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DEPARTMENT OF ECONOMICS
RESEARCH MEMORANDUM

**CORRECTION OF THE MATERIAL BALANCE
EQUATION IN DYNAMIC INPUT-OUTPUT MODELS**

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FEW 383

CORRECTION OF THE MATERIAL BALANCE EQUATION
IN DYNAMIC INPUT-OUTPUT MODELS*

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Abstract: The material balance equations of two established dynamic input-output models, one with instantaneous production and the other with distributed activities, are corrected.

* The authors would like to thank Thijs ten Raa for drawing the subject of input-output analysis to their attention and all those who delivered useful comments on the text.

1. Introduction.

Leontief (1970) sets up a dynamic input-output model built with parts like supply, final demand, demand for intermediate goods, and demand for capital goods. Leontief's material balance equates supply and total demand for each period. However, Leontief was imprecise in specifying the demand for capital goods, because no production on behalf of technological change was incorporated in his material balance equation.

Ten Raa (1986) describes a generalized version of Leontief's model, but by blindly following Leontief in his reasoning ten Raa incorporates the same flaw in his model.

Our paper will precisely derive the material balance equations. In section 3 we will show that the material balance equation formulated by Leontief is imprecise and provide the correction. In section 4 we will give the precise material balance equation for the dynamic input-output model with distributed activities as formulated by ten Raa and discuss the impact of our reformulation of the material balance equation on its solution. First, however, we will present the framework, as introduced by ten Raa (1986).

2. The framework.

Consider an economy which consists of n sectors. Each of these n sectors produces only one good. Thus, let sector j produce good j . The output of the j^{th} sector will be denoted as x_j ($j = 1, \dots, n$). These n

outputs, x_j , make up a column vector x . Because we will take time into account we attach a time index t to x . So $x(t)$ denotes the output vector of the economy at time t for the n different sectors.

For the production of x_j units of good j sector j needs intermediate goods and a certain capacity. Capacity in a period t will be defined as the total output the economy is able to produce in this period given the total stock of capital goods and the state of technological development of the stock of capital goods in this period. Let the units of capital good i , needed for the capacity to produce one unit of good j be denoted by b_{ij} . All the b_{ij} form an $n \times n$ -matrix B . So, if sector j wants to produce one unit of good j in period $t+1$, it has to install b_{ij} units of capital good i in or before period $t+1$. To install b_{ij} units of capital good i sector j has to make investments in the periods preceding $t+1$. With respect to the investment in and installation of capital goods we will make the following assumption:

Assumption 2.1: The capital goods needed in period $t+1$ will be invested according to a technologically determined distribution over the periods $t-s$. The installation lag of these investments in period $t-s$ is equal to $s+1$; $s=0,1,2,\dots$

Notice that the amount of capital goods i needed to produce one unit of good j differs from period to period because of technological development. To incorporate technological development and the subjects introduced in Assumption 2.1 into our notation we will define the

$n \times n$ -matrix $B_{t+1}(-s)$ as the investments made in period $t-s$ on behalf of the need for capital goods to produce one unit of each good in period $t+1$. The technological development is incorporated in $B_{t+1}(-s)$ by the fact that $B_{t+1}(-s)$ differs for all t , assuming perfect substitutability with respect to time of capital goods, as is usually done in the literature.

Except capital goods, incorporating capacity to produce goods, sector j will also need intermediate goods from the other sectors, as mentioned before. Let us represent a_{ij} as the amount of intermediate goods i sector j needs from sector i for the production of one unit of good j . These a_{ij} form an $n \times n$ -matrix A . Equivalent to the treatise of capacity we can make the following assumption with respect to these intermediate goods.

Assumption 2.2: The intermediate goods needed in period t are demanded according to a technologically determined distribution over the periods $t-s$. The consumption lag of the demand in period $t-s$ is equal to s ; $s=0,1,2,\dots$

In the same way as we did with the notation for capacity we define the $n \times n$ -matrix $A_t(-s)$ as the demand for intermediate goods in period $t-s$ for the production of one unit of each good in period t .

Thus far, we have introduced the most important variables in the model with regard to the demand and supply of goods of the producers. Besides the demand and supply of producers, the consumers will demand certain amounts of goods for consumption. These amounts of goods

constitute final demand and are stacked in a column vector c . So, let $c(t)$ be defined as the amount of final demand in period t . We will assume that $c(t)$ is given for each period t .

3. A dynamic input-output model with instantaneous production.

The dynamic input-output stated by Leontief (1970) can be characterized as a model of instantaneous production. To derive the model from the framework defined in section 2 we need a stronger assumption.

Assumption 3.1: The capital goods resulting from an investment in period t will be installed in period $t+1$ while intermediate goods produced in period t will be used in period t .

