**Entrepreneurs, Sticky Competition and the Schumpeterian**

**Cobb-Douglas Production Function**

**Mo Pak-Hung**

[phmo@hkbu.edu.hk](mailto:phmo@hkbu.edu.hk)

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Hong Kong Baptist University

School of Business

Department of Economics

**Abstract**

In this paper, we institute the role of entrepreneurs in technical progress and the mechanism of tools multiplication into the Cobb Douglas Production Function. After the advancements, the technology component in the function has technical meaning and is potentially observable. Unlimited technical progress becomes possible and automatic under sticky competitive markets. The coexistence of sustained growth, decline and stagnation across countries and time becomes obvious and the target of public policies for achieving sustained growth is clear and precise.

**Key words**: Entrepreneur, Sticky Competition, Cobb-Douglas Production Function, Endogenous Growth, Technical Progress, Tools Variety.

**JEL Classification**: O4, D2.

**1. Introduction**

‘My own favourite how-to-do-it injunctions are: (i) keep it simple; (ii) get it right; and (iii) make it plausible. (By getting it right, I mean finding a clear, intuitive formulation, not merely avoiding algebraic errors.’ <Robert Solow, 2007>

The Cobb-Douglas Production Function (CDOPF) has been chosen to investigate numerous economic problems for decades. It derives merits from its simplicity, easy to handle, transparent and encompassing in capturing the key elements determining aggregate output and growth. However, the production function is not developed on the basis of any knowledge of engineering, technology, or management of the production process. The technical element is exogenous, not independently measured and is considered only as the residual in the growth accounting exercise. Moreover, the diminishing marginal product in the function generates the gloomy prediction that every economy will finally stop growing and more importantly, the prediction is counterfactual. Despite all these criticisms, it is still the most popular functional form adopted in numerous economic investigations that have generated many useful theoretical and empirical results. Because of the remarkable merits, it is highly desirable to retain the basic structure of CDOPF along with the merits while eliminate the above-mentioned shortcomings.

In our model, the insights of Schumpeter (1934) on entrepreneurs and innovations, the possibility of quasi-rent for financing innovative activities under a ‘sticky competitive market structure’ as illustrated in Shell (1973) and the contribution of input/product variety to productivity attributed to Dixit and Stiglitz (1977) are instituted into the CDOPF. With the advancements, technology and its progress in the CDOPF are no longer a black box and being exogenous. They are embedded in the combinations of tools, machines and materials adopted by profit-maximizing entrepreneurs in their production process. In a sticky competitive environment, the potential short-run innovative rent generated from the lower production cost than the market provides incentive and financial source to entrepreneurs for conducting innovative activities. In the longer-run, the advanced production method is imitated by competitors. The spillovers of technical advancements to the whole economy raise the marginal product of investment and therefore induce more capital accumulation. Sustained increases in technology, investment and output are therefore automatic under the market mechanism. With the enrichments, the coexistence of sustained growth, decline and stagnation across countries and time becomes obvious and the target of public policies for achieving sustained growth is also clear and precise.

The divergence of our model from the current endogenous growth theories such as Romer (1990) is that sustained growth is driven by profit-maximizing entrepreneurs under a price taking sticky competitive market structure. Under the market structure, they innovate in order to capture the innovative quasi-rent or to catch up for survival. The framework is more straight-forward than the monopolistic R&D framework. The implications from the model are also richer, have stronger explanatory power and empirical contents. The growth determining factors implied by the current endogenous growth models such as R&D activities, government supports and human capital become neither necessary nor sufficient to sustained growth. We instill technical meaning into the technology component in the CDOPF and explain the automatic technical progress directly from the profit motive of entrepreneurs in their production process. This Schumpeterian Cobb Douglas Production Function (SCDOPF) is the direct extension of the CDOPF. It is highly transparent and operational which makes many important issues on economic growth and development have obvious and straight-forward answers. The voluminous literature questing for sustained growth is gauged into the level and effectiveness of entrepreneurial activities that drive the growth rate of tools variety.

