Measuring the Upstreamness of Production and Trade Flows (Long Version)

By Pol Antràs, Davin Chor, Thibault Fally and Russell Hillberry*

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 are likely to leave their imprint on international trade patterns: Are countries now specializing in particular stages of global production processes, or (to borrow from Paul Krugman (1995)) specific slices of the value chain?

Addressing this question requires first and foremost an industry-level measure of relative production line position. In this short article, we present three different approaches to building such a measure of the "upstreamness" of an industry. These measures capture the number of stages before final use at which an industry typically enters into production processes. The three approaches are motivated in distinct ways, but we prove that they yield an equivalent measure of industry upstreamness.

On the empirical side, we construct this measure using the 2002 US Input-Output (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 also construct our measure using the I-O Tables for selected OECD member countries from the STAN Database, in order to verify that upstreamness is a stable attribute of industries across different countries (with some caveats, see details in 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 country institutions pertaining to the rule of law and financial development are correlated with a propensity to export in relatively more downstream industries.

* Antràs: Harvard University, Cambridge, MA, pantras@fas.harvard.edu. Chor: Singapore Management University, Singapore, davinchor@smu.edu.sg. Fally: University of Colorado, Boulder, CO, fally@colorado.edu. Hillberry: University of Melbourne, Melbourne, Australia, rhhi@unimelb.edu.au.
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I. Three Measures of Upstreamness

A. Closed Economy Benchmark

To build intuition, we begin by considering an N-industry closed-economy with no investment or inventories. In such an economy, 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)

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

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's i 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

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

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-good use minus one and dividing by Y_i, or

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

It is clear that $U_{1i} \geq 1$ and that larger values are associated with relatively higher levels of upstreamness of industry i's output. 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 (or distance from final-good production) 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 note that $d_{ij} Y_j / Y_i$ is the share of sector i's 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.

A limitation of these two measures is that they impose an ad hoc cardinality in that the distance between any two stages of production is set arbitrarily to one. With that in mind, we finally propose a third measure of upstreamness that reflects how the demand for an industry's output responds to an increase in input-output linkages *within* industries (holding constant demand for final-good use)

$$U_{3i} = \frac{1}{Y_i} \sum_{j=1}^{N} \frac{\partial Y_i}{\partial d_{jj}}. \quad (5)$$

The idea behind this third measure is that when production becomes more circular, the effect on output will be disproportionately large in relatively upstream industries via a multiplier effect.

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

PROPOSITION 1: *$U_{1i} = U_{2i} = U_{3i}$ for all $i \in \{1, 2, ..., N\}$.*

B. *Open Economy Adjustment*

So far we have assumed that the economy is closed to international trade. Since one of our main goals is to measure the level of upstreamness of a country's exports, it is important to extend the measurement of upstreamness to an open-economy environment. Incorporating this, the 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 production, allowing for international trade flows would have no bearing on the measures of upstreamness discussed above. Nevertheless, it is important to emphasize

[1] Using the fact that $Y = [I - D]^{-1} F$, which is easily verified from (1), the 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.

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 a country's gross output in industry i that is used as intermediate input in industry j (at home or abroad) is given by the ratio

$$\delta_{ij} = \frac{d_{ij} Y_j + X_{ij} - M_{ij}}{Y_j}, \tag{6}$$

in practice we lack information on international interindustry flows X_{ij} and M_{ij}. It seems sensible, however, to assume

Assumption 1: $\delta_{ij} = X_{ij}/X_i = M_{ij}/M_i$.

In words, Assumption 1 imposes that the share of a countrty industry i's output used in industry j (at home or abroad), i.e., δ_{ij} in (6), is identical to the share of industry i's exports (imports) that are used by industry j producers. With this assumption, one can easily verify that our three measures of upstreamness in (3), (4), and (5) continue to coincide after replacing d_{ij} with

$$\hat{d}_{ij} = d_{ij} \frac{Y_i}{Y_i - X_i + M_i}. \tag{7}$$

Incidentally, the denominator in (7) is precisely the domestic absorption of industry i's output. It is important to emphasize that although Assumption 1 imposes a certain structure on cross-country variation in production patterns, it is perfectly consistent with countries specializing in different segments of the value chain. We next illustrate this with a simple example that also highlights the importance of the adjustment in (7).

