Resources, Conservation & Recycling 138 (2018) 207–214

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Modeling the material stock of manufactured capital with production function

Mihály Dombi

University of Debrecen, Faculty of Economics and Business, Institute of Economics, Department of Environmental Economics, 4032 Debrecen, Böszörmény str. 138, Hungary

ARTICLE INFO

Keywords:
Material stock
Manufactured capital
Production function
Productivity
Stock accumulation
Economic sectors

ABSTRACT

Material stocks play a key role in the increasing and unsustainable utilization of natural resources. However, comprehensive and disaggregated datasets are still scarce in the literature of socio-economic metabolism research. The model presented in this article is able to estimate the capital stocks of agriculture, industry and services both in physical and in monetary dimensions.

The estimation method based on Cobb-Douglas production function was introduced in this article through two example sectors of Hungarian economy, namely the agricultural production and transportation. Three capital stock estimations of four are statistically significant. The highest impact on output of transportation sector has the investment into machinery and ICT, it is proved with high input elasticity (0.656) relative to other factors. In case of agriculture, drought and machinery has significant influence on the production (-0.958 and 0.5633). Transportation sector requires 12,654 Mt of building stock and 2064 Mt of machinery and ICT, while agriculture utilizes 347,112 Mt building stock and 1891 Mt machinery and ICT.

In this article, a condition determining the weight of annual output relative to the specific type of capital stock is discussed as well. Furthermore, the significance of the internalization of externalities during the life cycle of the built capital stock is analyzed, with a correspondence to standard microeconomic theory. Although marginal product of machinery and ICT exceeds significantly those of buildings and infrastructures in the studied sectors, material stock of buildings and infrastructure are higher, hence they are available at lower per unit cost.

1. Introduction

The significance of material stocks in relation to the increasing and unsustainable utilization of natural resources has been analyzed for years. Material stocks provide services for the society like shelter, production, recreation, etc.; however, they also call for an enormous amount of construction and other materials along their whole life cycle, and so they are responsible for strong path-dependency of the socio-economic system (Weisz et al., 2015; Haberl et al., 2017).

Despite of the extensive literature of socio-economic metabolism related to material flows, the intense investigation of the interactions between the economic processes and the material stocks of the society, in which they are embedded, has started in the last years (e.g. Fishman et al., 2015; Lin et al., 2016; Fischer-Kowalski and Steinberger, 2017; Krausmann et al., 2017; Zhang et al., 2017). Major explanations of this asymmetry are the methodological issues and the lack of data suitable for any calculation. Dwelling stocks and infrastructures are less concerned in these problems; hence the objects of the estimation are rather homogenous and rich in data unlike the material stocks of different economic branches in agriculture, industry and services (e.g. factories, malls, specific machinery or hardware).

Generally, estimation of material stocks is possible with top-down, bottom-up, demand-driven and sensing methods (Tanikawa et al., 2015). Further classification is provided in Augiseau and Barles (2016). Top-down methods calculate material stocks from time series of material flows which are used to building up them; while bottom-up methods use objects as single data points during the aggregation of the mass of these objects weighted by their specific mass e.g. per floor space of per building. Accumulation of material stock is coupled to certain necessity of the society in case of demand-driven models, as shelter for instance. Recently, a widespread assortment of sensing tools is available for estimating stocks as well, e.g. GIS tools or aerial photos.

Recently, residential stock and infrastructures have been analyzed using the top-down methodologies by Krausmann et al., 2017; while the bottom-up approach has been utilized by Schiller et al. (2016), Gontia et al. (2018), and Han et al. (2018). Current applications of the demand-driven model are studies by Göswein et al. (2017), and Cau et al. (2017). The most cited work using demand-driven model is Müller (2006). The top-down methods are based on Fishman et al. (2014); Tanikawa et al. (2015); while Wiedenhofer et al. (2015) in case of bottom-up approach. Application of the sensing methods have been reported for instance by Inostroza (2014), Marcellus-Zamora et al. (2016), Kleeman et al. (2017).

Non-residential building stock was inventoried by Ortlepp et al.

https://doi.org/10.1016/j.resconrec.2018.07.015
Received 13 April 2018; Received in revised form 10 July 2018; Accepted 11 July 2018

(2015) and Schebek et al. (2017), with bottom-up studies in Germany. Regine Ortlepp and her colleagues pointed out that more attention has to be paid for non-residential building stock, since it represents 42–45% of the total building stock of Germany.

Infrastructures are of high importance to support the society as well, especially in public services and the operation of economic processes; with special regard to material requirement and emissions (Kennedy and Corfee-Morlot, 2013). Lwin et al. (2017) has been analyzed sewer pipeline network in Japan, while Wang et al. (2018) has been investigated water and sewage infrastructures in China. In both cases, demand-driven approach has been applied.

For the estimation of material stock of manufactured capital (capital stock) of the economy, two main approaches should be noted; the Australian Stock and Flows Framework (ASFF) (Lennox et al., 2005; Lennox and Turner, 2009; Turner et al., 2011) and the dynamic model of capital stocks by Pauliuk et al. (2015). ASFF is a well-established model with a significant advantage, i.e. the ability for analyzing material flows and stocks in the same context. The flow part operates with PIOTs, while the stock part uses process analysis to describe material stock requirement of distinct industries or services. Thereafter, the amount of material stocks is determined by the output of the particular sector. The dynamic model of Pauliuk and colleges (2015) utilizes also IOTs. Three methods are provided to link the output and the capital stock (production recipes, i.e. the endowment of capital stock to process the raw materials); the average capital requirement, the marginal approach and life cycle inventories.