The rest of the paper is organized as follows. Section 2 derives the SCDOPF by incorporating the role of entrepreneurs, tools variety, competition through innovations and the mechanism of tools multiplication into the CDOPF. It is followed by the discussion about its direct implications on some important issues of economic development and growth. The final section concludes the paper.

**2. Entrepreneurs, Tools Varity, Sticky Competition and SCDOPT**

‘Economic leadership in particular must be distinguished from “invention.” As long as they are not carried into practice, inventions are economically irrelevant. And to carry any improvement into effect is a task entirely different from the inventing of it, and a task, moreover, requiring entirely different kinds of aptitudes. Although entrepreneurs of course may be inventors just as they may be capitalists, they are inventors not by nature of their function but by coincidence … It is, therefore, not advisable, and it may be downright misleading, to stress the element of invention as much as many writers do.’ < Schumpeter, 1934 >

A theory of economic growth is a dynamic theory of production. It investigates how the input-output relationship changes over time. A major focus of researches on economic growth is therefore searching for a production function that can capture the fundamental inputs in production as well as how and why they might change over time. In recent decades, the endogenous growth theory can be considered as the effort to establish a production function that can explain sustained economic growth. The simplest theoretical model of endogenous growth is the *AK* model of Rebelo (1991) where he postulated that output is proportional to a broad concept of capital (*K*) thatcould include stock of knowledge, technology, and organizational technique. Capital can therefore be built up over time without limit that makes sustained growth possible. Romer (1986 and 1990) attempts to introduce the possibility of sustained growth by invoking knowledge or human capital as an additional factor of production which does not subject to the law of diminishing productivity. The specification in Romer (1990) emphasizes the importance of R&D while Romer (1986) shows that specialization and scale are important determinants of the rate of growth. As a result of the changes in assumption, human capital becomes the determining factor of sustained growth in his later contribution instead of country or population size as in Romer (1986). The contributions initiate various attempts to endogenize technical progress and to find other possible causes of sustained economic growth such as product quality improving innovations as modeled in Grossman and Helpman (1991a) and Aghion and Howitt (1992).

However, there is no shortage of negative comments on the endogenous growth models. For instance, as observed in Jones (1995), the endogenous growth literature has turned to a class of models in which growth is driven by technological change that in turn determined by R&D efforts of profit-maximizing agents in a monopolistic R&D sector. Introducing human capital and the R&D sector as the drivers of technical progress has made the implications from the models highly sensitive to their specific assumptions. In addition, the models fail to generate supportive empirical literature and the implications can easily be refuted by casual observations. After a thorough review on the endogenous growth models, Pack (1994) concluded that: ‘the long-term imprint of any growth theory must ultimately depend on the extent to which it generates a productive empirical literature. In this task, endogenous growth theory has led to little tested empirical knowledge.’ Obviously, there is a lot of room to advance in the endogenous growth literature by making the implications less restricted by the assumptions and parameters in the models while at the same time, having stronger explanatory power on the real world phenomena related to the causes and mechanism of sustained economic growth.

**2.1 Innovation, Entrepreneur and Tools Variety**

"Anything that we have to learn to do we learn by the actual doing of it: people become builders by building and instrumentalists by playing instruments." <Aristotle. Cited in: Dasgupta and Stiglitz (1988)>

