Measuring the Upstreamness of Production and Trade Flows

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The fragmentation of production across national boundaries has been a distinctive feature of the world economy in recent decades. Production now often entails the sourcing of inputs and components from multiple suppliers based in several countries. These trends may well have interesting implications for trade patterns: For example, are countries specializing in relatively upstream versus downstream stages of global production processes?

Addressing this question requires first and foremost an industry-level measure of relative production-line position. In this article, we present two approaches to building a measure of industry "upstreamness" (or average distance from final use). The two approaches are motivated in distinct ways, but we prove that they yield an equivalent measure. Furthermore, we provide two additional economic interpretations of this measure, one of them closely related to the concept of forward linkages in Input-Output (I-O) analysis.

On the empirical side, we construct this measure using the 2002 I-O Tables as a benchmark. The high level of disaggregation in the US Tables allows us to calculate upstreamness for a total of 426 industries. We separately construct our measure using the I-O Tables for selected countries in the OECD STAN database, in order to verify that upstreamness is a stable attribute of industries across different countries (with some caveats; see Section III). Finally, we present an application of our measure, by characterizing the average upstreamness of exports at the country level using trade flows in the year 2002. Our initial exploration indicates that stronger institutions and relative skill (but not physical capital) abundance are correlated with a propensity to export in relatively more downstream industries. A long version of this paper (Pol Antràs, Davin Chor, Thibault Fally and Russell Hillberry 2012), which we refer to hereafter as ACFH, contains additional discussion and results.

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We thank Jon Vogel for comments.

I. Two Measures of Upstreamness

A. Closed-Economy Benchmark

To build intuition, we begin by considering an N-industry closed economy with no inventories. For each industry $i \in \{1, 2, ..., N\}$, the value of gross output (Y_i) equals the sum of its use as a final good (F_i) and its use as an intermediate input to other industries (Z_i)

$$(1) \qquad Y_i = F_i + Z_i = F_i + \sum_{j=1}^{N} d_{ij} Y_j$$

where, in the last summation, d_{ij} is the dollar amount of sector i's output needed to produce one dollar worth of industry j's output. Iterating this identity, we can express industry i's output as an infinite sequence of terms which reflect the use of this industry's output at different positions in the value chain, starting with final use

$$\begin{aligned} Y_i \quad = \quad & F_i + \sum_{j=1}^{N} d_{ij} F_j + \sum_{j=1}^{N} \sum_{k=1}^{N} d_{ik} d_{kj} F_j \\ (2) \qquad & + \sum_{j=1}^{N} \sum_{k=1}^{N} \sum_{l=1}^{N} d_{il} d_{lk} d_{kj} F_j + ... \end{aligned}$$

Building on this identity, Pol Antràs and Davin Chor (2011) suggest computing the (weighted) average position of an industry's output in the value chain, by multiplying each of the terms in (2) by their distance from final use plus one and dividing by Y_i:

$$U_{1i} = 1 \cdot \frac{F_i}{Y_i} + 2 \cdot \frac{\sum_{j=1}^{N} d_{ij} F_j}{Y_i} + 3 \cdot \frac{\sum_{j=1}^{N} \sum_{k=1}^{N} d_{ik} d_{kj} F_j}{Y_i} + 4 \cdot \frac{\sum_{j=1}^{N} \sum_{k=1}^{N} \sum_{l=1}^{N} d_{il} d_{lk} d_{kj} F_j}{Y_i} + \ldots \quad (3)$$

It is clear that $U_{1i} \geq 1$ and that larger values are associated with relatively higher levels of upstreamness of industry i's use. Although computing (3) might appear to require computing an infinite power series, notice that provided that $d_{ij} < 1$ for all (i, j) (a natural assumption), the numerator of the above measure equals the i-th element of the $N \times 1$ matrix $[I - D]^{-2} F$, where D is an $N \times N$ matrix whose (i, j)-th element is d_{ij} and F is a column matrix with F_i in row i.[1]

Thibault Fally (2011) instead proposes a measure of upstreamness based on the notion that industries selling a disproportionate share of their output to relatively upstream industries should be relatively upstream themselves.[2] In particular, he posits the following linear system of equations that implicitly defines upstreamness U_2 for each industry i

$$U_{2i} = 1 + \sum_{j=1}^{N} \frac{d_{ij} Y_j}{Y_i} U_{2j}, \quad (4)$$

where $d_{ij} Y_j / Y_i$ is the share of sector i's total output that is purchased by industry j. Again it is clear that $U_{2i} \geq 1$, and using matrix algebra, we can express this measure compactly as $U_2 = [I - \Delta]^{-1} \mathbf{1}$, where Δ is the matrix with $d_{ij} Y_j / Y_i$ in entry (i, j) and $\mathbf{1}$ is a column vector of ones.