The consequences of making Assumption 3.1 for the matrices with the distribution coefficients are as follows,

$$B_{t+1}(-s) = 0, \quad s > 0$$

(1)

$$A_t(-s) = 0, \quad s > 0.$$

The matrices that remain are $A_t(0)$ and $B_{t+1}(0)$. In the remainder of this section these matrices will be denoted shortly A_t and B_{t+1} respectively. We will now proceed with the derivation of the material balance equation of the economy introduced in this section.

The economy supplies $x(t)$ units of the n goods at period t , where t runs through the integers, such that total demand is fulfilled. Total demand divides in three parts.

The first part of total demand consists of demand for intermediate goods in period t . In an equilibrated or rationally planned economy this demand is equal to

$$A_t x(t), \quad (2)$$

because no storage of intermediate goods takes place in such an economy. Therefore no reservations are made at period t on behalf of the need for intermediate goods in the future periods.

The second part of total demand consists of final demand in period t

$$c(t). \quad (3)$$

The third part consists of the investments in capital goods in period t on behalf of the demand for capacity in period $t+1$. The economy plans to produce $x(t+1)$ units of goods. So, in period $t+1$ this economy needs a capacity equal to

$$B_{t+1} x(t+1). \quad (4)$$

Therefore the demand for capital goods at period t is equal to (4).

However, to produce $x(t)$ in period t there already is a capacity of

$$B_t x(t) \quad (5)$$

available in the economy at period t . The minimal but necessary investments in period t must be sufficient to fill the gap between the existing capacity at period t to produce $x(t)$ and the capacity needed at period $t+1$ to produce $x(t+1)$. So, the investment in capital goods in period t has to be equal to

$$B_{t+1} x(t+1) - B_t x(t). \quad (6)$$

Equivalent to the situation with intermediate goods no investments are made at period t in an equilibrated or rationally planned economy on behalf of the need for capital goods in the periods succeeding period $t+1$. This leaves us with (6) as the total demand for capital goods at period t .

This completes the description of the total demand in the economy at period t . Setting the supply in period t , $x(t)$, equal to total demand we obtain the following material balance equation

$$x(t) = A_t x(t) + B_{t+1} x(t+1) - B_t x(t) + c(t). \quad (7)$$

Notice that Leontief (1970) comes to a slightly different material balance equation than (7), namely

$$x(t) = A_t x(t) + B_{t+1} [x(t+1) - x(t)] + c(t). \quad (8)$$

To find the cause of the difference, isolate the investment part (6) of our material balance (7) and rewrite it in the following way

$$B_{t+1} x(t+1) - B_t x(t) = B_{t+1} [x(t+1) - x(t)] + [B_{t+1} - B_t] x(t) \quad (9)$$

Equation (9) shows that the investments in period t on behalf of the need for capacity in period $t+1$ consists of two parts. The first term on the right hand side of (9), $B_{t+1} [x(t+1) - x(t)]$, can be interpreted as the investments necessary at period t to fulfil the need for capacity induced by a change in output equal to $x(t+1) - x(t)$, given the new state of technology in period $t+1$. The second term on the right hand side of (9), $[B_{t+1} - B_t] x(t)$, can be interpreted as the investments necessary at period t to adjust the capacity to sustain a production level of $x(t)$ units of goods in period $t+1$ due to a change in the state in technology. Note that in case of technological progress, elements will be negative.

If no technological change occurs, i.e. $B_{t+1} = B_t$, for all t , then the capital part of the corrected material balance equation (7) reduces to the capital part of the material balance equation (8) formulated by Leontief.

The main point of this section shows that the material balance equation formulated by Leontief and used by many other economists is imprecise. The corrected material balance equation is given in (7).

The consequences for the derivation of the dynamic inverse will be discussed in section 4.

4. A dynamic input-output model with distributed activities.

This section concentrates on the derivation of the material balance equation of a dynamic input-output model with distributed activities, which has been defined in section 2. Ten Raa has already formulated a dynamic input-output model with distributed activities in ten Raa (1986), which is a generalization of the input-output model with instantaneous production introduced by Leontief (1970). But by blindly following Leontief in his way of reasoning, ten Raa incorporates the same flaw in his model as Leontief. In this section we derive the precise material balance equation.

As in section 3, the economy supplies $x(t)$ units of the n goods at period t , where t runs through the integers, such that total demand is fulfilled. Total demand again divides in three parts.