Schumpeter (1934) emphatically distinguishes innovations from inventions. An invention is an idea, a sketch or model for a new or improved device, product, process or system. Such inventions do not necessarily lead to technical innovations. In fact, the majority do not. An innovation in economic sense is accomplished only with the first commercial transaction involving the new production method, device, product is completed. The chain of events from invention to economic application is often long and risky. Schumpeter always stresses the crucial role of entrepreneurs in this complex innovative process. As stated in Schumpeter (1934), the carrying out new combinations can no more be a vocation than the making and execution of strategic decisions. The entrepreneur’s essential function must always appear mixed up with other kinds of activity. However, everyone is an entrepreneur only when he actually carries out new combinations. In this section, we extend the CDOPF by incorporating the insights of Schumpeter (1934) relating to the role of tools, the nature of innovations, the function of entrepreneurs and competition through innovations in economic development process. The most common type of innovations is the introduction of new tools variety that can raise the productivity of the firm. Real-world examples include steam engine, train, and computer that generate new mixes of tools variety for communication, transportation, education, manufacturing and finance. They substantially lower the costs for satisfying many needs and wants. Of course, innovations need not be as revolutionary as the examples. Most innovations are just incremental improvements based on old production methods. In the production process, a routine job of entrepreneurs is to select an optimal combination of tools to minimize/maximize cost/profit. In a competitive environment with imitation lag, entrepreneurs are supported and induced to innovate by innovative quasi-rent and/or are pressed to innovate and catch up for long-run survival.

There are two fundamental inputs in the model, labor and a set of tools that generate capital services.[[1]](#footnote-1) Behind the production scene is entrepreneur who is responsible for decision-making, risk-taking and most importantly, conducting innovative activities. Innovation is defined as introducing a new mix of tools in the production process that can raise the productivity of capital service. The output level (Q*j*) depends on the amount of capital service (*Kj*) and labor (*Lj*) employed by representative firm *j*, such that:

 with*α* + *β* = 1 ; and 0 < *α* < 1 . (E1)

In order to introduce the contribution of innovations in the production process, we follow the product/input variety literature attributed to Dixit and Stiglitz (1977). A combination of tools is aggregated by the CES function that gives a positive value to an increase in tools variety in generating the capital service, such that:

, (E2)

with 0 <*θ* < 1 and, *i* = *1* to *vj*.[[2]](#footnote-2)

The parameter *θ* is greater than zero and less than one that governs the elasticity of substitution between the tools. A higher value of *θ* indicates that the tools variety (*Xij*) can be more easily substituted for each other in the production of capital services while a lower values of *θ* correspond to greater differentiation among the set of tools. The capital service function has identical structure as in Dixit and Stiglitz (1977) that are followed closely by the others. Similar functional form is then adopted in the works of Ethier (1982) for introducing the gains caused by the increase in input variety to study the implications on international trade. The conventional Cobb-Douglas production function treats all man-made tools for enhancing production are perfect substitutes that is equivalent to considering *θ* equals one.[[3]](#footnote-3)

The measurement unit of each tool is normalized so that the unit price of each tool equals to *r*. For all output level, a profit-maximizing entrepreneur in firm *j* choose an optimal level of each tool, *Xij\**, *i = 1…h,…vj ,* to maximize the value of capital servicesubject to a given allocated for capital service with =. The first-order conditions and the symmetry imply that for all *i*, *Xij\* = Xhj\* = (r, , Vj)*, with , , ; where *Vj* is the number of tools variety exogenously given to firm *j*. Therefore, for all output level,

** = ** , (E3)

(E3) indicates that the Dixit-Stiglitz capital service function can be decomposed into the variety component, *Vj*and the tools component *Xj*. Capital service now has an exact definition. It is an aggregation of the tools adopted by the cost-minimizing entrepreneurs in production. Moreover, the higher the *Vj*, the higher the productivity of  and the lower the average cost of capital service (*/*) for all .[[4]](#footnote-4) Substitutinginto (E1), we have:

 = ; where *Aj* equals. (E4)

The formulation results in *Aj* equals  in the CDOPF. The ‘*Aj*’ in the CDOPF has observable and transparent definition which is the number of tools variety adopted by the profit-maximizing entrepreneurs in production. The higher the *Vj*, the higher the productivity of capital service and the lower the average cost of production.