These two measures of upstreamness might appear distinct, but simple manipulations (see ACFH) demonstrate that they are in fact equivalent, which leads us to

PROPOSITION 1: *$U_{1i} = U_{2i} = U_i$ for all $i \in \{1, 2, ..., N\}$.*

A limitation of these two measures is that they impose an ad hoc cardinality in the sense that the distance between any two stages of production is set to one. In ACFH we show, however, that these measures can in fact be given two precise economic interpretations. Holding constant the final-use vector F and the off-diagonal elements of the matrix D, we have

$$U_i = \frac{1}{Y_i} \sum_{j=1}^{N} \frac{\partial Y_i}{\partial d_{jj}},$$

so U_i equals the semi-elasticity of an industry's output to a uniform change in input-output linkages *within* industries. Furthermore, holding constant the allocation matrix Δ and letting V_i be value added (or cost of primary factors) in industry i, we have

$$U_i = \sum_{j=1}^{N} \frac{\partial Y_j}{\partial V_i}.$$

Thus, U_i also equals the dollar amount by which output of *all* sectors increases following a one dollar increase in value added in sector i. This is a standard measure of cost-push effects or total forward linkages in supply-side I-O models and is intuitively increasing in upstreamness.

B. *Open-Economy Adjustment*

Given the goals of this paper, it is important to extend the measurement of upstreamness to an open-economy environment. Incorporating trade flows, the output identity in (1) is now modified to

$$Y_i = F_i + \sum_{j=1}^{N} d_{ij} Y_j + X_i - M_i,$$

where X_i and M_i denote exports and imports of sector i output. It might appear that as long as net exports $X_i - M_i$ are not more or less upstream than domestic

[1] Because $Y = [I - D]^{-1} F$, this numerator also equals the i-th element of the $N \times 1$ matrix $[I - D]^{-1} Y$, where Y is a column matrix with Y_i in row i.

[2] It should be noted that despite the order in which we introduce these measures, Fally (2011)'s measure chronologically precedes the one in Antràs and Chor (2011). Fally (2011) also proposes a measure of the number of stages embodied in an industry's output.

production, allowing for international trade would have no bearing on the measures of upstreamness discussed above. Nevertheless, it is important to note that the interindustry commodity flow data used to construct the matrix of US input-output coefficients D do not distinguish between flows of domestic goods and international exchanges.[3] Hence, although the share of gross output in industry i that is used as intermediate inputs in industry j (at home or abroad) is given by the ratio

$$\delta_{ij} = \frac{d_{ij} Y_j + X_{ij} - M_{ij}}{Y_i}, \tag{5}$$

in practice we lack information on international interindustry flows X_{ij} and M_{ij}.

It seems sensible, however, to assume that $\delta_{ij} = X_{ij}/X_i = M_{ij}/M_i$, so that the share of industry i's exports (imports) that are used by industry j producers is identical to the share of industry i output used in industry j (at home or abroad). With this assumption, one can easily verify that our two measures of upstreamness in (3) and (4) still coincide after replacing d_{ij} with

$$\hat{d}_{ij} = d_{ij} \frac{Y_i}{Y_i - X_i + M_i}, \tag{6}$$

where the denominator in (6) is the domestic absorption of industry i's output. It is worth stressing that the assumptions that lead to (6) are perfectly consistent with countries specializing in different segments of the value chain (see ACFH for a simple two-country example that also highlights the importance of the adjustment in (6)).[4]

II. Upstreamness in US Production

We construct the above measure of industry upstreamness using the 2002 US benchmark I-O Tables, as made available by the Bureau of Economic Analysis (BEA) on their website. A key advantage of the US data is that it reports information on production linkages between industries at a highly disaggregated level, namely six-digit I-O industry codes. There are altogether 426 industries in the I-O Tables, of which 279 are in manufacturing.

We employ the detailed Supplementary Use Table after redefinitions. The (i, j)-th entry of this Use Table reports the value of inputs of commodity i used in the production of industry j in the US economy. An additional set of columns records the value of commodity i that enters into final uses, namely consumption, investment, net changes in inventories, and net exports.