The required data in both models are material flow based (IOT) and/or technology based, as described above. In the former case, either initial stock or long time series are necessary; and in the latter case, calculation calls for detailed investigation of the technologies. Nevertheless, to study the sectors of the economy in a disaggregated way, these information are not available, or their collection is extremely time- and labor-intensive. In several sectors, including agriculture and food industry, material stocks possibly remain extremely elongated time, commonly more than a century. Note, that it is applicable for buildings as well, which constitute the majority of the mass of the material stocks.

The model proposed in this article is able to estimate the capital stocks both in physical and in monetary dimensions. Currently, the physical dimension of the economic processes is presented. The calculation process is relatively data-effective, and fulfillment of sets of process analyses or definition any of production recipes is not essential. The ability and the limitations of the model is demonstrated by the material stock estimates of transportation and agricultural sectors of Hungary. Additionally, the model itself derives certain associations between the efficiency and productivity of utilizing and the accumulation of material stock.

2. Methods

In this article, estimation of material stocks in the economic subsystem is aimed. Therefore, this approach assumes that amount of the material stock accumulated by the society to support the processes of provision the commodities and services, i.e. the capital stock; is driven by economic factors. The model introduced in this study utilizes this economic relation between capital stock, other resources and the output of a process in physical terms either on company or on sectoral level. This relation is described by the production function.

In economic terms, capital stock is one of the resources (production factors, inputs) of the production process, together with labor and others. All of the resources have their deterministic influence on the output described in the production function. The resources of the production have different influence on the outcomes of the process, i.e. the amount or the value of the output commodities. Additionally, the variation of the output in time (growth rate) differs from the sum of the growth rate of the utilized resources. This difference is assumed to be the effect of technological progress – the Total Factor Productivity (TFP) or Solow residual (Solow, 1957; Comin, 2010).

A specific form of the production function was invented by Paul H. Douglas and Charles W. Cobb in 1928, and it is still widely used to describe the bond between resources, output and technology in economic and development studies (Miller, 2008). A Cobb-Douglas production function for a specific sector is given by:

$$q = A(L^{\alpha} K_m{}^{\beta_m} K_b{}^{\beta_b} Z^{\gamma}) \tag{1}$$

$$\ln q = \ln A + \alpha \ln L + \beta_m \ln K_m + \beta_b \ln K_b + \gamma \ln Z \tag{2}$$

where L, K_m, K_b and Z are the inputs (factors, resources), labor, capital stock of machines and ICT, capital stock of buildings and other infrastructures, and other sector-specific inputs, respectively; while q is the output. K_b and K_m have been distinguished since these two aggregates differ significantly with regard to their role, lifespan, economic value, and specific mass. Hence different types of capital stock result in broad variety of effects on productivity of economic processes, separated estimation of K_b and K_m is valuable from the socio-economic metabolism point of view. All of these variables are defined as physical variables, consequently, q is the amount of product or service in mass, L is measured in labor force (person), K in mass. Z can be specified, for instance, in agriculture as additional factors with a significant influence on q; e.g. arable land area, and amount of utilized fertilizers and pesticides (Griliches, 1964; Lau and Yotopoulos, 1989; Echevarria, 1998). Normalized data are used, hence these physical variables has different fundamental unit.

The parameters of the Cobb-Douglas production function are A, α, β_m, β_b and γ. A is a positive efficiency parameter, hence the higher A is the higher the output rises. A is assumed to be identical to TFP/Solow residual. Remaining parameters, α, β_m, β_b and γ are input intensity parameters, they represent the elasticities of the output with respect to each input (Dawson and Lingard, 1982). Intensity parameters provide information on the role of change in a factors utilized amount on the result of the process, i.e. the output.

Theoretically, there is a possibility to consider unintended outputs as well, even though it has no relevance economically. Pollution, biodiversity loss, resource depletion are not aimed by the production process, thus until these effects remain external, they do not play any role in the decisions regarding the utilized level of inputs and production. In such an 'unintended production function', distribution of α, β_m, β_b and γ input intensity parameters may significantly deviate from parameters of the classical production function.

Intensity parameters imply on the role of a given input on the amount of output. At this point, q, L and Z are determinable. Shifts in labor force L, sector-specific input Z and output q are published in national or sectoral statistics. For instance, Hungarian statistics contain datasets of these variables on sectoral level from 1920. Next steps aim the estimation of input intensity parameters α, β_m, β_b and γ. Fig. 1 provides an overview of datasets and methods utilized by the model.

Firstly, material requirement denoted to the gross fixed capital formation (GFCF) is calculated by the Leontief inverse of the input-output table (IOT), the final demand for commodities and services, and the domestic extraction as fallows. The letter one is an extension of the classical IOT (EE-IOT), and it provides the description of the physical basis required for the economic processes.

$$x = (I - A)^{-1*} y \tag{3}$$

where: x is the output, I is an identity matrix, A is the coefficient form of the IOT describing the direct connections between the sectors, and y is the final demand (all variables at country level). The inverse matrix in the equation above is the Leontief inverse (L), which now covers all direct and indirect monetary flows of a specific sector into another one. In the next step the material requirement of the final demand categories (MR) is given by involvement of the array of used domestic extraction (DE) into L and then multiplying it with the final demand (Steen-Olsen