**2.2 Creative Destruction in the Price-taking Sticky Competitive Market Structure**

“Development in our sense is then defined by the carrying out of new combinations….new good…new quality of a good…new method of production…new way of handling a commodity…new market…new sources of supply of raw materials…new organization of any industry…*new combinations should be carried out by the same people who control the productive or commercial process which is to be displaced by the new…new combinations are, as a rule, embodied, as it were, in new firms which generally do not arise out of the old ones but start producing beside them*.” **<**Schumpeter (1934). Italics mine.>

Schumpeter (1934) described a competitive mechanism that spurs innovation during a creative destruction process among firms. Innovative effort is motivated by the resulting source of profit that exceeds the normal level. He also described how competitors’ imitation erodes the profit and forces the profit-maximizing firm to advance further if the innovative quasi-rent (IR) is not to dry up. The unmatched production and growth performances of free enterprise economies are mainly due to the competition for the IR among entrepreneurs who constantly innovate to reduce cost or increase production. Shell (1973) suggests a price-taking sticky competitive market structure that can support innovative activities as the leading firms enjoy lower cost of production before the lagged firms catch up. Under the framework, the level of technology may differ among many small firms. The reasons can be due to the high technology transmission costs between firms. Firms with advanced technologies have incentives for not revealing their technologies, and employ secrecy to achieve this end. Patents can also give some limited legal protection to the leading firms and therefore increase the level of competition stickiness. Other potential sources are also described in Gerschenkron (1968): ‘Very few modern industrial entrepreneurs were truly great innovators, in the sense of being the first to apply a revolutionary, unprecedented technique. Most of them were imitators, a part of what Schumpeter called the “secondary wave,” which spread a new signal innovation over broad segments of industrial economy. But, as everyone who has ever worked inside a modern enterprise knows, the distinction between the innovator and imitator is a very uncertain one. Every imitation requires a great deal of energy to overcome inertia, to abandon the accustomed way of doing things. It raised a million technical and economic problems that must be solved. And they will not be solved unless there are alert minds to welcome the new and to see the solutions and strong wills to carry the tasks to successful termination.’



For modeling the competition process through innovations, we assume there are many price-taking small firms characterized in (E4) that employ different level of *V* for producing same product at the same time. The characteristics of this ‘price-taking sticky competitive environment’ are captured in Figure 1.[[5]](#footnote-5) At time t0, the economy has three types of firm producing the same product with different levels of *V* and therefore different average cost of production (AC): the leading firms produce with *VH* and have the lowest AC of Pe ; the lagged firms produce with *VL*and have the highest AC of P0 ; the intermediate firms produce with *Vm* and have the ACm with Pe < ACm < P0 since *VH* > *Vm*> *VL* . Since it is always possible to produce the final good using the well-known traditional technology of *VL*, there is unlimited supply at P0. The ACt0 of Peacs therefore represents the supply curve of the product at. Given the market demand curve D, the market price equals P0 and the output produced is Q0. The leading and intermediate firms are earning the total innovative quasi-rent (IR) amounting to P0caPe while at the same equilibrium price, the potential IR to be captured amounts to acf .

The existence of IR implies that  will not be in equilibrium. Besides the leading firms will expand their output by setting up new small production units, all other firms will try to capture the IR by imitating the production method of the leading firms by adopting similar tools variety such that the supply curve moves to ACt1 with the equilibrium  and finally ACte with the long-run equilibrium e when more and more lagged firms catch up the technology of the leading firms. In the process, all stagnant lagged firms with AC higher than Pe are driven out from the market when the market price decreases from P0 to P1 and finally Pe.[[6]](#footnote-6) In the long run, all firms produce with *VH* when the technology is a common knowledge, available to and adopted by all entrepreneurs. All survival firms have the same AC, enjoying normal profit with zero innovative rent before some firms find a better method of production with *V* higher than *VH*that initiates a new catch up process again. In this price-taking sticky competitive environment, innovative activity is a routine activity of the entrepreneurs in all firms targeting for capturing the potential IR and/or for survival.

