

Dynamic Externalities of Circular Economy loops: A Microeconomic Analysis of inter-temporal production systems

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1. Introduction

At the assembly of MasterUp held on Monday 30th October 2017, I was asked to present a contribution on the role of innovation in modern economy particularly for small and medium enterprises (SME). The main lines of such presentation are given here while their application to the case of MasterUp, a former spin-off of the University of Perugia operating in the market of industrial innovation, is discussed in the paper “*On a circular economy proposal on CO₂ reuse to produce methane using energy form renewable sources*” by A. Laganà and L. Di Giorgio [1].

2. Economics and Industrial Innovation

Traditional classical and neoclassical approaches, to the modeling of industrial economic development have focused on tangible and immediately verifiable parameters such as the levels of production, prices and quantities described by a rigorous algebraic relationship. For this reason, in previous centuries, the role of innovation has been considered marginal.

Important contributions to the study of the role played by innovation in economic processes came from A. Smith (who introduced the notion of specialization and growth in marginal productivity) and from D. Ricardo (whose theory of growth was associated with the introduction and accumulation of innovative capital by factories).

However, the key contribution to the evolution of economic models was given by J. Schumpeter who, in the XX century, developed models of industrial innovation and mathematical models to explain economic growth.

Schumpeter’s models distinguish between invention and innovation and articulate the last one into 3 sub-types leading to different economic and mathematical effects on business economics’ models.

J. Schumpeter differentiated the concept of innovation from the invention one in fact that the first generates a new product or production process whereas the latter concerns the direct application of the former idea. [2]

The differentiation is extremely important and has been adopted by various researchers when separating radical from incremental innovations. [3]

More specifically, J. Schumpeter singles out 4 different kinds of innovative models:

- I. Process Innovations
- II. Product Innovations
- III. Exploitation of New Markets
- IV. Organizational Innovations

3. Process and Product Innovations

Process Innovations [I] consist of industrial production processes improvements related to production costs. In this case J. Schumpeter describes 3 sub-cases:

Case **a**) Process Innovations with Lower Fixed Costs (FC) and Constant Marginal Costs (MC) (see upper panel of Fig. 1)

In this case, one has:

- Reduction of FC with an adjustment of Average Costs (AC);
- Downward translation of AC_1 ;
- Reduction of MES (Minimum Efficient Scale) that is the quantity of goods produced efficiently at minimum AC with a resulting reduction of Economies of Scale (EoS).

Case **b**) Process Innovations with lower MC and constant FC (see central panel of Fig.1)

In this case, one has:

- Downward translation of both curves MC and AC;
- Reduction of AC and MC;
- Increment of medium level of production;
- Reduction of MC with a resulting increase of MES.

Case **c**) Process Innovations with lower MC and incremental FC (see lower panel of Fig.1)

In this case, one has:

- Labour Intensive process regime (LI) which has a steep slope and intercept with lower FC (and consequent higher MC)
- Capital Intensive process regime (CI) which was a less steep slope and intercept with high FC and lower MC.

This means that a LI regime leads to maintaining a Constant Return to Scale (CRS), with a positioning on a lower production scale, whereas a CI regime leads to a higher exploitation of EoS and a transition to Increasing Return to Scale(IRS). [4]

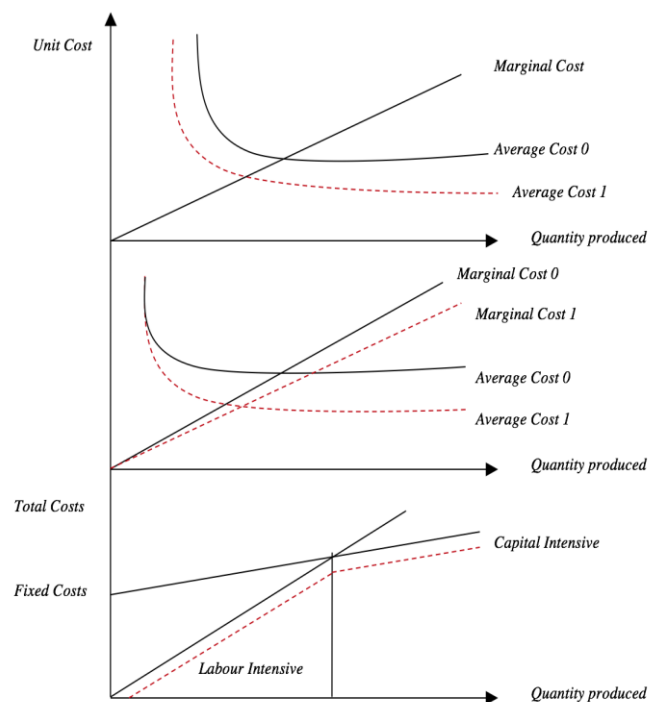


Fig.1: Plot of Unit and Total Costs as functions of Quantity Produced

This model, as pointed out by J. Schumpeter, would allow a small enterprise to grow thanks to the exploitation of new economies of scale (EoS) according to the transition from the LI regime to the CI one.