[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, specifically the description of the Import Matrix in the I-O Tables. The OECD STAN data described below do have separate information available on import and domestic flows, but this information is often imputed under an assumption of proportional use of domestic and imported components.

Example. Suppose that there are two industries, 1 and 2, and two countries, Home and Foreign. Industry 2 produces only intermediate inputs which are entirely sold to producers in sector 1, while sector 1 produces only final goods. Clearly, our closed-economy measure would suggest upstreamness values of 1 and 2 for industries 1 and 2, respectively. Suppose, however, that Home exports part of its production of good 1 to final consumers in Foreign, while Foreign producers of good 2 sell part of their output to Home producers in sector 1. Hence, relative to Foreign, Home appears to specialize in the relatively downstream sector. It is straightforward to verify that our adjusted measure delivers the correct values of upstreamness in each industry and each country (that is, 1 and 2), while, without the adjustment, the measure of upstreamness in industry 2 would be biased upwards at Home and biased downwards in Foreign, with the size of the bias increasing in the value of Foreign exports to Home.

The above discussion abstracts from changes in inventories for ease of notation. A similar set of considerations is involved with inventories, as the input-output matrix D does not separately identify inputs obtained from a draw-down of inventories as opposed to from fresh production. It is nevertheless straightforward to show that if we adopt a condition analogous to Assumption 1 in the treatment of inventories, then (7) is still valid so long as Y_i is calculated subtracting the value of any net change in inventories of i (see appendix for details). This is in fact what we do in our empirical implementation below.

II. Upstreamness in US Production

We construct the above measure of industry upstreamness using the 2002 US benchmark Input-Output (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 is reports information on production linkages between industries at a disaggregate level, namely at the level of six-digit I-O industry codes.[4] There are altogether 426 industries in the I-O Tables, of which 279 are in manufacturing.

For our purposes, we use the detailed Supplementary Use Tables 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 also records the value of commodity i that enters into final uses, namely consumption, investment, net changes in inventories, and net exports.[5]

We construct the square matrix Δ with the open-economy adjustment in (7) 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 therefore plug in the (i, j)-th entry from the Use Tables 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 Tables, less that recorded under net exports and net changes in inventories. With this Δ, the formula $[I - \Delta]^{-1}\mathbf{1}$ then delivers a column vector whose i-th entry is the upstreamness measure for industry i, as shown in Section I.

The values we obtain reveal that industries vary considerably in terms of their average production line position. The measure of upstreamness ranges from a minimum of 1 (19 industries in which 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.[6] The average industry therefore enters into use in production processes roughly one stage before final consumption or investment. For illustrative purposes, Table 1 lists the ten least and most upstream manufacturing industries. Of note, automobiles, furniture and footwear are among the most downstream of industries, with almost all of their output going directly to the end-user. On the other hand, the most upstream industries tend to be involved in the processing of raw materials.[7]

III. Upstreamness in Other Countries

The upstreamness measure is most likely to be useful if it is stable across countries. In practice, stability is somewhat difficult to verify because national I-O tables differ in their product/industry classifications and the level of aggregation employed. Fortunately, there have been some efforts to collect and produce I-O tables that are consistent across countries. The OECD STAN database contains easily accessible 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 European Union. We employ the STAN data for a subset of 16 EU countries that share an exact aggregation of the data for 2005.[8] 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 whether upstreamness calculated from the US table in the STAN database is highly correlated with the EU measures.[9] Bear in mind however that different national industry definitions mean that the US data is aggregated differently in the STAN database than in the European data we employ. In particular, three industries that are reported for

[4]The 2002 I-O codes map neatly into the more well-known NAICS industry codes.

[5]The Use Table reports a further breakdown of the final use value of consumption and investment into private and government purchases. We will however not be using this breakdown in our analysis.

[6]These summary statistics are similar when restricting to manufacturing industries only.

[7]For the 426 industries, the correlation between upstreamness calculated with the open-economy and inventories corrections and upstreamness calculated without these corrections is a relatively high 0.89.

[8]The included countries are: Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, Germany, Greece, Hungary, Italy, Luxembourg, the Netherlands, Portugal, Slovakia and Spain. Some notable countries - such as the UK, France, and Poland - have data that is imperfectly matched, so they are excluded from this analysis.

[9]We also construct an aggregate EU table, bringing in imperfectly concorded data from the EU countries not represented in our sample. The results from the EU table is represented as EUR below. It appears that Upstreamness measures in this aggregate table are also highly correlated with their country-level counterparts.

the European countries are not reported for the US.