In the long-run equilibrium, each firm is producing with the same *V*, the aggregate output is obtained by summing up the output of the *n* identical firms in the economy:

*GDP = Y = n Qj =  = *, (E5)

where *X* and *L* equals to *nXj* and *nLj* respectively. (E5) suggests that when resources are under-utilized in an economy, increase in the number of firms with the same technology can generate short-term growth when *n* increases. However, when resources are fully utilized, expansion of *V* is the only way to unlimited growth.

While IR financially motivates and supports each firm to innovate during production, this framework is the direct extension of the CDOPF and preserves the vastly adopted price-taking competitive market structure that is much more general, transparent, less restrictive and easier to handle than the product/input variety growth models based on monopolistic R&D sector. However, when (*α/θ*) is less than one, introducing the tools variety into the production function may not be able to escape the dismal conclusion that economic growth will finally stop. Tools variety may remain subject to the law of diminishing productivity and the economy will finally approach a steady state of zero growth even *V* increases over time.[[7]](#footnote-7)

**2.3 The Unlimited Possibilities of Innovations**

In reviewing the evolution process of production technology, innovations are complimentary to each other. In the words of Rosenberg (1976) ‘for technological change as in other aspects of human ingenuity, one thing often leads to another – not in a strictly deterministic sense, but in the more modest sense that doing some things successfully creates a capacity for doing other things … experience in the production of firearms made it a relatively simple matter to produce sewing machines, just as the skills acquired in producing sewing machines and bicycles greatly facilitated the production of the automobile**.’** (p. 30) The observation suggests that a ‘new’ tool/machine/material is not really new in most cases. It embodies all or most of the characteristics/components of the old tools/machines/materials although it is modified or upgraded by new way of combination and/or by new devices/materials. As a result, the likelihood of devising a new tool depends on the number of existing tools variety. This idea is exemplified by the evolution of drills, watch, automobile and various machines. It becomes increasingly obvious that tools variety multiplies in the sense that the larger the stock of tools/machines/materials, the larger will be the increase in tools variety over time. Moreover, the potential number of tools variety is unlimited.

This mechanism of tools multiplication find corollary in other discipline like biology. In biology, the growth of organism is defined by the multiplication of cells. Bacterial growth is the [division](http://en.wikipedia.org/wiki/Asexual_reproduction) of one [bacterium](http://en.wikipedia.org/wiki/Bacterium) into two identical daughter cells during a process called [binary fission](http://en.wikipedia.org/wiki/Binary_fission). The two daughter cells may not both survive. However, if the environment is favorable and on average, the number of survival exceeds unity, the bacterial population will undergo [exponential growth](http://en.wikipedia.org/wiki/Exponential_growth).

Similar corollary can be found in the ancient Chinese Tao philosophy. The Tao philosophers suggest that the complexity of nature is generated by the multiplication and combination of Yin and Yan. The ‘singularity’ divides into Yin and Yan. The existing Yin and Yan further combine with either Yin or Yan which generates the four ‘phenomena’. The process continues and the variety/complexity of natural phenomena multiplies with the base of 2 following a sequence of: 20, 21 , 22 , 23 and so on. The number of multiplication therefore defines the number of the variety or the level of complexity/development in the nature.

Romer (2007) suggests that similar to the exploratory synthesis in physical chemistry, the possibilities of discovering new mixture of materials do not merely add up, they multiply. He proposes that the source of economic growth is driven by the combinatorial explosion of ideas that potentially has no limit and is not subject to the law of diminishing productivity.

The commonality among different disciplines and insights suggests that tools variety does evolve through multiplication and limited only by imagination. We therefore assume that tools variety evolves through multiplication, such that:

*V = eγ* , (E6)

where *γ* ≥ 0 is a variable indicating the number of multiplication. The higher the *γ* , the higher the *V* and the level of development/technology.[[8]](#footnote-8) More importantly, unlike the inputs like tools and labor, tools variety is not limited by the non-producible land. It implies that *γ* or *V* has no limit by its nature. Substituting (E6) into equation (E5), we have:

 , (E7)

with *γ ≥ 0 ; a = γ(α/θ) ≥ 0* , and *A = ea*.

