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Abstract This note shows that the demand-driven input-output (IO) quantity model developed by Wassily Leontief may also be interpreted as the almost unknown revenue-pull IO price model measured in value terms, instead of in prices. This new interpretation opens up hitherto unused possibilities to simulate interindustry demand-driven inflationary processes.

Keywords Input-output table, Leontief model, Ghosh model, Supply-driven inflation, Demand-driven inflation

Introduction

All four basic input-output (IO) models are mathematically very similar, but economically they are worlds apart. The two quantity models are each other's mirror image, as are their two dual price models. The demand-driven IO quantity model (Leontief, 1941) and its cost-push IO price dual (Leontief, 1951) are very well known. The supply-driven IO quantity model (Ghosh 1958) is little known and – for good reasons – hardly used since the 1980s, while its revenue-pull IO price dual (Davar, 1989) is not known at all and has never been used, despite its potential.

Interestingly, this least known IO model can be rewritten such that it mimics the best known IO model. As a consequent, the demand-driven IO quantity model may be interpreted as the revenue-pull IO price model measured in value terms, instead of in prices. As such, it may empirically be used to simulate demand-driven inflation processes, as opposed to supply-driven inflation processes that may be simulated with the cost-push IO price model. Before showing this equivalence, we briefly summarize the four basic IO models.

The four basic input-output models

All four models are based on the accounting identities of the industry-by-industry type of input-output table (IOT) shown in Figure 1, which also contains the definitions of the main matrices used. IOTs are always expressed in monetary values. However, for IO modelling purposes these values are usually interpreted as quantities measured in unit prices of one. Figure 1 also shows that an IOT essentially represents a double sectoral breakdown of the well-known macro-economic accounting identity for the Gross Domestic Product: $Y = C + I + G + E – M$.

Both sets of quantity annex price models can be given a *micro-economic foundation*, as both sets may be based on simplifications of the most general production function with

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multiple inputs and multiple outputs, as measured in the columns and rows of Figure 1, respectively. The set of Leontief models assumes single homogenous outputs with uniform prices across the rows of the IOT combined with multiple heterogenous inputs with different prices across its columns, whereas the Ghosh/Davar set of models assumes single homogenous inputs with uniform prices across the columns of the IOT combined with heterogenous outputs with different prices across its rows (see the Appendix for all assumptions of both sets of models).

Figure 1. Input-output table with macro totals

	Industries	Final demand	Total output
Industries	$z_{ij} \in \mathbf{Z}$	$y_{iq} \in \mathbf{Y}$	$x_i \in \mathbf{x}$
Primary supply	$v_{pj} \in \mathbf{V}$	$r_{pq} \in \mathbf{R}$	M Y
Total input	$x_j \in \mathbf{x}'$	$C\,I\,G\,E$	

In the classic *demand-driven IO quantity model*, along the rows of the IOT, exogenous final demand $\mathbf{y} = \mathbf{Y}\,\mathbf{i}$, along with endogenous intermediate demand $\mathbf{Z}\mathbf{i}$, determines the size of total output $\mathbf{x} = \mathbf{Z}\mathbf{i} + \mathbf{y}$, where $\mathbf{i}$ = a summation column with ones. At constant prices, total output, in turn, backwardly along the columns of the IOT, determines the use of both intermediate and primary inputs by means of fixed intermediate input coefficients $a_{ij} = z_{ij} / x_j \in \mathbf{A}$ and fixed primary input coefficients $c_{pj} = v_{pj} / x_j \in \mathbf{C}$, with $\mathbf{i}'\mathbf{A} + \mathbf{i}'\mathbf{C} = \mathbf{i}'$, where $\mathbf{i}'$ = a summation row with ones. The solutions for total output, intermediate inputs, and primary inputs (i.e. imports and value added) read as follows:

$$\mathbf{x} = \mathbf{A}\,\mathbf{x} + \mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{L}\,\mathbf{y}\,, \quad \mathbf{Z}\,\mathbf{i} = \mathbf{A}\,\mathbf{x} = \mathbf{A}\,\mathbf{L}\,\mathbf{y}\,, \text{ and } \mathbf{V}\,\mathbf{i} = \mathbf{C}\,\mathbf{x} = \mathbf{C}\,\mathbf{L}\,\mathbf{y} \quad (1)$$

where $\mathbf{L}$ = the so-called Leontief-inverse. Obviously, reality only comes close to this model when all markets are characterized by excess supply, i.e. around the bottom of the business cycle, but even then price reactions may dampen the predicted quantity changes (see further Oosterhaven, 2019, Ch. 6)