We calculate the upstreamness measure for each individual country, following the methodology described in Section II. To verify the consistency of industry upstreamness across countries, we conduct a Spearman rank correlation test among all country pairs in the sample. These results are reported in Table 2. 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. In particular, the US measures yield industry rankings that are consistent with that from the European data. 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. Luxembourg is a clear outlier in this regard, in that the correction for trade generates an upward shift in its measures of upstreamness relative to what is observed in less trade-dependent countries.[10]

We also check the joint correlation of upstreamness across all 16 European countries through a principal component analysis, and find that 76 percent of the total variation in the measure is captured by a single component. Not only are the measures correlated among pairs of countries, the measures are *jointly* correlated to a very high degree. Moreover, the correlation of US upstreamness with the principal component of the European measures is 0.81.

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 the European countries other than Luxembourg, we find a mean upstreamness of 2.45, and a standard deviation of 0.82. The mean upstreamness for industries across European countries ranges from 1.09 (Health and social work) to 3.87 (Iron and steel). 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 reported in the STAN database.

IV. Application to Trade

We briefly explore how our measure of industry upstreamness, specifically that based on the more disaggregate 2002 US I-O Tables, can provide some new perspectives on trade patterns at the country level. In particular, with this new measure, we are now equipped to describe a country's average position in global production chains, namely whether the country tends on average to be an exporter in relatively upstream versus downstream industries.

Toward this end, we calculate a summary measure of the upstreamness of a country's exports as follows. Data on world trade flows at the Harmonized System six-digit (HS6) level are taken from the BACI dataset.[11] BACI draws originally on the UN Comtrade database, but applies a procedure to harmonize and clean the data to reconcile trade flows reported by exporting and importing countries. We map the trade flows from HS6 to US I-O 2002 categories using a concordance provided by the BEA. We then take a weighted average of industry upstreamness values for each country, using the total exports by the country in the respective industries as weights. Naturally, this assumes that the US measures of upstreamness provide a good description of production line position in other countries as well, but as we have seen in Section III, this appears to be a reasonable starting point.

In what follows, we consider trade flows from 2002 for a core sample of 181 countries.[12] Constructing country upstreamness as described above, we obtain a mean value of export upstreamness of 2.30 with a standard deviation of 0.58. If attention is re-

[10]For example, Luxembourg's Finance & Insurance sector has an upstreamness measure of 22.21. Only Luxembourg has outliers so large that they affect measures of central tendency across the European sample.

[11]At: http://www.cepii.fr/anglaisgraph/bdd/baci.htm

[12]This consists of the 181 countries for which the export upstreamness measure could be constructed, and for which data on real GDP per capita for 1996-2005 was available in the Penn World Tables, Version 7.0. We merged Belgium and Luxembourg as the BACI do not report separate trade flows for the two countries.

stricted to manufacturing trade flows, this mean country upstreamness 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 enter production processes at relatively upstream stages.[13]

Looking beyond these broad averages, Table 3 reports the mean values of export upstreamness by country income groups. We split the countries in our sample into quartiles, as determined by the mean log real GDP per capita between 1996-2005, calculated from the Penn World Tables, Version 7.0 (Alan Heston, Robert Summers and Bettina Aten 2011). At first glance, taking into consideration all trade flows, the export activities of poorer countries appear to be in slightly more upstream industries than that of richer countries. However, when we focus in on manufacturing trade flows alone, no simple relationship between country per capita GDP and export upstreamness is evident. This is not entirely surprising given that we have seen that diverse manufacturing industries can feature similar values of upstreamness. Recall for instance that automobiles and footwear both rank among the five most downstream industries.

More interestingly, the standard deviation of export upstreamness within each country quartile decreases as the mean income level rises. Countries in the top quartile are thus more similar in terms of the average position they occupy in global production lines, while there is much more variation across poorer countries on this dimension.[14] To give an example, consider Bangladesh and Tajikistan, two countries with a similarly low level of per capita income. Although both countries are in the bottom income quartile of our sample, they are at opposite ends of the spectrum in terms of export upstreamness. Bangladesh ranks among the five most downstream countries in terms of its manufacturing exports (country upstreamness = 1.26), due to its position as a major exporter of apparel, a good that tends to be sold directly to end-consumers. Tajikistan instead ranks among the five most upstream countries (country upstreamness = 3.53), as processed alumina takes up the lion's share of its exports. Once again, there does not appear to be a simple uniform story that connects a country's income level to its average production line position.