Total differentiation implies:

 =  = , (E8)

with *(α/θ)* ≥ 1.[[9]](#footnote-9)

After the role of entrepreneurs and the combinatorial nature of tools variety are instituted into the CDOPF, we have a clear definition of technology and its evolution mechanism while sustained growth becomes possible and automatic.[[10]](#footnote-10) At the same time, we retain the simplicity and all the other merits of the CDOPF. As commonly observed across countries and time, (E8) suggests that an economy can experience increasing sustained growth when *dγ* increases over time. On the other hand, an economy can be stagnant when dγ equals zero, or can be declining in growth rate when *dγ* is decreasing. As indicated in (E7), if the ‘*a*’ remains unchanged and is exogenous, the production function becomes the CDOPF with identical growth implications in related literature.

**3. Direct Answers and Implications on Major Growth Issues**

“When you adopt a new systematic model of economic principles you comprehend reality in a new and different way.” <Samuelson, P.A. 1967, *Economics*, 7th ed., New York, McGraw-Hill, p.10.>

Building upon the contributions from Cobb-Douglas (1928), Schumpeter (1934), Shell (1973) and the product/input variety literatures attributed to Dixit-Stiglitz (1977), our model provides a clear and precise target for all decision-makers who care about growth. Moreover, the model has some obvious, straight-forward answers for many important issues related to economic development and growth. We list some of them as follows:

1. The differences in the level and growth rate of tools variety account for most of the differences in the level and growth rate of GDP across time and countries. Poor countries remain poor because they have low level of tools adopted in the production process due to their bad motivation system that discourages entrepreneurs to innovate and/or apply the global stock of tools variety for productive uses. The model suggests that nothing is inevitable. The rate of tools multiplication across countries explains sustained growth, decline, stagnation and the structure of the long-run world income distribution over time.
2. In the long-run equilibrium, the innovations by individual firm *j* will be imitated by all other production units in the economy, such that: *Y = GDP = *. Moreover, the inter-firm innovation spillover effects among entrepreneurs through learning from watching, interactions and imitation imply that a firm *j*’s innovation ability depends on the number of firms in its neighborhood such that: *dVj = g(n, Z)*, with *gn > 0* and *Z* is a vector of other factors like public policies and infrastructures. At the same time, higher *Vj* raises the imitation opportunities and therefore the potential IR to existing and new firms which will attract expansion of new ventures, such that *dn=dn(dVj)* with. Therefore, in the development process with expanding *Vj* among firms, *V* and *n* tends to reinforce each other such that:

. (E9)

This interdependent nature of the related growth variables implies that productivity, intensity of entrepreneurial activities, expansion of tools variety, number of firms and investments tend to move together in the growth process across countries and time.[[11]](#footnote-11)

1. Similarly, the mechanism in (E9) also induces within country concentration. The higher level and growth rate of specific tools variety in certain places will therefore induce related firms to flow in to capture the benefits generated by the innovation spillovers and interaction opportunities between entrepreneurs. Industries and firms that can be benefited from the innovative activities of each other will therefore form natural clusters.
2. Factors of production flow to the same places. Economies with motivation structure and environment favorable to entrepreneurial activities will enjoy higher multiplication rate of tools variety and higher potential IR to capture. Entrepreneurs, physical inputs and financial capital will flow to the economies with favorable ‘economic substrates’ and vice versa.
3. The enormous increase in standards of living during the last few centuries and recent decades can be attributed to the explosion of tools variety generated by the discoveries and applications of some general technology, along with important breakthroughs in transportation and information technology. They initiate a globalization process that results in rapid expansion of market size and therefore a drastic increase in the demand curve in Figure 1 to each firm in the world. The enormous increase in the potential IR incentivizes the proliferation, imitation, application and invention of new tools in the national as well as in the firm level. In notation, *dn/n*, *dV/V* and *dX/X* in (E9) are positively driven by the potential IR that expands rapidly to all firms in the globalization process.
4. In the model, entrepreneurs are assumed to conduct innovations in their regular production learning by doing process and no extra market resources are expended in the process apart from their implicit opportunity costs.[[12]](#footnote-12) Market-driven innovative activities and technical progress are always Pareto-improving.
5. The extensive spillover effects of innovations and the multiplicative mechanism of tools variety imply that the external effects of individual entrepreneurial activities to the whole society tend to be extensive and cumulative over time. Decentralized innovative activities tend to be sub-optimal and therefore market-driven innovative/entrepreneurial activities should be encouraged and subsidized by public policies.[[13]](#footnote-13)
6. Tools variety in the production process is the key to technical progress. Entrepreneurial activities innovate and/or apply and/or transform new ideas, new knowledge, new invention to new mix of tools variety for producing final goods and services are the key to sustained growth. All other factors emphasized in the endogenous growth literature like R&D, education, knowledge and inventions are not sufficient to economic growth. They should only be considered as supplementary to entrepreneurial activities for achieving sustained economic growth.