The *cost-push price dual* of this classic IO quantity model, along the columns of Table 1, assumes that the exogenous primary input prices $p_p \in \mathbf{p}_v$, along with the endogenous intermediate input prices $p_i \in \mathbf{p}$, multiplied with their respective cost shares $\mathbf{C}$ and $\mathbf{A}$, determine the cost of total inputs in (2). At constant quantities, any change in the cost of total inputs is passed on uniformly, along the rows of the IOT, to all intermediate and final users of the outputs of the industry at hand. The solution for the prices of total input/output reads as follows:

$$\mathbf{p}' = \mathbf{p}'\,\mathbf{A} + \mathbf{p}'_v\,\mathbf{C} = \mathbf{p}'_v\,\mathbf{C}(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{p}'_v\,\mathbf{C}\,\mathbf{L} \quad (2)$$

Obviously, with constant quantities, this cost-push price model is suited to simulate the further supply-driven price impacts of e.g. an increase in the prices of oil and gas imports.

The duality of the two Leontief models may be illustrated by post-multiplying (2) with total final demand $\mathbf{y}$. This gives:

$$\mathbf{p}'\mathbf{y} = \mathbf{p}'_v\,\mathbf{C}\mathbf{L}\mathbf{y} = \mathbf{p}'_v\,\mathbf{v} \quad (3)$$

Although the values of the solutions (1) and (2) are linked in (3), the variables of both models move independently. Exogenous final demand quantities $\mathbf{y}$ backwardly determine primary input quantities $\mathbf{v}$ in the quantity model, whereas exogenous primary supply prices $\mathbf{p}'_v$ forwardly determine final output prices $\mathbf{p}'$ in the price model.

On to the hardly known mirror image, second set of basic IO models. The *supply-driven IO quantity model*, along the columns of Figure 1, assumes that the exogenous supply of primary inputs $\mathbf{v}' = \mathbf{i}'\mathbf{V}$, along with the endogenous supply of intermediate inputs $\mathbf{i}'\mathbf{Z}$, determines total input $\mathbf{x}' = \mathbf{i}'\mathbf{Z} + \mathbf{v}'$, and thus total output. At constant prices, total output, in turn, forwardly along the rows of the IOT, determines intermediate and final outputs by means of fixed intermediate output coefficients $b_{ij} = z_{ij} / x_i \in \mathbf{B}$ and fixed final output coefficients $d_{iq} = y_{iq} / x_i \in \mathbf{D}$, with $\mathbf{B}\mathbf{i} + \mathbf{D}\mathbf{i} = \mathbf{i}$. The solutions for total input/output, intermediate output and final output (i.e. domestic final demand and exports) read as follows:

$$\mathbf{x}' = \mathbf{x}'\mathbf{B} + \mathbf{v}' = \mathbf{v}'(\mathbf{I} - \mathbf{B})^{-1} = \mathbf{v}'\mathbf{G}\,,\ \mathbf{i}'\mathbf{Z} = \mathbf{x}'\mathbf{B} = \mathbf{v}'\mathbf{G}\mathbf{B}\,,\ \text{and}\ \mathbf{i}'\mathbf{Y} = \mathbf{x}'\mathbf{D} = \mathbf{v}'\mathbf{G}\mathbf{D} \quad (4)$$

where $\mathbf{G}$ = the so-called Ghosh-inverse. The assumption of a single homogenous input, hidden in (4), makes this model is highly implausible, as it allows factories to work without labour and cars to drive without gas (see further Oosterhaven, 1988).[2]

In the *revenue-pull price dual* of this model, along the rows of the IOT, exogenous prices for the single homogeneous types of final demand of category *q*, $p_q \in \mathbf{p}_{y'}$, along with the endogenous prices for the single homogenous intermediate inputs of industry *j*, $p_j \in \mathbf{p}$, multiplied with their respective revenue shares $\mathbf{D}$ and $\mathbf{B}$, determine total output prices $\mathbf{p} = \mathbf{B}\mathbf{p} + \mathbf{D}\mathbf{p}_{y'}$. At constant quantities, any change in revenues, in turn, is fully passed on backwardly, along the columns of the IOT, into the prices paid for intermediate and primary inputs. The solution for the prices of total output/input reads as follows:

$$\mathbf{p} = \mathbf{B}\mathbf{p} + \mathbf{D}\mathbf{p}_{y'} = (\mathbf{I} - \mathbf{B})^{-1}\,\mathbf{D}\mathbf{p}_{y'} = \mathbf{G}\mathbf{D}\mathbf{p}_{y'} \quad (5)$$

[2] See Gruver (1989) and Rose & Allison (1989) for attempts to defend the Ghosh quantity model, and Oosterhaven (1989) for a rejoinder. After this exchange the Ghosh quantity model has hardly been used anymore.