Product innovations, on the other side, are different because they do not lead to a change in production processes but only on the proportions of production factors in the production function (presented in Cobb-Douglas form):

$$Y = AL^\beta K^\alpha$$

In the above equation Y is the total production (i.e: the value of all the goods produced in a year of 365.25 days), A is the total productivity factor (TFP) (i.e.: the value of the total quantity of output) formulated as a multi-combination of the L and K factors with L being the Labour given as the Production Factor expressed as the total number of person-hours in a year and K being the Capital given as the Production Factor expressed as the actual value of all machineries, equipment and buildings also for a year. The exponents α and β are the output elasticities of both Capital and Labour factors determined using available technology. In this case, the analysis is more complex because the new product will follow the dynamical industrial and market processes.

4. The Reward Theory of Patents of W. Nordhaus

The definition provided by J. Schumpeter for product innovation although universally accepted, needs appropriate clarifications. In fact, when innovation is introduced, regardless or, whether it is of “Process” or “Product” type, it creates distortive effects. These affect in fact both the user enterprise (allowing an increase in production possibilities) and the other companies and economic agents operating in the economy (“Externality”). According to K. Arrow [5] indeed all forms of innovation which alter the production processes generate also knowledge within the market. This knowledge is then transformed into a public good that because of Non-Rivalry and Non-Exclusion nature can be enjoyed by anyone creating so far a free riding distortion (FR). Because of this K. Arrow pointed out the necessity of introducing patent protection in order to:

1. Encourage new Innovative Processes
2. Resolve the externalities and possible FR phenomena

In 1969 W. Nordhaus modeled this effect [6] by highlighting how patent protection, as an exclusive right, guarantees a monopoly position to the owner while creating forms of social welfare for the entire economy. Formally, the innovative Nordhaus model is based on the following relationship (see Fig. 2).

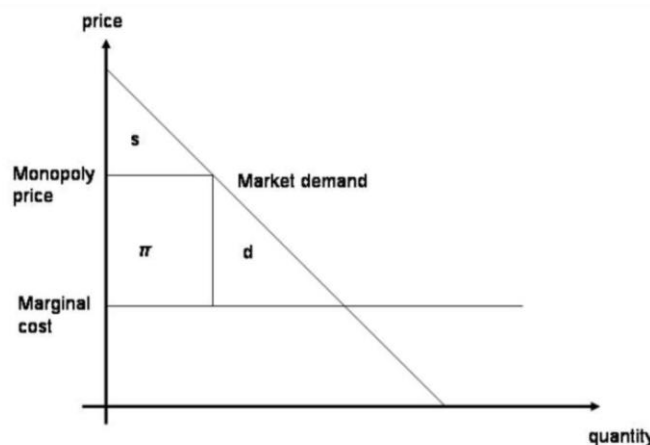


Fig 2: Plot of the Quantity of Good demanded in the market and the related prices

The exclusive right in fact involves a trade-off between welfare, which would be created with its positive externalities and profits and monopolistic incentives for the industry. Formally the model relates the Guaranteed Prize from Surplus “ W ” ($W = \pi + s + d$) to “ π ” (the premium guaranteed to the monopolist based on the price set for maximum profit, “ s ” (the consumer surplus) and “ d ” (the deadweight loss of social welfare and disequilibrium due to the monopoly). This stimulates innovations by avoiding dynamic loss of social welfare and, at the same time, by ensuring both a flexible creation of knowledge. [4] and a wise use of the “Patent Time Length”. As a matter of fact, “ π ” should be not so large to monopolize excessively the market for a long time and sufficiently large to create the knowledge needed by the company.