**4. Conclusions**

The development process and technological improvements since the industrial revolution are characterized by substantial increases in entrepreneurial activities and the varieties of tools/machines/materials in production. However, the CDOPF does not include the role of entrepreneurs and representations of the advances in plant and machinery that make modern industrial economies possible. In this paper, we provide a simple integration of different ideas by incorporating entrepreneurial activities and the variety of tools/machines/materials and its evolution mechanism into the production function largely based on the insights of Schumpeter (1934). This resolves many important puzzles in the studies of economic development and growth.

The divergence of our model from the endogenous growth theories such as Romer (1990) is that sustained growth is driven by profit-maximizing entrepreneurs under a price-taking sticky competitive market structure. The framework is more straight-forward than the monopolistic R&D framework. The implications from the model are also richer, have stronger explanatory power and less restrictive by specific assumptions.[[14]](#footnote-14) In our model, it is not population or ideas or human capital or number of researchers determines the rate of sustained growth but the entrepreneurial activities that drive the rate of tools multiplication. Escaping the law of diminishing productivity becomes possible, market-driven and supported by behavioral foundations. Investigations on the causes and phenomena about economic growth and development become much easier and straight-forward. Our contributions have made the mechanism of endogenous growth simpler, more intuitive and closer to the numerous theoretical and empirical models based on CDOPF while at the same time, having stronger explanatory power on the real world observations. The shortcomings of the endogenous growth models as criticized by Jones (1995) and Pack (1994), among others, are eliminated.**References**