Obviously, at constant quantities, this model is suited to simulate the further demand-driven price impacts of e.g. an increase in the export prices of particular industries.

The duality of these last two basic IO models may be illustrated by pre-multiplying (5) with total primary input $\mathbf{v}'$:

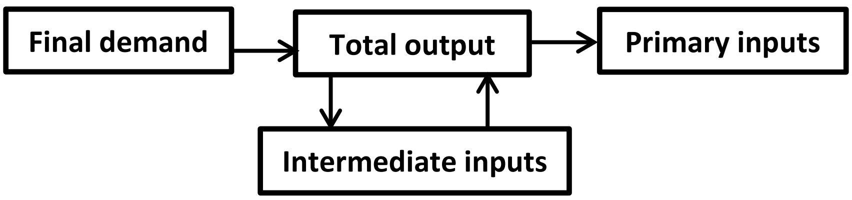
$$\mathbf{v}'\mathbf{p} = \mathbf{v}'\mathbf{G}\,\mathbf{D}\mathbf{p}_{y'} = \mathbf{y}'\mathbf{p}_{y'} \tag{6}$$

Again both model solutions (4) and (5) are linked by their values in (6), whereas their variables move independently: with exogenous primary supply quantities $\mathbf{v}'$ forwardly determining the quantities of final output $\mathbf{y}'$, and exogenous final output prices $\mathbf{p}_{y'}$ backwardly determining the prices of primary inputs $\mathbf{p}$.

Turning Leontief quantities into the revenue-pull prices

The economic logic of the reinterpretation of the demand-driven IO quantity model (1) as the revenue-pull IO price model (5) measured in values, instead of in prices, follows from their identical causal structure shown in Figure 2. In both models, any change in exogenous final demand, irrespective whether it regards a price change or a quantity change, leads to a direct change in total output. In the quantity model it is the quantity of total output that changes, whereas it is the price of total output that changes in the price model. Next, any change in total output leads to changes in both intermediate and primary inputs, again with the quantities changing in the quantity model and the prices changing in the price model. Finally, any change in intermediate inputs, in turn, leads to a further change in total output, with the quantities changing in the quantity model and the prices changing in the price model. And so on.

Figure 2. Common causal structure of the two input-output models.



Not only the causal structure of the two models is identical, but also the size of the causal effects along the arrows in Figure 2. If e.g. the exogenous price of the say 50 million large exports of the dairy industry, with an total dairy output of say 100 million, increases with 20%, then the revenue-pull price model, at constant quantities, predicts a direct impact on the price of total output of ($b_{\text{dairy, exports}}$ = 50/100) x 20% = 10%, which implies an increase in the value of total output of 100 x 10% = 10 million. In the demand-driven quantity model, the comparable size of the increase in dairy exports equals 50 x 20% = 10 million, which leads to a direct impact on total output of also 10 million, which is size-wise comparable to the total output price increase of 10%.

The first round backward impacts are numerically also equal in both models. If the 100 million of total output of the dairy industry requires say 40 million of milk, then the first round backward impact, at constant prices, in the Leontief quantity model will be a quantity increase of ($a_{\text{milk,dairy}}$ = 40/100) x 10 = 4 million of milk. In the revenue-pull price model the first round backward impact on the price of milk will be equal to the price increase of the dairy industry, i.e. 10%, which implies an increase in the value of the milk inputs into the dairy industry of 10% x 40 = also 4 million. The same holds, of course, for the second and higher round backward effects.

Mathematically, the equivalence follows from substituting $\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{Z} = \hat{\mathbf{x}}^{-1}\mathbf{A}\,\hat{\mathbf{x}}$ into the first part of (5), and pre-multiplying the result with $\hat{\mathbf{x}}$, which indicates a diagonal matrix with $\mathbf{x}$ on its diagonal. This gives:

$$\hat{\mathbf{x}}\mathbf{p} = \hat{\mathbf{x}}\,\hat{\mathbf{x}}^{-1}\mathbf{A}\,\hat{\mathbf{x}}\mathbf{p} + \hat{\mathbf{x}}\,\mathbf{D}\mathbf{p}_{y'} \tag{7}$$

Next, $\mathbf{Y} = \hat{\mathbf{x}}\,\mathbf{D}$ is substituted into (7), and the result is simplified and solved as follows:

$$\hat{\mathbf{x}}\mathbf{p} = \mathbf{A}\,\hat{\mathbf{x}}\mathbf{p} + \mathbf{Y}\mathbf{p}_{y'} = (\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{Y}\mathbf{p}_{y'} = \mathbf{L}\,\mathbf{Y}\mathbf{p}_{y'} \tag{8}$$

