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CAN THE MARGINAL COST BE EXTENDED TO LIFE CYCLE COST? A THEORETICAL CASE STUDY FOR TRANSPORT

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Abstract: In this article, the authors investigated the connection between marginal cost and life cycle cost with the analytic tools of microeconomics. The authors collected the most relevant literature to have a solid basis for comparison. Firstly, the marginal cost was derived and defined later than the life cycle cost. The preliminary result is that the marginal cost could be extended to life cycle cost based on our hypothesis. The extension is of theory has been supported by tools of mathematics. Authors have found algebraic connections between marginal cost and life cycle cost theory. These findings are valuable and important because, with the help, life cycle cost is easier to be estimated.

Keywords: marginal cost, life cycle cost, transport.

1. Introduction

Authors to reveal research gap connected to marginal cost have investigated 1,004 open access articles in the Scopus database from 1964 to 2022 that have the connection to marginal cost. VoSViewer visualised the exported dataset in order to reveal scientific connection (Fig. 1).

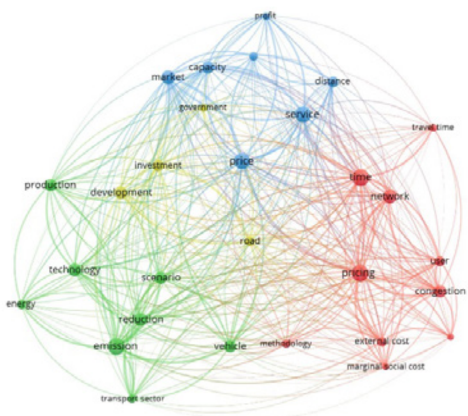

Fig. 1.
Bibliographic Connection of Selected Papers in the topic of marginal costs from Scopus Database by VosViewer

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The statistical analysis of articles showed that four clusters of scientific papers could be distinguished. With green colour the cluster about emission and energy reduction. The second one with red colour is about congestion pricing and travel time. The third one with blue colour is about capacity optimisation with pricing. The smallest fourth cluster is about road infrastructure development. These were the key areas where marginal costing has played an important role since 1964 based on Scopus.

After this, the authors also investigated 1,225 open access articles in the Scopus database from 1988 to 2022 that connect to the life cycle. VoSViewer visualised the exported dataset in order to reveal scientific connection (Fig. 2).

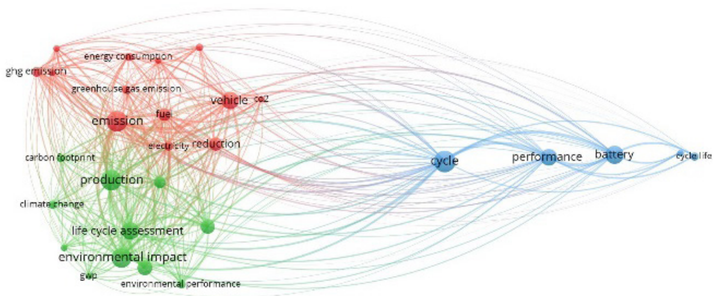

Fig. 2.
Bibliographic Connection of Selected Papers in th topic of life cycle from Scopus database by VosViewer

The statistical analysis of articles showed that 3 clusters of scientific papers could be organised. With green colour, the cluster about life cycle assessment and environmental impact or environmental performance. The second one with red is about emission reduction, electricity, greenhouse gas emission and energy consumption—the third one with a blue, separated cluster about batteries' life cycle. Based on Scopus, these were the key areas where life cycle played an important role since 1988.