The first part of total demand consists of the aggregated demand for intermediate goods. So, consider period t . Because intermediate goods are demanded according to a distribution, the economy has to produce intermediate goods in period t on behalf of the need for these intermediate goods in future periods. Then, for the production of $x(t+s)$ units of goods in period $t+s$ the economy has to produce $A_{t+1}(-s)x(t+s)$ units of intermediate goods in period t . This means that the aggregated demand in period t on behalf of the need for intermediate goods in all succeeding periods is

$$\sum_{s=0}^{\infty} A_{t+s}(-s)x(t+s). \quad (10)$$

The second part of the total demand consists of final demand in period t .

$$c(t). \quad (11)$$

The third part consists of the aggregated investment in capital goods in period t on behalf of the demand for capital goods in the periods following t . So, assume that the economy is at period t and consider a certain period in the future, say $t+s+1$. The demand for capital goods in period t needed for the capacity to produce $x(t+s+1)$, is equal to

$$B_{t+s+1}(-s)x(t+s+1). \quad (12)$$

However, in period t the demand of the economy for capital goods in period $t-1$ on behalf of the need for capital goods in period $t+s$ is already available. These capital goods will be used for economic reasons in all periods succeeding $t+s$. This demand is equal to

$$B_{t+s}(-s)x(t+s). \quad (13)$$

We will assume that capital goods are perfectly substitutable with respect to time. So, we can subtract (13) from (12), to obtain period t investment in capital with installation time s ,

$$B_{t+s+1}(-s)x(t+s+1) - B_{t+s}(-s)x(t+s). \quad (14)$$

Summing over the various installation times, total investment in capital goods at period t becomes

$$\sum_{s=0}^{\infty} [B_{t+s+1}(-s)x(t+s+1) - B_{t+s}(-s)x(t+s)]. \quad (15)$$

This completes the description of the parts of total demand in the economy at period t . The economy has to supply $x(t)$ to fulfil total demand, yielding the following material balance equation,

$$x(t) = \sum_{s=0}^{\infty} A_{t+s}(-s)x(t+s) + c(t) + \quad (16)$$

$$\sum_{s=0}^{\infty} [B_{t+s+1}(-s)x(t+s+1) - B_{t+s}(-s)x(t+s)].$$

Rewriting this, gives,

$$[I - A_t(0) + B_t(0)]x(t) + \quad (17)$$

$$\sum_{s=1}^{\infty} [-A_{t+s}(-s) - B_{t+s}(-s+1) + B_{t+s}(-s)]x(t+s) = c(t).$$

Defining shorthand $G_t(s) := -A_{t+s}(-s) - B_{t+s}(-s+1) + B_{t+s}(-s)$ for $s=1,2,\dots$ and $G_t(0) := I - A_t(0) + B_t(0)$, (17) can be rewritten as

$$G_t(0)x(t) + \sum_{s=1}^{\infty} G_t(s)x(t+s) = c(t). \quad (18)$$

The solution to (18) for $x(t)$ is equal to

$$x(t) = G_t(0)^{-1}c(t) + \sum_{s=1}^{\infty} D_t(s)c(t+s), \quad (19)$$

with $D_t(s) := R_t(s_1) \dots R_{t+s_1+\dots+s_\ell} G_{t+s}(0)^{-1}$ where $R_t(s) := -G_t(0)^{-1}G_t(s)$, the summation is over all $(s_1, \dots, s_\ell)$ with each component in $\{1, \dots, s\}$ and the sum of the components equal to s . For a proof of this result we refer to ten Raa (1986).

The comments we gave with respect to the material balance equation formulated by Leontief (1970) in the last part of section 3 can also be applied to the material balance equation formulated by ten Raa (1986). Just rewrite (15) in the following way

$$\begin{aligned} \sum_{s=0}^{\infty} [B_{t+s+1}(-s)x(t+s+1) - B_{t+s}(-s)x(t+s)] = \\ \sum_{s=0}^{\infty} B_{t+s+1}(-s)[x(t+s+1) - x(t+s)] + \\ \sum_{s=0}^{\infty} [B_{t+s+1}(-s) - B_{t+s}(-s)]x(t+s). \end{aligned} \quad (20)$$

Again, no technological change implies that $B_{t+s+1}(-s) = B_{t+s}(-s)$ for all s , collapsing ten Raa's and our material balances into one.

5. Conclusions.

In section 3 and 4 we showed that Leontief and ten Raa both incorporated the same flaw in their models. We formulated the precise material balance equations for both models and derived that both ten Raa as Leontief did not incorporate investments on behalf of the technological change into their models. The impact of their flaw on the solution of the input-output as given by ten Raa (1986) was not serious as could be seen in (19). Our correction only changed the definition of $G_t(0)$ and $G_t(s)$, $s=1,2,\dots$. So, no theoretical harm was done. His empirical results are not affected either, as there is no technological change in his study. However, the impact on empirical studies of the material balance and its solution could be quite serious if there is technological change. Then the material balance of Leontief (1970) or ten Raa (1986) have to be revised as spelled out in this paper to incorporate the investment requirements of technological change.

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