The quantities “ π ” and “ d ” will have to be proportioned so that the monopolistic (based on patent length) loses a “ π ” every year “ t ” equal to the Discount Rate “ $X(t)$ ” according to the equation:

$$X(t) = \frac{1 - e^{-rt}}{r}$$

In the above equation “ r ” is the interest rate and “ $W - dX(t)$ ” is the net expected benefit for the company with “ $dX(t)$ ” being the discounted value of the deadweight loss during the “ t ” years of the duration of the patent protection. By maximizing the expected benefit subject to the constraint:

$$c \leq X(t) \cdot \pi$$

with “ c ” being the cost value required to introduce new innovation. The respect of the Price-Cost Margin, placed as an argument of the function of the deadweight loss “ $d(\pi)$ ” will allow the monopolist to keep a correct proportion between P and MC so as to balance its Market Power with the benefits to the society. This means that, thanks to the presence of patents, the creation of innovation is a significant incentive for the company to achieve possible monopolistic position grounded by the prospect of expected profits.

5. The S. Klepper’s model: The Dynamic Microeconomic Analysis

At this point it is useful to analyze the process of monopoly exclusivity both Microeconomically (with a focus on entry and exit of companies from the economic and industrial system) and Macroeconomically (with a focus on the benefits of innovation on economic growth).

For the microeconomic approach, we refer here to one of the most accredited models in order to explain the dynamics of entry and exit of companies from a given industry: the model of S. Klepper. [7,8]

The Klepper’s model rationalizes, using a dynamic system in which regularities are singled out, the ways in which companies make their entry and exit from highly innovative markets.

The model assumes that in any given period there is a number of potential “ i ” incoming companies in the industry. This industry changes in time dynamically in its knowledge and production capacity. The industry sets as well certain technological- productive competence requirements in order to allow the potential New Entrants to access the market. This set of competences embodied by the variable “ s ” (which tends, for each company, to the maximum value “ $SMax$ ”) associated with the success in introducing a product innovation will depend on how the R&D activities will be

implemented. In the “ t ” period the probability of success will be given by the equation “ $s_i + g(rd_{i,t})$ ” where “ rd ” is the cost of the R&D activity and the “ $g(rd)$ ” function is the probability of success of R&D in producing innovation.

In this way, any manufacturer will be able to obtain extra profit from its new innovative product having higher quality and characteristics when compared with the standard one until that product becomes the new market standard, conceding the mono or oligopolistic annuity.

The period characterized by monopoly rents is called “ G ” and is characterized by the fact that the company will have to consistently look for new process innovations to produce at lower costs and to monitor competitors for related innovation at a high fixed cost called “ F ”. As in any market there will be a given demand for the good denoted by the demand function

$$Q_t = f_t(p_t)$$

that will tend, as time “ t ” increases, to make the quantity produced always larger, with automatic price “ p ” (variable in time) adjustments based on the demand function and on the new total costs incurred:

$$Q_{i,t} - I \left(\frac{Q_t}{Q_{t-1}} \right) + \Delta Q_{i,t}$$

From these premises, it can be argued that Incumbents (the companies that will remain active in the market) and new Entrants will interact at the level of product and process innovation by changing their chances of entering and leaving the industry.

This is formalized in the following equation embodying the model of S. Klepper in its full expression:

$$E(\pi_{i,t}) = [s_i + g(rd_{i,t})]G - rd_{i,t} + \left[Q_{i,t} - I \left(\frac{Q_t}{Q_{t-1}} \right) + \Delta q_{i,t} \right] [p_t - c + I(rc_{i,t})] - rc_{i,t} - m(\Delta q_{i,t}) - F$$

Where:

- $[s_i + g(rd_{i,t})]G - rd_{i,t}$ indicates the company expected profit from R&D for product innovation net of the cost for the R&D activity
- $[s_i + g(rd_{i,t})]$ indicates the probability for i -th firm to develop a product innovation
- $rd_{i,t}$ is the expenditure of i -th firm in R&D for a product innovation
- G is net profit of monopoly in period “ t ”
- $\left[Q_{i,t} - I \left(\frac{Q_t}{Q_{t-1}} \right) + \Delta q_{i,t} \right] [p_t - c + I(rc_{i,t})] - rc_{i,t} - m(\Delta q_{i,t})$ indicates the profit from producing a quantity of the pre-innovative standard product net of both the expenditure in R&D processes and the adjustments made on the Quantity of Output adapted to new market demands with innovations in the production process
- $Q_{i,t}$ indicates the output of standard product for the i -th firm in period “ t ”
- $\left(\frac{Q_t}{Q_{t-1}} \right)$ denotes the growth rate of total quantity demanded by the market for standard product in from period “ $t-1$ ” to period “ t ”

