Resources Policy 44 (2015) 161–165

Contents lists available at ScienceDirect

Resources Policy

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

Assessing the national economic importance of metals: An Input–Output approach to the case of copper in France

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ARTICLE INFO

Article history:
Received 31 October 2014
Received in revised form
16 February 2015
Accepted 17 February 2015

Keywords:
Metal criticality
Input–Output Analysis
Hybrid Input-Output tables
Copper

ABSTRACT

The national economic importance of a metal is usually considered as one of the indicators of this metal's vulnerability to supply restrictions at a national level. In a context of developed economies in which service activities stand for the largest share of GDP, this study proposes to account for the interplays between economic activities, including service activities, in the assessment of a metal's national economic importance. An index for qualifying a metal's relative economic importance is defined in such a way as to highlight to what extent the value added domestically induced by each domestic final use is dependent on this metal. The methodology, based on hybrid monetary physical Input–Output Analysis, is described and applied to the case of copper in France for the year 2008. “Constructions and construction works” represent the largest contribution to the index of copper's national economic importance. The hidden copper consumptions induced by the final uses of certain services (e.g. “public administration and defense services”) imply that these are more critical in terms of supply restrictions than some other copper-containing products (e.g. “computer, electronic and optical products”). The limitations and corresponding necessary future developments of such an approach are finally discussed.

Introduction

The technological development of modern societies relies on metals. From base metals to the more recently highlighted rare earth elements, these are necessary inputs to products that provide essential services to humans, such as transport, communication or energy production. Driven by the growing demand for these services and products over the world, the consumption of metals has dramatically increased in the last century. The global extraction of metals showed a 19-fold rise between 1900 and 2005, with copper increasing over 30-fold (Krausmann et al., 2009). In parallel, the supply of metals to companies, nations or at a global scale is faced with potential risks (in particular ever-decreasing ore grades and geopolitical tensions) and constant evolutions (such as the increasing share of supply from secondary sources).

In this context, several criticality analyses have been carried out recently with respect to different types of metals and considering distinct systems (technologies, companies or the global economy; Erdmann and Graedel, 2011). The identified critical metals are set as high priorities by policies regarding raw materials, e.g. in Europe, Japan or the USA, and have led in particular to incentives to recycle final products. Most of the analyses include the evaluation of supply risks and of vulnerability of the system to a real supply disruption. However, no consensus currently exists as to the methodology to be followed to determine the criticality of a metal. The choice for the “indicators” and “components” (following the nomenclature set by Graedel et al., 2012) associated to supply risks and vulnerability to supply restriction, and the way these indicators and components should be determined and further aggregated, are still a broad field of research.

This is in particular the case for the determination of the national economic importance of a metal, set as one of the indicators of the vulnerability to supply restriction at a national level. Graedel et al. (2012) consider the value (quantity multiplied by price) of the metal that is used in a given country in light of the country's gross domestic product (GDP) for a specified year. However, it could be objected that the use of this metal, even if of high value in monetary terms, may be devoted to economic activities with relatively low influence on the country's GDP and employments. The method developed by the European Commission instead measures quantitatively the economic importance of a material as the affected gross value added (GVA) generated by a mega-sector (European Commission, 2010). The mega-sectors are defined in order to aggregate all sectors or sub-sectors belonging to the same value chain. Yet the mega-sector approach mainly focuses on manufacturing activities while disregarding services, which should nevertheless be taken into account for at least two reasons. Firstly, services represent a growing share of our economies'

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http://dx.doi.org/10.1016/j.resourpol.2015.02.007
0301-4207/

GDP, amounting to 79% in France (World Bank, 2009). Secondly, and despite the fact that they do not directly consume metals, services require electronic devices, transportation means, energy, etc., and therefore indirectly require metals along the supply chain. Thus a supply restriction may not only affect industrial activities but also service activities in a way that should be accounted for when assessing the national economic importance of a metal.

This study proposes to account for the interplays between economic activities, including service activities, in the assessment of the national economic importance of a metal. The methodology, based on the Input–Output approach, is firstly described and then applied and discussed with reference to the case of copper in France for the year 2008.