Based on a review of the literature, these two economic phenomena may have common interests, which may also arise in the transport sector. Transportation services cover moving goods, from one place to another. A comprehensive and clear cost model could be defined that reflects shipping costs and the impact of transport. The usage of complex cost model could be largely influenced by raw material price, the changes in labour productivity and average wages. Cost function also depends on cost allocation unit (Zöldy and Zsombók, 2018), (Ivković, Čokorilo, Kaplanović, 2018). Cost models set up for trucking companies make more sense if they are structured according to the fleet structure, for example vehicle weight category (Ďurišová, 2011). Here we summarize the fundamentals of the marginal cost curve. For this reason, it is necessary to firstly define the fixed cost curves (FC) curve eq.(1):

$$FC = \text{constant} \quad (1)$$

FC is independent of the dependent variable, for instance, in transport from time [h], performance [pkm], or distance [km]. Then secondly, the variable cost (VC) needs to be defined – in the simplest case, it is linear eq.(2):

$$VC\ (q) = \alpha \cdot q \quad (2)$$

where VC is dependent from q, α is regression parameter (in the linear case α is slope). Please note that is the simplest linear model. All more sophisticated models influence cost modelling. Variable and fixed cost is considered together as the total cost (TC), which could be written algebraically eq.(3):

$$TC = VC + FC = \alpha \cdot q + FC \quad (3)$$

According to the Microeconomic Theory for Social Sciences book, average costs could be divided into the average fixed cost (AFC) and average variable cost (AVC). Average fixed cost is considered fixed cost per one unit of production, and variable cost per one unit of production is called average variable cost. For further analysis, average cost curves are not critical; therefore, one must analyse the incremental cost for an incremental unit of production (Ficzere, 2021; Ficzere, Borbás and Török, 2013). This is marginal cost (MC) (4):

$$MC\ (q) = TC(q)' = \lim_{q_0 \to q_1} \frac{TC(q_1) - TC(q_0)}{q_1 - q_0} \quad (4)$$

Since the fixed cost part disappears after taking the derivative, the fixed cost does not affect marginal cost. Moreover, please note that if variable cost is linearised model, then derivate of the linear model gets simplified to constant, the slope of linear. Let us now turn to life cycle cost (Nadanyiova *et al.,* 2020b). Nowadays, in the life cycle sustainability assessment (LCSA), it is considered to have social, economical in addition to environmental aspects (Klöpffer, 2008; Zamagni, 2012; Nadanyiova *et al.,* 2020a) eq.(5):

$$LCSA = LCA + LCC + SLCA \quad (5)$$

LCA stands for Life Cycle Assessment, which aims to quantify all environmental costs. LCC stands for Life Cycle Cost and aims to quantify all product life cycle costs. SLCA means Social Life Cycle Assessment which aims to assess social impacts throughout the life cycle (Fauzi *et al.,* 2021). According to the literature, several variants of the LCC can be distinguished. Environmental LCC is compliant with LCA in terms of system boundaries, functional blocks, and methodological steps. Finally, societal LCC involves the monetization of other externalities, including environmental and social impacts (Pomucz and Csete, 2015). Since LCCs accumulate costs over their lifetime, it should be taken into account that cash flows occur at different times. This makes analysis and comparison difficult for two reasons. First, prices vary based on market dynamics. For example, it is likely that all of the costs, raw material, labor, and fuel will change from year to year. Over the long term, the total price of goods is constantly changing. The LCC wants to compare costs based on the different base year, so all costs when comparing need to be adjusted for same basic year, therefore discount ratio has been introduced.

2. Methodology: Merging Theories

Fig. 3.
The Life Cycle of the Product

For merging the theories, one should notice that marginal cost theory covers the usage, production or consumption (Rothengatter, 2003). For instance, the polluter pays principle or the marginal cost-based road tolling (Martin, and Thoresen, 2015). Therefore, eq. 4. could be considered the incremental cost for an incremental unit of a road vehicle or the incremental unit of transport performance (Maffii *et al.,* 2010). Can this theory be extended to the whole life cycle? Based on the authors' opinion, it is possible. Please note that marginal cost until nowadays was defined only for production or for usage (Simoni *et al.,* 2015). Therefore, as one concentrating on a single unit in life cycle cost theory now performance or unit-based it has to been changed to time basis eq.(6):

$$\int_0^T MC(t)dt = \int_0^{t_1} MC_1(t)dt + + \int_{t_1}^{t_2} MC_2(t)dt + \cdots + \int_{T-1}^{T} MC_T(t)dt \qquad (6)$$