We construct the square matrix Δ with the open-economy adjustment in (6) as follows. The numerator of the (i, j)-th entry of Δ, $d_{ij} Y_j$, is precisely the value of commodity i used in j's production; we plug in the (i, j)-th entry from the Use Table for this numerator. The denominator $Y_i - X_i + M_i$ is in turn calculated as the sum of values in row i of the Use Table, less that recorded under net exports and net changes in inventories. With this Δ, the formula $[I - \Delta]^{-1} \mathbf{1}$ delivers a column vector whose i-th entry is the upstreamness measure, U_i.

We find that industries vary considerably in terms of their average production line position. The measure of upstreamness ranges from a minimum of 1 (19 industries where all output goes only to final uses) to a maximum of 4.65 (Petrochemicals). Its mean value across the 426 industries is 2.09, with a standard deviation of 0.85.[5] The average industry therefore enters into production processes roughly one stage before final use. For illustrative purposes, Table 1 lists the five least and most upstream manufacturing industries. Automobiles, furniture and footwear are among the most downstream of industries, with almost all of their output going directly to the end-user. In contrast, the most upstream industries tend to be involved in processing raw materials. Within man-

[3] In other words, the coefficient d_{ij} is computed as the total purchases by industry j of industry i's output, regardless of whether those purchases are domestic or involve imports. See Karen J. Horowitz and Mark A. Planting (2009) for more discussion.

[4] The above discussion abstracts from changes in inventories for ease of notation. See ACFH for details of the analogous adjustment for dealing with inventories.

[5] These summary statistics are similar when restricting to manufacturing industries only. Furthermore, the correlation between upstreamness calculated with the open-economy and inventories corrections and upstreamness calculated without these corrections is 0.89.

ufacturing, upstreamness is positively correlated with physical capital intensity and negatively correlated with skill intensity (see Fally (2011)).

Table 1. Least and Most Upstream Industries (Manuf.)

US IO2002 Industry	Upstream
Automobile (336111)	1.000
Light truck and utility vehicle (336112)	1.001
Nonupholstered wood furniture (337112)	1.005
Upholstered household furniture (337121)	1.007
Footwear (316200)	1.007
Alumina refining (33131A)	3.814
Other basic organic chemical (325190)	3.853
Secondary smelting of aluminum (331314)	4.064
Primary smelting of copper (331411)	4.355
Petrochemical (325110)	4.651

III. Upstreamness in Other Countries

The upstreamness measure is most likely to be useful if it is stable across countries. In practice, stability can be difficult to verify because national I-O tables differ in their classification systems and level of aggregation. Fortunately, recent efforts such as the OECD STAN database have made available I-O tables for many countries in a reasonably well-concorded fashion. A subset of the STAN tables were submitted by Eurostat, the statistics office of the EU. We employ the STAN data for a subset of 16 EU countries that share an exact aggregation of the data for 2005.[6] These Eurostat tables contain 41 sectors, 13 of which are in manufacturing. As the rest of our paper relies on US data, we also check how upstreamness calculated from the US table in the STAN database compares with the EU measures.[7] Lastly, we constructed an aggregate EU table, denoted below by EUR, that brings in imperfectly concorded data from countries outside our sample of 16.

[6] The 16 countries are: Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, Germany, Greece, Hungary, Italy, Luxembourg, the Netherlands, Portugal, Slovakia, Slovenia and Spain.

[7] This US measure also correlates well with upstreamness calculated for the wider sample of countries in the STAN database, including several non-European countries (see ACFH). However, more caveats apply to these findings as the number of industries that can be successfully matched is lower.

We calculate the upstreamness measure for each individual country, following the procedure in Section II. To verify the consistency of industry upstreamness across countries, we conduct a Spearman rank correlation test among all country pairs. A subset of these results are reported in Table 2 (see ACFH for the full matrix). The rank correlation is always large and positive; in all country pairs, this is significantly different from zero at a p-value of 0.01. A useful point to note is that the correlations tend to be slightly lower for small countries where trade features as a large percentage of output, for which the open-economy adjustment would matter more.[8]

Table 2. Rank Correlations of Industry Upstreamness

	USA	EUR	CZE	DEU	DNK	ESP	ITA	LUX
USA	1.00							
EUR	0.85	1.00						
CZE	0.60	0.79	1.00					
DEU	0.78	0.94	0.80	1.00				
DNK	0.75	0.82	0.72	0.83	1.00			
ESP	0.79	0.92	0.80	0.86	0.78	1.00		
ITA	0.81	0.93	0.79	0.87	0.74	0.86	1.00	
LUX	0.66	0.76	0.56	0.75	0.72	0.61	0.74	1.00

The variation of our upstreamness measure in the European data is also largely consistent with the range of values reported earlier in Table 1. In sum, the European evidence gives us great confidence that the industry measures are stable across countries, at least at the higher level of aggregation in the STAN database.

