and Adam Smith's increasing returns, it is worthwhile to examine the connection of our Keynesian predecessors to the long-period analysis of the classical political economy first. Furthermore, in the last two decades of his life, Samuelson (2000a; 2000b) came back to address Sraffa's interpretation of classical economics regarding linear analysis and returns

to scale. The debate on neutral technical progress is connected to the classical theory of value.

The implications of the measure of value for neutral technical progress are significant. They suggest the possibility of reconciling a consistent theory of value with the growth and distribution literature. The post-Keynesians and the neoclassical-Keynesians share a common concept of neutral technical progress. This paper describes the history of thought behind the analysis. There are useful intuitions from the effect of technical progress debate to be reconsidered regarding the measure of value in the framework of the Cambridge Capital Theory Controversy.

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Footnote

1 see Martin (2016). See also Harcourt's assessment (2015b) of Piketty's *Capital in the Twenty-First Century.*

2 Dorfman, Samuelson and Solow, 1958, Ch. 12. See also Harcourt (2015a, p.247) cited from Gram (2010, p.362). The neoclassical production function is discussed extensively in Felipe and McCombie (2013).

3 See Robinson (1956, p. 99)

4 See also Tavani and Amparelli (2017) for a survey of endogenous technical progress

5 See Thirlwall (1999)

6 However, Kennedy also pointed to the complications of a multi-sector scheme and the obsolescence/depreciation of capital. Neutral technical progress in the system as a whole would complicate the matter and require some net investment (accumulation).

7 Harcourt (1963, p.24; 1982, p.72) commented that "it is unrealistic to assume that businessmen desire to maintain a constant relationship between capital invested and output." This argument came from James Meade and Hugh Hudson, which Kaldor addressed in the Corfu Capital Theory Conference (1961, p.212). See also Harcourt (2006, p.114) for further discussion.

8 See also Kennedy and Thirlwall (1972, p.21) and Harcourt (1962, p.390)

9 Kindleberger effect (Samuelson, 1964, p. 346)

10 Kennedy criticized Samuelson's use of mathematic weight in the production function as improper because there were inter-correlations from the production function that would alter the innovation possibility frontier.

11 Harcourt commented that the Salter process "is worthy to be called a major break-through" (1972, p.66, p.73)

12 Moreover, the conflict between Kaldor and Robinson was from their claims on Keynesian distribution theory, see King (1998). Robinson has provided a lengthy analysis on the effect of technical progress. However, it was Kaldor who dominated the literature of endogenous growth models. Their writings seem to be disconnected. This paper hopes that the analysis of neutral technical progress and the measure of value can bridge some gaps between their contributions.