Method

Input–Output Analysis

Economic Input–Output Analysis has been widely used for calculating the supply chain impacts of producing goods and services, both in economic and environmental terms (Lave et al., 1995; Joshi, 2000; Palm et al., 2006). A simple economic Input–Output model is based on the economic identity between the total output of an economic sector (x_i) and the sum of the demand for that sector's output from other sectors (z_{ij}) plus the final demand (y_i):

$$x_i = \sum_{j=1}^{n} z_{ij} + y_i \tag{1}$$

Deriving the technological requirement matrix A of coefficients a_{ij} (Eq. (2)), the total sectoral output for a particular demand (y) can be calculated while distinguishing each sector according to the matrix Eq. (3), with I the identity matrix.

$$a_{ij} = \frac{z_{ij}}{x_j} \tag{2}$$

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

Input–Output Analysis may not only be based on flows of products in monetary units, but may instead combine both flows in monetary units and flows in physical units in a so-called “mixed-unit” or “hybrid” framework (Hawkins et al., 2007; Schmidt et al., 2010). The set of Eqs. (1)–(3) then remains valid, with y_i, x_j, z_{ij} and a_{ij} either in monetary or in physical units.

In the following, imports are more precisely distinguished from domestic products. Assuming n industries, we denote[1]:

A^d $n \times n$ matrix of domestic input coefficients;
A^m $n \times n$ matrix of imported input coefficients;
$A = A^d + A^m$; $n \times n$ technology coefficient matrix;
x^d $n \times 1$ vector of domestic sectoral outputs;
x $n \times 1$ vector of total sectoral outputs;
u^d $n \times 1$ vector of domestic final uses (final consumption expenditures, gross capital formation and exports of products and services domestically produced);
V^d $n \times 1$ vector of direct value added coefficients of domestic industries;
v^d $n \times 1$ vector of value added domestically induced by the domestic final uses.

The domestic sectoral outputs as a response to domestic final uses are calculated as

$$x^d = (I - A^d)^{-1} u^d \tag{4}$$

accordingly enabling to derive the value added domestically induced by the domestic final uses

$$v^d = V^d (I - A^d)^{-1} u^d \tag{5}$$

The induced value added can then be reallocated to the domestic final uses according to:

$$v^d_{u_d} = \text{vdiag}\left\{ [V^d (I - A^d)^{-1} < u^d >]^T \times 1 \right\} \tag{6}$$

The total sectoral outputs as a response to final domestic uses correspond to the sum of domestic sectoral outputs (as calculated according to Eq. (4)) with foreign sectoral outputs, required as intermediate goods for the domestic production. Assuming that the imported products are produced in other countries with the same intermediate consumptions as in domestic production, the total (domestic and foreign) sectoral outputs as a response to domestic final uses are calculated as (Cadarso et al., 2012):

$$x = (I - A^d)^{-1} u^d + (I - A)^{-1} A^m (I - A^d)^{-1} u^d \tag{7}$$

In particular $x(m)$ corresponds to the output of the mth activity (e.g. the metal M production sector) induced by the French domestic final uses. The sectoral outputs can then be reallocated to the domestic final uses according to

$$X = (I - A^d)^{-1} < u^d > + (I - A)^{-1} A^m (I - A^d)^{-1} < u^d > \tag{8}$$

Considering the activity of metal M production, the corresponding mth line of matrix X stands for the vector x_M of requirement in metal M embodied in the domestic final uses, with $x_M(k)$ the requirement in metal M induced by the domestic final uses of product k.

The value added induced by each product and service of the domestic final uses along the supply-chain, in the country of interest (France in the following), is set to stand for these goods' economic importance. The national economic importance is therefore considered in a consumer perspective (“by product”), rather than the producer perspective adopted by the European Commission in its calculation of the criticality index (“by activity”). Subsequently the index of relative economic importance of metal M, EI_M, is set to highlight to what extent value added induced domestically by the domestic final uses is dependent on metal M. Or in other words, the economic importance of each good is put in perspective with its dependence on metal M in order to derive the index EI_M (Eqs. (9) and (10)).

$$EI_M = \frac{1}{\text{Total domestically induced Value Added} \times \text{Total induced requirement in metal M}} \sum_{k=1}^{n} v^d_{u_d}(k) x_M(k) \tag{9}$$

$$EI_M = \frac{1}{\sum_{l=1}^{n} v^d_{u_d}(l) \sum_{h=1}^{n} x_M(h)} \sum_{k=1}^{n} v^d_{u_d}(k) x_M(k) \tag{10}$$

Hybrid Monetary Physical Input–Output model

To illustrate the approach, a Hybrid Monetary Physical Input–Output model is built for France for the year 2008. The matrices of

[1] The notations for algebraic operations are set as follows: $< . >$: transformation of a vector to a diagonal matrix;vdiag{ }: transformation of a matrix into its diagonal vector;[.]^T: transpose of a matrix; 1: matrix of coefficients set to 1.