Building on this discussion, we examine the correlations between export upstreamness and various country characteristics more systematically in Table 4. We stress that our objective here not to establish causality or mechanism, but simply to uncover interesting patterns that relate to a country's average production line position. Panel A in Table 4 reports regression findings in which country upstreamness based on all exports is the dependent variable, while Panel B reports the corresponding findings when upstreamness is calculated for manufacturing exports only. We use explanatory variables that are from standard sources of cross-country data; where possible, we have calculated these as averages over 1996-2005.

In Column 1, we verify that the simple bivariate correlation between country upstreamness and log real GDP per capita (from the Penn World Tables) is not statistically significant.[15] We find much more interesting results in Columns 2-4 where we introduce variables related to country institutions, namely: (i) a rule of law index from Daniel Kaufmann, Aart Kraay and Massimo Mastruzzi (2011), that is often used as an indicator of the strength of contracting institutions; and (ii) the ratio of private credit to GDP from Thorsten Beck, Asli Demirguç-Kunt and Ross Levine (2010), reflecting the level of financial development in the economy. The negative partial correlations obtained here imply that better rule of law and stronger financial development are

[13]The mean value of our upstreamness measure for the 30 industries related to agriculture, forestry and mining (I-O codes starting with '1' or '21') is 2.84, compared to the mean upstreamness of 2.10 for the 279 manufacturing industries (I-O codes starting with '3').

[14]A similar conclusion is reached if we consider the coefficient of variation instead.

[15]We do not obtain significant results either if we further control for the square of log real GDP per capita.

associated at the country level with a basket of exports that is relatively more downstream in terms of production line position.

Column 5 explores whether factor endowments have a role to play in determining a country's export upstreamness. We include a measure of log physical capital per worker, calculated from the Penn World Tables using the perpetual inventory method in Robert E. Hall and Charles I. Jones (1999), as well as the average years of schooling the the population aged 15 and over from Robert Barro and Jong Wha Lee (2010). To avoid a multicollinearity problem, we drop the log income per capita variable in this column. The findings here indicate that the negative correlation between country upstreamness and financial development is a particularly robust one; that for country rule of law in contrast becomes imprecisely estimated in both panels. Moreover, there appears to be some potential role for factor endowments in explaining a country's average production line position: Countries with more capital per worker appear to be engaged in more upstream industries, and human capital is associated with more downstream exports. These last findings nevertheless need to be taken with a pinch of salt, as these correlations are no longer significant in the lower panel that focuses on manufacturing trade flows. (We also control in this column for openness, namely exports plus imports over GDP, obtained from the Penn World Tables, but this variable has little explanatory power for export upstreamness.)

V. Conclusion

We have developed and constructed a measure of industry upstreamness in this short note. The empirical applications which we have presented in Section IV, though preliminary in their nature, suggest that this is an industry attribute that warrants further attention particularly in this age of cross-border production fragmentation. We have started exploring these potential research directions ourselves in our separate work. Fally (2011) for example has explored issues related to production line position, its evolution over time, and its implications for comparative advantage, using more detailed time-series, cross-country, cross-industry variation in trade flows. Taking contracting issues seriously, Antràs and Chor (2011) seek to understand how cross-border firms would organize themselves when production is sequential, vis-à-vis the integration versus outsourcing decision.

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A. Appendix

This Appendix provides the proof of our key result on the equivalence of the three separately-defined measures of industry upstreamness. It also derives the open-economy adjustment, as well as that for the treatment of inventories. The notation follows that in our main paper.

A. *Proof of Proposition 1*

To see that $U_{2i} = U_{1i}$, recall first that U_{2i} is defined recursively by

$$U_{2i} = 1 + \sum_{j=1}^{N} \frac{d_{ij} Y_j}{Y_i} U_{2j}. \tag{8}$$

Multiply both sides of (8) by Y_i to obtain

$$U_{2i} Y_i = Y_i + \sum_{j=1}^{N} d_{ij} U_{2j} Y_j.$$

Defining $P_i = U_{2i} Y_i$ for all $i \in \{1, 2, ..., N\}$, we have

$$P_i = Y_i + \sum_{j=1}^{N} d_{ij} P_j. \tag{9}$$

Let P be the column vector whose i-th entry is P_i. Also, let D denote the square matrix whose (i, j)-th entry is d_{ij}, which is the amount of input i needed to produce one dollar of j. Stacking up the P_i's in (9) into column-vector form, we have: $P = Y + DP$, where Y is the column vector with Y_i as its i-th entry.