- $Q_{i,t} - I\left(\frac{Q_t}{Q_{t-1}}\right)$ indicates the difference between standard product produced in period “ $t-1$ ” and in period “ t ” by the i -th enterprise
- $[p_t - c + I(rc_{i,t})] - rc_{i,t} - m(\Delta q_{i,t})$ indicates the average cost of i -th firm for process innovation with the probability to obtain a process innovation denoted by $I(rc_{i,t})$
- F indicates the cost of monitoring the innovative processes of competing companies

In this way, it is possible to rationalize the entry/exit dynamics of companies from/to an innovative industry on the ground of net of costs and profits from innovative processes as quantified by positive “ $E(\pi_{i,t})$ ” values. The New Entrants, however, will be subject to an entry constraint given by the limit:

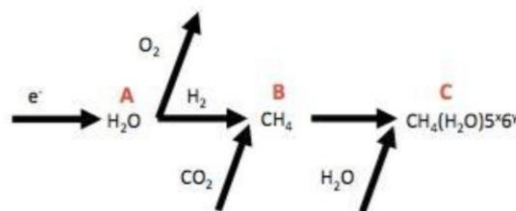
$$E_t = K_t(1 - H(s_i))$$

Where “ K_t ” are the potential entrants and “ $H(s_i)$ ” is the aggregate function of innovative and accumulated competences of enterprises in the industry at any period “ t ” necessary to entry into the industry. It is therefore intuitive that as time “ t ” increases the system will tend to both require more and more experiences and radical innovations and the consequent cost reductions. [6]. Then, after a first Embryonic Phase (“EP”) and a second one of Growth (GP) there will be a phase of Industrial Maturity (IM) in which the market will be complete with constant output growth (in equilibrium with demand) and market shares stabilized later the old competitions. In this way, the expected profits will tend either to zero or below (accordingly to “ $E(\pi_{i,t}) < 0$ ”) because the too lower prices generated by the competition will lead to a difficult entry for New Entrants (regardless of their accumulated competence “ $H(s_i)$ ”). [7,8]. The Klepper’s model applied to innovative realities allows to draw important conclusions on a possible strategic positioning in the industry, based first on the analysis and then on the knowledge of the phase in which the market itself is operating at a given moment.

6. Circular Economy and Molecular Applications by Master Up with the “Esodis Project”: The increasing Marginal Ecological Positive Externalities and the deadweight loss Compensation Effect

The above described models can be applied to the activities of Master Up some of which are based on proprietary patents. In particular, we discuss here the case of “Esodis”, an apparatus designed for the reuse of carbon dioxide (CO_2) by making it react with molecular hydrogen (H_2) to produce methane (CH_4) in a circular economy model. The scheme adopted by Master Up to implement this type of innovation and the value of the parameters of the related economic equation is articulated into the following components: (see Fig. 3):

Fig.3: Graph of the Processes occurring in the “Esodis” Apparatus



- An innovative electrolyser that produces H₂ with optimization of profit/cost ratio (patent request n°10201600009794)
- An innovative CH₄ production from CO₂ resulting from industrial/agricultural wastes (patent request n° 102016000426534)
- An innovative production of methane clathrate hydrates out of gaseous methane (patents EP07010346 and WO/2007/122647)

To date the project has led to the design of a prototype apparatus that incorporates the A and B phases of Fig. 3 which are being considered for production on industrial scale. As apparent from the above illustrated features, the “Esodis Project” is, at present, mature enough to be considered as a technology possessing the characteristics for innovating the energy storage scenario rapidly generating new production dynamics. Its framing within appropriate economic models and suitable production processes shall provide the ground for designing a product placement plan in B2B processes and possible financial plan scenario for the support of industrial planning activities. However, it is useful to frame the “Esodis” process into a wide model of application. In fact, as can be seen in Fig. 4 “Esodis” can be seen as a concrete application of Circular and Ecological Economic Theories.

A circular economy is a “regenerative system in which resource input and waste emission and energy leakage are minimized by slowing, closing and narrowing material and energy loops”. According to Ellen McArthur Foundation’s (document of Ref [9]) in a circular economy “the economic activity builds and rebuilds overall system health. The concept recognizes the importance of the economy needing to work effectively at all scales- for large and small businesses for organizations and individuals, globally and locally. [...] Transitioning to a circular economy does not only amount to adjustments aimed at reducing the negative impacts of the linear economy. Rather, it represents a systemic shift that builds long-term resilience, generates business and economic opportunities and provides environmental and societal benefits”.