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1. Man-made tools for enhancing production include simple tools, machines and materials. Each variety provides differentiated services that are complimentary to each other in production. They are combined to generate ‘capital service’ for specific production to meet certain needs and wants. [↑](#footnote-ref-1)
2. Obviously, the labor service (*L*) can be treated in an identical manner such that labor service depends on a combination of workers with different skills and human capital. However, the sacrificed technical detail allows us to simply and compactly formalize important ideas about the role of tools variety in the production function. [↑](#footnote-ref-2)
3. The source of sustained growth based on CDOPF is driven by exogenous growth in technology. In Romer (1990), capital service is the outcome of the aggregation of tools that are additively separable. Technology/tools variety increase is generated by a profit-maximizing monopolistic R&D sector with inputs including existing stock of knowledge and human capital. The conclusions of the model such as the rate of technological change is sensitive to the rate of interest, a larger total stock of human capital will experience higher sustained growth and free international trade can speed up growth are driven by the assumptions. [↑](#footnote-ref-3)
4. . An increase in *Vj* has two effects on the value of capital service. The first component indicates its direct positive effect while the second component indicates its negative displacement effect that lowers the level of each *Xj\**. Given the cost/resource constraint, employing additional tools variety has to reduce the quantity of other tools variety. This displacement effect tends to be very small when *Vj* is sufficiently large relative to . For simplicity, we drop the star in denoting *Xj\** as in (E4). This has no effect on our analyses as the positive direct effect of *V* always dominates. [↑](#footnote-ref-4)
5. According to (E4), for any total cost, higher *V* always result in higher output level and therefore lower AC. Shell (1973) illustrates how the market structure can generate quasi-rent for supporting innovative activities in a two firms model. The market price is determined by the minimum AC of the marginal firm. To focus on the key issues, we define the innovative quasi-rent generated by the difference in tools variety per unit output is the difference between the market price and the minimum AC of each firm. [↑](#footnote-ref-5)
6. Notice that the exit of stagnant firms does not imply the obsolescence of old production method and tools. In most cases, the main characteristics of many simple tools/products are embodied in the advanced tools/products that can better satisfy certain needs or wants. The original simple tools/products are embodied rather than obsolete. The creative destruction process in this model is defined as the expansion of leading firms and the exit of stagnant lagged firms instead of being treated as the obsolescence of ‘inferior products’ as in Aghion and Howitt (1992), for instance. Moreover, old technology is always observed to be adopted if it is profitable. New methods that are cost effective in some countries/environment may not be so in other places. Due to the complementarities among inputs, ‘better tools’ are very difficult to define. For examples, car may be superior or inferior to horse for satisfying the travelling needs which depends on the condition of roads; candle lighting is more effective than light-bulbs if electricity is not available or very expensive. [↑](#footnote-ref-6)
7. Sustained growth is feasible if (*α/θ*) is greater than or equal to one. However, making this assumption arbitrarily will make the model fall into the ‘linearity critique’ as in the existing endogenous growth models. That is, the possibility of sustained growth depends on the magnitude of the parameters that is purely arbitrary without behavioral foundations. (Jones, 2005) [↑](#footnote-ref-7)
8. Choosing ‘*e*’ as the base of multiplication is for convenience only. It can be any number larger than unity. Exponential gets its name from the number of times the number is multiplied by itself. Linear growth is incremental and gradual while exponential growth is drastic and dramatic. [↑](#footnote-ref-8)
9. As shown in footnote 4, >0. It indicates that the marginal productivity of a new tools variety to capital service is maximized when *θ* approaches zero. Since the possibilities of innovation are unlimited, other things equal, IR maximizing entrepreneurs tend to adopt/invent new tools variety with the lowest *θ* , that is, tools of highest differentiation to the existing tools. Therefore, under proper environment, the ratio (*α/θ*) is likely to be greater than one on average. Escaping the law of diminishing productivity becomes possible, automatic and supported by behavioral foundation. [↑](#footnote-ref-9)
10. Although escaping the law of diminishing productivity becomes possible and market driven, economic growth will not become sustaining or explosive automatically. It is confined by the growth rate of tools variety that is determined by many vary institutional factors documented by a long list of theoretical and empirical papers on long-run growth and development. (among many others, the paper series contributed by Mo, various years) [↑](#footnote-ref-10)
11. Higher *dV* raises *dX*. The marginal product of *X* equals. Given the same rental price of tools, higher *dV* implies higher profit-maximizing *dX* , other things being equal. [↑](#footnote-ref-11)
12. Similar to academic researchers, besides the financial motivation, probably it is not uncommon that most entrepreneurs can satisfy their creative instinct in their innovative activities and find them enjoyable in the process. [↑](#footnote-ref-12)
13. According to (E5), in the long-run equilibrium, *Y = GDP =*and, . The scale of spillover effect generated by the innovation of firm *j* is proportional to the number of firms in its neighborhood. [↑](#footnote-ref-13)
14. Mo (2010b) applies the ideas related to SCDOPF for analyzing trade liberalization policy for sustained economic growth in developing economies. By combining the insights from institutional literatures with the SCDOPF, the factors, channels, mechanism and the key to sustained economic growth becomes clear, straight-forward and precise as demonstrated in Mo (2010c). [↑](#footnote-ref-14)