Solving for P leads to

$$P = [I - D]^{-1} Y.$$

But as discussed in footnote 1 of our main paper, the i-th row of $[I - D]^{-1} Y$ is precisely equal to the numerator of U_{1i}. Since $P_i / Y_i = U_{2i}$, it follows that $U_{2i} = U_{1i}$.

Next, to see that $U_{3i} = U_{2i}$, start from the basic identity that decomposes output for industry i into its final-use value and that which goes to intermediate input uses:

$$Y_i = F_i + \sum_{j=1}^{N} d_{ij} Y_j. \tag{10}$$

Differentiating (10) yields

$$\begin{aligned} \frac{\partial Y_i}{\partial d_{ii}} &= Y_i + \sum_{k=1}^{N} d_{ik} \frac{\partial Y_k}{\partial d_{ii}}, \text{ and} \\ \frac{\partial Y_i}{\partial d_{jj}} &= \sum_{k=1}^{N} d_{ik} \frac{\partial Y_k}{\partial d_{jj}} \text{ for } i \neq j. \end{aligned}$$

Summing over these partial derivatives and dividing by Y_i, we have

$$\frac{1}{Y_i} \sum_{j=1}^{N} \frac{\partial Y_i}{\partial d_{jj}} = 1 + \sum_{k=1}^{N} \frac{d_{ik} Y_k}{Y_i} \frac{1}{Y_k} \sum_{j=1}^{N} \frac{\partial Y_k}{\partial d_{jj}},$$

or

$$U_{3i} = 1 + \sum_{k=1}^{N} \frac{d_{ik} Y_k}{Y_i} U_{3k}.$$

This is the same recursive equation that defines U_{2i} in (8), and thus proves that $U_{3i} = U_{2i}$.

B. *Open-Economy Adjustment*

Recall that we calculate our upstreamness measure for all N industries via the formula $[I - \Delta]^{-1} \mathbf{1}$, with $\mathbf{1}$ being a column vector of N one's, and Δ being the square matrix whose (i, j)-the entry is $d_{ij} Y_j / Y_i$ in the closed-economy setting. Note in particular that $d_{ij} Y_j / Y_i$ is the share of output from industry i that is purchased for use as inputs by industry j. In the open-economy, we therefore need to determine the correction that needs to be applied in order for the entries of the matrix, Δ, to continue to reflect the share of domestic output from i that is purchased by industry j as inputs, regardless of whether the purchasing industry is located at home or abroad.

With trade, the basic output identity for each industry i now becomes

$$\begin{aligned} Y_i &= F_i + Z_i + X_i - M_i \\ &= F_i + X_{Fi} - M_{Fi} + Z_i + X_{Zi} - M_{Zi}, \end{aligned}$$

where F_i and Z_i denote the value of output produced domestically in industry i that goes respectively towards final uses and intermediate input uses *in the home economy.* X_i and M_i denote total exports and imports of industry i. These in turn can be broken down into exports and imports that go to final uses (X_{Fi} and M_{Fi} respectively), and exports and imports that are used as inputs in the production of other goods (X_{Zi} and M_{Zi}).

Note that

$$Z_i + X_{Zi} - M_{Zi} = \sum_{j=1}^{N} \left(d_{ij} Y_j + X_{ij} - M_{ij} \right),$$

where the sum is taken over industries j that purchase inputs of i. X_{ij} and M_{ij} refer respectively to the exports and imports from industry i that are purchased for intermediate input use specifically in industry j. In the open-economy, let δ_{ij} denote the share of i's domestic production that is purchased directly by industry j (both at home or abroad). δ_{ij} is thus given by

$$\delta_{ij} = \frac{d_{ij} Y_j + X_{ij} - M_{ij}}{Y_i}, \tag{11}$$

which takes into account the fact that in the U.S. Input-Output (I-O) Tables, the final-use and intermediate-use values reported do not distinguish between goods/intermediates that are produced domestically versus that which is imported.[16]