MC is the marginal life cycle cost [€/unit]
MC_i is the part of marginal cost [€/unit]
t_i is the time period of the life cycle [h]

where [0..T] interval is the total life cycle, [0..t_1] interval could be design, [t_1..t_2] interval could be planning, etc. Please note that time intervals could differ and are not necessarily equidistant $\sum_{i=1}^{T} t_i = T$.

3. Results and Discussion

Originally life cycle cost theory often cumulates data, not on a monetary base but rather naturally like [toe] (tonnes oil equivalent) or [GHG emission $MtCO_2e$] (carbon dioxide equivalent) (Asghar *et al.,* 2021; Hawkins *et al.,* 2013).

The transport system is a critical element of the economy; therefore, they also play an important role in sustainability. Nowadays, sustainability assessment is different due to the involvement of different scientific fields. Divergent indicators for evaluating sustainable transportation are crucial (Buzási and Csete, 2015).

Mobility is mainly affected by technology development. The future form of transport holds many questions on the expected role and potential of emerging mobility solutions (autonomous vehicles, shared mobility, and electrification) and includes socio-economic and environmental perspectives (Miskolczi *et al.,* 2021).

The extension of marginal cost theory to life cycle cost theory is Ok, but as marginal cost theory focuses on one spot when the extra unit is produced or used, life cycle theory considers the whole flow. In LCC, one would like to compare costs based on a chosen reference year, and therefore all costs need to be adjusted to that year when making the comparison. This is done by using the discount factor. Therefore, eq. (6) is modified with a discount rate as follows eq. (7):

$$\int_0^T \frac{MC(T)dT}{(1+r)^T} = \int_0^{t_1} \frac{MC_1(t)dt}{(1+r)^{t_1}} + \int_{t_1}^{t_2} \frac{MC_2(t)dt}{(1+r)^{t_2-t_1}} + \cdots + \int_{T-1}^{T} \frac{MC_T(t)dt}{(1+r)^{T-(T-1)}} \quad (7)$$

$$\int_0^T \frac{MC(T)dT}{(1+r)^T} = \int_0^{t_1} \frac{MC_1(t)dt}{(1+r)^{t_1}} + \int_{t_1}^{t_2} \frac{MC_2(t)dt}{(1+r)^{t_2-t_1}} + \cdots + \int_{T-1}^{T} \frac{MC_T(t)dt}{(1+r)^{T-(T-1)}}$$

where:
r is the discount rate;
T_i is the discount period.

4. Conclusion

Finally, the authors find the extension possibility of marginal-cost theory. This solution is to separate or divide the whole process into subprocesses and describing their cumulative effect. This can be accomplished by cumulating the marginal costs of subprocesses. Until nowadays the marginal cost is considered in transport sector mostly in usage part. Life cost estimation is rarely used due to its extreme data requirement. By merging these theories, the data required can be divided to find more precise estimations. Therefore, the algebraic merging can be described by Eq. 8:

$$\lim_{\substack{\Delta q \to 0 \\ t_i \to 0 \\ t_j \to T}} \int_{t_i}^{t_j} \frac{\frac{\Delta TC\,(q,t)}{\Delta q} dt}{(1+r)^{t_j - t_i}} = \mathrm{LCC} \quad (8)$$

$$\lim_{\substack{\Delta q \to 0 \\ t_i \to 0 \\ t_j \to T}} \int_{t_i}^{t_j} \frac{\frac{\Delta TC(q,t)}{\Delta q} dt}{(1+r)^{t_j - t_i}} =$$

The above-described method only focuses on marginal cost theory extension to environmental life cycle theory. Further considerations should be made to ensure extension to life cycle sustainability assessment.

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