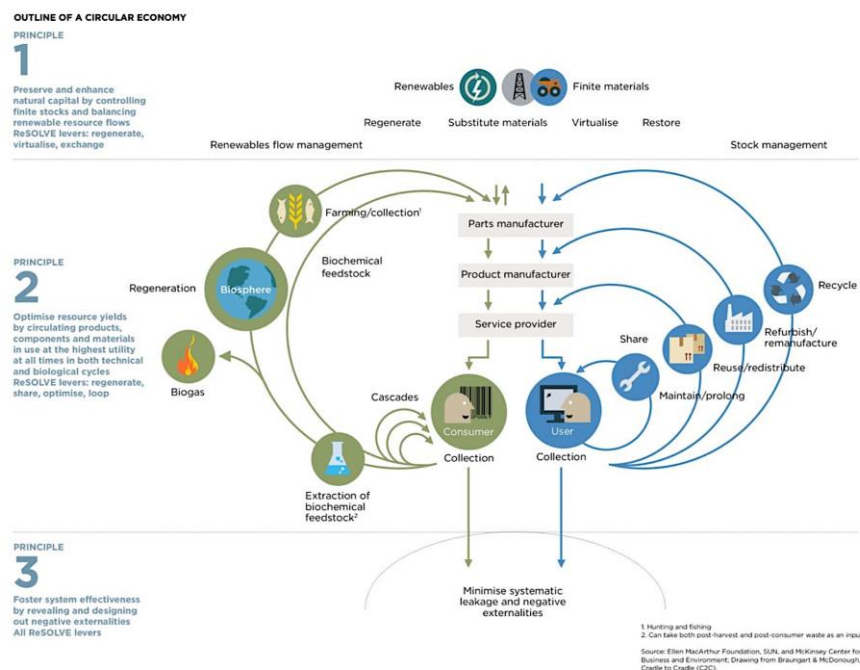


Fig. 4: Outline of a Circular Economy from “Ellen MacArthur Foundation” [9]

The system diagram and related captions (see Fig.4) are a clear example of the continuous flow of technical and biological materials through the “value circle”, letting us to understand as the re-use and the concept of recycling CO₂ to produce CH₄ as implemented by “Esodis” is a clear example of circular scheme in the scenario of innovative industrial production process. This Master Up apparatus is in fact a typical industrial formalization of the “10 Key Elements” of the Circular Economy models:

1. Prioritize Regenerative Resources
2. Use waste as a New Resource
3. Future Perspectives
4. Preservation and Extension of Re-Use model
5. Collaboration and Transparency in Supply-Chain
6. Using of High-Tech tools to improve industrial innovation processes
7. Respect for Price-Cost rate to guarantee a competitive market
8. Reality of Externalities assuming market imperfections
9. Reduction of circular economy transition costs to guarantee entrance of new business in industries
10. New Pro-Suming focus with new solution based “concurrent engineering” and “Service dominant Logic”

As a matter of fact, “Esodis” and Master Up are indeed a clear example of the meaning and practice of creating new economic and industrial relationship based not just on profits but also on long-term sustainability. For this purpose, it is necessary to understand why an enterprise should decide to move from linear to a circular economy model. To this end it is useful to identify possibilities and models for new production paradigms in this field and we discuss in the remainder of the section simplified application of the previously analyzed model. In particular, we focus our attention on the Nordhaus model in which the expected monopoly profit is provided by the creation of the patent form that guarantees even if for a limited period a possible dominant position and at the same time, however, it is also required that the patent form maximized also social welfare by reducing dynamic deadweight loss. This is made possible by conceiving the creation of patents as a machinery aimed at acting as a sustainable paradigm of the production cycle. In this patent protection would create a triple benefit:

- Microeconomic on Business: Allowing the creation of max profit with monopoly positions
- Microeconomic on the Society: Allowing the creation of increasing positive externalities thanks to the reduction and reuse of waste material
- Macroeconomic on the environment: Allowing long-term environmental sustainability with the creation of EPEx (Ecological Positive Externalities)

This would lead in a dynamic way, as shown by Klepper, to continuous innovative research in these areas by companies in order to ensure their survival in the industry, ensuring, once the patent protection on the new process is over the maintaining of a relationship price/cost adjusted to market demand. Every time, however, that companies will seek new innovations and invest in R&D for new circular production models this only produce more positive benefits and externalities that make the production cycle itself social welfare by minimizing the process of deadweight loss (see Fig. 5).