One problem with taking (11) directly to the data is that X_{ij} and M_{ij} are typically not observed. To make progress, we argue that it is reasonable to assume that the share of industry i's output used in industry j (at home and abroad) be identical to the share of industry i's exports (imports) that are used by industry j producers, namely

$$X_{ij} = \delta_{ij} X_i$$

[16]The Bureau of Economic Analysis does provide an accompanying "Import Matrix" with the 2002 Tables that reports final-use and intermediate-use values that come from foreign sources. However, due to the limited information on the use of imports at the industry level, the "Import Matrix" is actually constructed based on a proportionality assumption that the share of import use is the same across all final use and industries. See Horowitz and Planting (2009) for details.

and

$$M_{ij} = \delta_{ij} M_i.$$

This is precisely Assumption 1 in our main paper. Substituting these expressions in (11), straightforward manipulation leads to

$$\delta_{ij} = \frac{d_{ij} Y_j}{Y_i - X_i + M_i}.$$

We therefore implement the open-economy adjustment by replacing $d_{ij} Y_j / Y_i$ with the above expression for δ_{ij} for the entries of the matrix Δ. This is equivalent to replacing d_{ij} with

$$\hat{d}_{ij} = d_{ij} \frac{Y_i}{Y_i - X_i + M_i} \tag{12}$$

as stated in the main paper.

C. *Treatment of Inventories*

There is one remaining item classified under final uses in the input-output tables that requires careful treatment, namely net changes to inventories. We have abstracted from this when discussing the open-economy adjustment, to avoid cluttering the notation, but it can be readily seen that a similar set of considerations is involved. The input-output matrix D does not distinguish between inputs that are obtained from past inventories as opposed to new production. Taking this into account, the relevant share of i's domestic production that is purchased directly by industry j (both at home or abroad) is given more precisely by

$$\delta_{ij}^{inv} = \frac{d_{ij} Y_j + X_{ij} - M_{ij} + N_{ij}}{Y_i},$$

where N_{ij} denotes here the net value of industry i output purchased by industry j for the purposes of inventorization. (The superscript 'inv' indicates that this expression for δ_{ij} explicitly spells out the role of net inventories.) When N_{ij} is positive, this means that industry j is on net increasing its inventories of input i; a negative N_{ij} in turn indicates a net draw-down of j's inventories of i.

To take this to the data, we once again

face the problem that N_{ij} is not easily observed. We therefore make the same proportionality assumption as with the open-economy correction

$$N_{ij} = \delta_{ij}^{inv} N_i,$$

where N_i is the aggregate net change in inventories of output from industry i. In words, we assume that the share of industry i's output that is purchased by industry j is equal to the share of net changes of inventories of i that can be attributed to the net changes made by industry j.

With this assumption, straightforward algebra yields

$$\delta_{ij}^{inv} = \frac{d_{ij} Y_j}{Y_i - X_i + M_i - N_i}.$$

This means that the correction for net inventories requires that we correct for net changes of inventories, N_i, in the denominator of δ_{ij}^{inv}. Alternatively, as stated in the main paper, the expression for δ_{ij} in (11) is valid so long as the Y_i in the denominator is calculated excluding the value of net changes in inventories of i.

Table 1— The Ten Least and Most Upstream U.S. Manufacturing Industries

US IO2002 Industry	Upstreamness
Automobile (336111)	1.000
Light truck and utility vehicle (336112)	1.001
Nonupholstered wood household furniture (337112)	1.005
Upholstered household furniture (337121)	1.007
Footwear (316200)	1.007
Motor home (336213)	1.012
Truck trailer (336212)	1.017
Manufactured home (mobile home) (321991)	1.019
Women's and girls' cut and sew apparel (315230)	1.024
Mattress (337910)	1.029
Plastics material and resin (325211)	3.571
Copper rolling, drawing, extruding and alloying (331420)	3.611
Alkalies and chlorine (325181)	3.611
Carbon and graphite product (335991)	3.748
Fertilizer (325310)	3.762
Alumina refining and primary aluminum (33131A)	3.814
Other basic organic chemical (325190)	3.853
Secondary smelting and alloying of aluminum (331314)	4.064
Primary smelting and refining of copper (331411)	4.355
Petrochemical (325110)	4.651

Notes: Tabulated for manufacturing only. Six-digit U.S. Input-Output industry codes are in parentheses.