IV. Application to Trade

We conclude by briefly exploring how our measure, specifically that based on the more disaggregate 2002 US I-O Tables, can shed some new perspectives on trade patterns, with regards to whether a country's exports tend to be in relatively upstream versus downstream industries.[9]

[8] The upstreamness measures for the 16 EU countries are also *jointly* correlated to a high degree, as 76 percent of the total variation in the measures is captured in a principal components analysis by a single component. The correlation of US upstreamness with this principal component of the EU measures is 0.82.

[9] For further applications, see Fally (2011) and Antràs and Chor (2011).

We calculate a summary measure of the upstreamness of a country's exports by combining our US-based measure with detailed product-level trade data. We take a weighted average of industry upstreamness values for each country, using the total exports by the country in the respective industries as weights. We consider trade flows from 2002 for a core sample of 181 countries. The cross-country mean value of export upstreamness is 2.30 with a standard deviation of 0.58. If attention is restricted to manufacturing trade flows, this mean falls to 2.05, with a standard deviation of 0.49. This drop reflects the fact that many primary and resource-extracting industries tend to be relatively upstream.

Mean values of export upstreamness do not vary widely across country income groups. Taking into consideration all trade flows, the mean upstreamness of countries in the poorest income quartile is 2.41 (standard deviation = 0.69) versus 2.26 (standard deviation = 0.45) for the highest income quartile. Focusing on manufacturing trade alone, these mean country upstreamness values are 2.03 and 2.10 respectively. Thus, no simple relationship between country per capita GDP and export upstreamness is evident. More interestingly, we do observe that countries in the top income quartile are more similar in terms of their average position along global production lines, while there is much more variation across poorer countries on this dimension (see ACFH for details).

Building on this discussion, Table 3 examines some correlations between export upstreamness and various country characteristics. Our country variables are from standard sources, and are averages over 1996-2005 when the data is available. (See ACFH for a detailed documentation and further results exploiting cross-country *and* cross-industry variation.) We stress that our objective here is not to establish causality or investigate particular mechanisms, but simply to uncover patterns that relate to a country's average production line position. In Column 1, we verify that the bivariate correlation between country upstreamness and log real GDP per capita is not statistically significant. We find much more interesting results in Columns 2-4 where we introduce variables related to country institutions and endowments. The negative partial correlations in Columns 2-3 suggest that better rule of law and stronger financial development are associated with a more downstream basket of exports. Column 4 indicates that the role of the private credit variable is especially robust. Moreover, human capital is associated with more downstream exports; this needs to be taken with a pinch of salt though, as this correlation is no longer significant when only manufacturing trade flows are considered.

Table 3. Export Upstreamness and Country Features

	(1)	(2)	(3)	(4)
Log(Y/L)	−0.035	0.146***	0.156**	0.083
	(0.032)	(0.054)	(0.060)	(0.142)
Rule of Law		−0.313***	−0.164*	−0.029
		(0.070)	(0.091)	(0.103)
Credit/Y			−0.404***	−0.437***
			(0.128)	(0.136)
Log(K/L)				0.156
				(0.131)
School				−0.085***
				(0.031)
N	181	181	151	120
R^2	0.01	0.11	0.11	0.15

Notes: Robust standard errors reported. ***, **, and * denote significance at the 1, 5 and 10 percent levels respectively.

REFERENCES

Antràs, Pol, and Davin Chor. 2011. "Organizing the Global Value Chain." mimeo.

Antràs, Pol, Davin Chor, Thibault Fally, and Russell Hillberry. 2012. "Measuring the Upstreamness of Production and Trade Flows." NBER Working Paper No. ?????

Fally, Thibault. 2011. "On the Fragmentation of Production in the U.S." mimeo.

Horowitz, Karen J., and Mark A. Planting. 2009. "Concepts and Methods of the Input-Output Account." Bureau of Economic Analysis documentation.