The end result shows that the Leontief quantity model (1) may indeed be interpreted as the revenue-pull price model (5) wherein the price changes are evaluated in terms of the changes in value that accompany them, i.e. with $\hat{\mathbf{x}}\mathbf{p}$ and $\mathbf{Y}\mathbf{p}_{y'}$.[3]

Note that the exogenous final output prices in (5) and (8) are defined per column of final output. This is done in order to keep the mathematics as simple as possible as well as to show the mirror image character of the four models as clearly as possible. In empirical applications of (5) and (8), however, it will often be much more useful to assume that the prices of the cells of $\mathbf{Y}$ can move independently. If that more realistic assumption is applied to all of the cells of $\mathbf{Y}$, (5) and (8) change into:

$$\mathbf{p} = (\mathbf{I} - \mathbf{B})^{-1}\,(\mathbf{D} \otimes \mathbf{P}_y)\,\mathbf{i} \text{ and} \tag{5a}$$

$$\hat{\mathbf{x}}\mathbf{p} = (\mathbf{I} - \mathbf{A})^{-1}\,(\mathbf{Y} \otimes \mathbf{P}_y)\,\mathbf{i}\ , \tag{8a}$$

respectively, where $\otimes$ = the cell x cell multiplication of two matrices, and $p_{iq} \in \mathbf{P}_y$ = the matrix with exogenous final output prices.

[3] Note that analogous transformations of (2) result in $\mathbf{x}'\hat{\mathbf{p}} = \mathbf{p}'_v\,\mathbf{V}\,(\mathbf{I} - \mathbf{B})^{-1}$. This shows that the solution of the supply-driven IO quantity model (4) may also be reinterpreted as the solution of the Leontief cost-push IO price model (2) measured in value terms, instead of in prices (see Dietzenbacher, 1997, for a further discussion).

Conclusion

This note shows that the well-known Leontief input-output (IO) quantity model may equally well be interpreted as the almost unknown revenue-pull IO price model measured in value terms, instead of in prices. This opens up hitherto unused opportunities to do all kind of demand-driven inflation simulations of exogenous final output price changes. These may be done with the basic Leontief model, but of course also with extensions of this basic model.

International extensions would e.g. allow for simulations of demand-driven, backward price impacts along international interindustry supply chains, whereas extensions with endogenous household expenditures would e.g. allow for simulations of demand-driven interindustry price-wage-price spirals. These are just some examples of the list of possible applications of this alternative interpretation of the Leontief IO model.

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Appendix. Assumptions and solutions of the four basic input-output models.

Demand-driven quantity & cost-push price model:	Supply-driven quantity & revenue-pull price model:
For the individual firm:	
- given demand for its single homogeneous output, i.e. perfect substitution among all outputs	- given supply of its single homogeneous input, i.e. perfect substitution among all inputs
- full complementarity of all inputs (fixed input ratios)	- perfect jointness of all outputs (fixed output ratios)
- cost minimization at given input prices	- revenue maximization at given output prices
- derived demand for inputs (backward linkages)	- derived supply of outputs (forward linkages)
- full competition, i.e. forward passing on of all input price changes into the single output price	- full competition, i.e. backward passing on of all output price changes into the single input price
For the economy as a whole:	
- exogenous demand for final outputs per industry	- exogenous supply of primary inputs per industry
- endogenous demand for all inputs per industry	- endogenous supply of all outputs per industry
- perfectly elastic supply of all primary inputs, i.e. exogenous primary input prices	- perfectly elastic demand for all final outputs, i.e. exogenous final output prices
- endogenous total output prices and quantities	- endogenous total input prices and quantities
Solution of the two Leontief models:	*Solution of the two Ghosh models:*
- $\mathbf{v} = \mathbf{C}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}$, with $\mathbf{y} = \mathbf{Y}\mathbf{i}$ and $\mathbf{v} = \mathbf{V}\mathbf{i}$	- $\mathbf{y}' = \mathbf{v}'(\mathbf{I}-\mathbf{B})^{-1}\mathbf{D}$, with $\mathbf{y}' = \mathbf{i}'\mathbf{Y}$ and $\mathbf{v}' = \mathbf{i}'\mathbf{V}$
- $\mathbf{p}'_y = \mathbf{p}' = \mathbf{p}'_v\mathbf{C}(\mathbf{I}-\mathbf{A})^{-1}$	- $\mathbf{p}_{v'} = \mathbf{p} = (\mathbf{I}-\mathbf{B})^{-1}\,\mathbf{D}\,\mathbf{p}_{y'}$

Source: Oosterhaven (2019, Ch. 6).

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