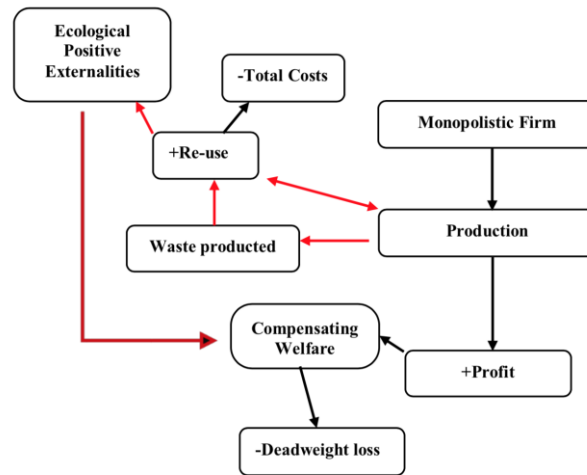


Fig. 5: EPEX and compensating effects of the Re-use of production processes

Now let assume that:

$$Dl = p_m + Ex^-$$

Where “ Dl ” is the deadweight loss seen in Nordhaus model, “ p_m ” are the prices set by monopolistic firms which are always greater than zero and “ Ex^- ” are the negative externalities created by production processes.

Now let assume that all possible $Ex^- = Wst$ with “ Wst ” being the Waste Flow created by the monopolistic firm. In this way when “ Wst ” grows we have an increasing of negative externalities.

On the other side, we have an increase of Positive Externalities (Ex^+) when it decreases as formulated below in terms of partial derivatives:

$$\frac{\partial Ex^-}{\partial Wst} > 0 \text{ and } \frac{\partial Ex^+}{\partial Wst} < 0$$

In this way, all the industrial externalities are created by Waste Flows of Production processes. When creating a Circular Economic Process, we assume that there are no wastes and a total re-use of wasted production factors is achieved. Accordingly, one can write:

- If $Wst = 0 \rightarrow Ex^- = 0 \rightarrow Dl = p_m$
- If Re-use exists $\rightarrow Wst < 0 \rightarrow Ex^- < 0 \rightarrow Ex^+$

The fact that negative externalities become Positive compensates the negative ones created by prices set by the monopolistic industry in “Welfare/Dl” ratio. In this way the patent concession is the key factor for ensuring a monopolistic position inducing, according to Klepper’s model, New Entrants to improve their innovation expenditure “[$s_i + g(rd_{i,t})$] $G - rd_{i,t}$] + [$p_t - c + I(rc_{i,t})$]” and try to enter into the industry or to assume the temporary monopolistic position assuming the creation of a very simple Circular model every business’s effort in time $t=I$ (with $i=1,2,\dots,n$) it is possible to obtain an exponential product and processes innovation for re-use of waste factors guaranteeing an indirect Increasing Marginal Ecological Positive Externalities (Increasing EPEX) for the society.

7. Final Remarks and Conclusions

The work carried out shows that from, these results, we can finally conclude that the dynamics of the Klepper's model and especially Nordhaus "Welfare Surplus" variable are not just theoretical and mathematical formulations useful to understand economics but a real feature of new circular industry path which could be the theoretical foundation for new projects as "Esodis" and a new scenario for new businesses as Master Up especially when assuming a positive effect of Re-use on industrial processes and an increase of the welfare for the entire society.

8. Acknowledgment

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References:

1. A. Laganà, L. Di Giorgio, “On a circular economy proposal on CO₂ reuse to produce methane using energy from renewable sources”, Lecture notes on Computer Science, presented at International Conference on Computational Science and its Applications (ICCSA), SPRINGER, in the press, 2018
2. Oxford Handbook of Innovation (OHEI), Edited by Jan Fagerberg and David C. Mowery, 2005
3. Economics of Innovation, Volume 1, Edited by Hall, B.H. and Rosemberg N., 2010
4. F. Pompei, Lectures of Economics of Innovations, Department of Economics, University of Perugia, 2017
5. K. Arrow, The Economic Welfare and the allocation of Resources for invention in the rate and direction of Inventive Activity: Economic and Social Factors, Princeton University Press, 1962
6. W. D. Nordhaus, Invention, Growth and Welfare: A theoretical Treatment of Technical Change, The MIT Press, Cambridge MA, USA, 1969
7. S. Klepper, “Entry, Exit, Growth and Innovation over the Product Life Cycle”, The American Economic Review, Vol. 86, N°3 (1996)
8. S. Klepper, Graddy, Elizabeth, “The Evolution of New Industries and The Determinants of Market Structure”, Rand Journal of Economics, 1990
9. ellenmacarthurfoundation.org, Circular Economy System