Table 2— Rank Correlations of Industry Upstreamness across Countries

	USA	EUR	AUT	BEL	CZE	DEU	DNK	ESP	EST	FIN	GRC	HUN	ITA	LUX	NLD	PRT	SVK	SVN
USA	1.00																	
EUR	0.84	1.00																
AUT	0.77	0.88	1.00															
BEL	0.70	0.88	0.84	1.00														
CZE	0.61	0.80	0.75	0.78	1.00													
DEU	0.78	0.95	0.86	0.86	0.81	1.00												
DNK	0.75	0.81	0.75	0.85	0.74	0.83	1.00											
ESP	0.79	0.92	0.87	0.79	0.81	0.87	0.78	1.00										
EST	0.65	0.76	0.65	0.71	0.70	0.81	0.81	0.69	1.00									
FIN	0.82	0.85	0.84	0.77	0.80	0.81	0.79	0.86	0.60	1.00								
GRC	0.74	0.91	0.85	0.86	0.75	0.90	0.81	0.85	0.78	0.77	1.00							
HUN	0.67	0.82	0.76	0.69	0.90	0.84	0.68	0.81	0.65	0.81	0.72	1.00						
ITA	0.81	0.94	0.81	0.80	0.79	0.88	0.73	0.85	0.71	0.83	0.86	0.78	1.00					
LUX	0.64	0.75	0.70	0.77	0.55	0.74	0.73	0.59	0.70	0.59	0.82	0.54	0.73	1.00				
NLD	0.75	0.88	0.87	0.85	0.78	0.86	0.84	0.82	0.67	0.89	0.84	0.78	0.87	0.70	1.00			
PRT	0.73	0.91	0.90	0.85	0.85	0.88	0.77	0.93	0.70	0.84	0.89	0.78	0.87	0.64	0.86	1.00		
SVK	0.57	0.78	0.78	0.78	0.76	0.82	0.68	0.77	0.73	0.62	0.79	0.71	0.69	0.56	0.67	0.78	1.00	
SVN	0.61	0.84	0.84	0.81	0.87	0.83	0.70	0.84	0.78	0.74	0.77	0.77	0.81	0.59	0.77	0.89	0.81	1.00

Notes: All Spearman rank correlations are significantly different from zero at the 1% level.

Table 3— Upstreamness of Exports by Country Income Quartiles

	All		Manufacturing	
Income quartile	Mean	S.D.	Mean	S.D.
Bottom	2.41	0.69	2.03	0.60
2nd	2.30	0.60	1.98	0.48
3rd	2.23	0.55	2.11	0.51
Top	2.26	0.45	2.10	0.34

Notes: Countries are grouped into income quartiles based on the average log real GDP per capita over 1996-2005, from the Penn World Tables. The average upstreamness of country exports and its standard deviation within each quartile under the first set of columns labeled "All". The second set of columns restricts the calculation to manufacturing exports only.

Table 4— Export Upstreamness and Country Characteristics

	(1)	(2)	(3)	(4)	(5)
Panel A: Country Upstreamness, All Exports (2002)					
Log (Real GDP per capita)	−0.035	0.146***	0.100**	0.156**	
	(0.032)	(0.054)	(0.047)	(0.060)	
Rule of Law		−0.313***		−0.164*	−0.016
		(0.070)		(0.091)	(0.094)
Private Credit / GDP			−0.585***	−0.404***	−0.416***
			(0.123)	(0.128)	(0.137)
Log (Capital per worker)					0.228***
					(0.070)
Years of Schooling					−0.085***
					(0.031)
Openness					−0.001
					(0.001)
N	181	181	151	151	120
R^2	0.01	0.11	0.09	0.11	0.15
Panel B: Country Upstreamness, Manufacturing Exports (2002)					
Log (Real GDP per capita)	0.031	0.112**	0.115***	0.124**	
	(0.028)	(0.053)	(0.042)	(0.061)	
Rule of Law		−0.140**		−0.027	0.054
		(0.068)		(0.088)	(0.086)
Private Credit / GDP			−0.312***	−0.282**	−0.259**
			(0.105)	(0.111)	(0.119)
Log (Capital per worker)					0.102
					(0.068)
Years of Schooling					−0.026
					(0.027)
Openness					0.000
					(0.001)
N	181	181	151	151	120
R^2	0.01	0.04	0.06	0.06	0.05

Notes: Robust standard errors in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels respectively. All right-hand side variables are averages over annual data from available years between 1996-2005.