Input-Output Linkages and Sectoral Volatility

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November 30, 2019

Abstract

Why are some sectors more volatile than others? This paper uncovers evidence of an empirical regularity in the U.S. economy: upstream sectors that are far removed from final consumers have higher levels of output volatility. The relationship between volatility and upstreamness is not driven by sector size, sector concentration, trade openness or the level of aggregation at which sectors are defined. Rather, the paper shows a stronger link between upstreamness and nominal output volatility, than with indexes of real output volatility. Aggregate exports at the national level also reflect the empirical regularity of higher volatility with upstreamness: Export volatility is higher in economies with trade portfolios dominated by upstream sectors. On average, reducing the upstreamness of exports by one, also reduces aggregate export volatility by about 10%. The pattern of higher volatility for upstream sectors is explained with a model of demand shock transmission between sectors.

*Thanks to mentors and colleagues at the University of Michigan: Jagadeesh Sivadasan and Kyle Handley, as well as Yves Atchade at Boston University. I am indebted to Yuriy Gorodnichenko, the editor and two anonymous reviewers for helpful comments. Thanks also to the 2016 AEA-NSF Summer Pipeline Conference Participants. Jiaoping Chen provided excellent research assistance.

1 Introduction

Sectoral volatility is the primary source of aggregate GDP fluctuations for most economies. Understanding why some sectors have higher output volatility is therefore important, given how several negative economic outcomes are associated with high aggregate volatility, including low economic growth Ramey and Ramey (1995), higher levels of poverty and inequality (Laursen and Mahajan, 2005) and low investment (Aizenman and Marion, 1999; Pindyck and Solimano, 1993). Higher output volatility at the sector-level also matters for employment. Gross output and hours worked are tightly linked- with a relative volatility of almost exactly one (Jaimovich et al., 2013). Other papers in the labor adjustment literature provide additional evidence to motivate concerns about output volatility (e.g. Artuç et al., 2010; Hall, 2004; Bentolila and Saint-Paul, 1994). The strong connection to employment motivates the paper's focus on sectoral output volatility.[1]

This paper presents evidence that sectors farther upstream from final consumers in production networks have higher levels of output volatility. The pattern is explained with a simple model of demand shocks propagating through an open economy, so that sectors farther upstream experience sharper fluctuations in growth rates because they accumulate shocks from all sectors downstream in the value chain. The model builds on the intuition laid out in the recent literature on shock transmission through vertical linkages, (e.g. Di Giovanni et al., 2014; Kelly et al., 2013; Acemoglu et al., 2012; Di Giovanni and Levchenko, 2010). In developing a conceptual framework of

[1]Evidence on sectoral volatility being the primary driver of aggregate volatility comes from multiple sources (e.g. Koren and Tenreyro, 2007; Atalay, 2017). Further evidence comes from studies of declining US volatility or the Great Moderation. The changing sectoral composition of output in the US economy accounted for about 30% of its volatility decline since the 1950s (Alcalá and Sancho, 2004). The rise in service sector's share of the US economy explains much of its GDP volatility relative to other countries (Moro, 2015). A cursory look at employment and output growth for 4-digit NAICS industries at https://www.bls.gov/emp/tables/industry-employment-and-output.htm confirms the strong link between output and long-run employment growth. A regression of the compounded annual employment growth rate for 2004 to 2014 on the output growth rate yields a statistically significant coefficient of 0.45. This is not surprising, given how GDP and output are highly correlated.

linked sectors, the paper follows Acemoglu et al. (2016). It also builds on the main argument in Hulten (1978) – that growth effects for the crude materials sectors differ from those for sectors that are farther downstream.[2]

Using upstreamness to explain volatility is novel, and is the paper's *main contribution*. The distance from final consumers - formally measured as upstreamness, explains about 15% of the variation in sectoral volatility. The findings add needed clarity to the crude convention of expecting service industries to be stable and primary sectors to be volatile. Generally, primary sectors like oil and gas mining, and manufacturing sectors like photographic and photocopying equipment with no direct connections to final consumers consistently have high output volatility in the data. However, several consumer-facing manufacturing sectors like snack-food manufacturing have low output volatility. The pattern is consistent with service sectors that are broadly customer-facing, and thus have low upstreamness. The definition of upstreamness follows existing papers, and for robustness, the paper uses stages-of-production data as a proxy to test the same volatility-upstreamness relationship. The findings are interpreted as causal, given how upstreamness, as a feature of economy is relatively exogenous to output growth and volatility.

For each unit increase in upstreamness, or additional step away from final uses, the average U.S. sector's output volatility increases by about 10 standard deviations. The relationship between output volatility and upstreamness is statistically significant, and robust to several alternative specifications, as shown in section 4. The paper's findings complement earlier papers that link sectoral volatility to manufacturing sectors'

[2] The argument about how shocks propagate through the economy spans a broad swath of the international trade and macroeconomics literature. These include papers on international business cycle co-movement (Bems et al., 2010; Di Giovanni and Levchenko, 2010; Ng, 2010), and understanding macroeconomic trends in aggregate fluctuations like the Great Moderation (Carvalho and Gabaix, 2013; Acemoglu et al., 2012). The paper's findings are also consistent with recent work that show how microeconomic shocks might propagate through production networks and contribute to aggregate fluctuations (Ozdagli and Weber, 2017). The online appendix to this paper sheds light on the unresolved difference between papers that argue for production shocks - forward propagation (e.g. Boehm et al., 2015; Acemoglu et al., 2012; Carvalho, 2008) and those that argue for demand shocks, or backward propagation, (e.g. Kelly et al., 2013).

trade openness (Di Giovanni and Levchenko, 2009), product complexity (Krishna and Levchenko, 2013), as well as sectoral size and concentration (e.g. Di Giovanni and Levchenko, 2012). The impact of volatility on growth and employment is particularly relevant to export-dependent developing economies, given that exports and imports consistently have higher levels of volatility than other components of GDP (Engel and Wang, 2011; Heathcote and Perri, 2002; Backus and Kehoe, 1992). While exports are generally more volatile than the rest of the economy, differences across sectors in terms of export volatility are marginally explained by upstreamness, after controlling for size and other covariates suggested by the literature.

The primary relationship between upstreamness and volatility applies to nominal output volatility: the volatility of sectoral price indices is more sensitive to upstreamness the volatility of quantity indices. This finding provides a reasonableness check: it highlights how quantity adjustments by producers may be less common than price adjustments, and how price adjustments in response demand shocks may contribute to the observed higher volatility in upstream sectors. As far as I know, this will be the first paper to explain output volatility in terms of both quantities and prices. The statistically significant relationship between price volatility and upstreamness, relative to the marginally or inconsistently significant relationship with quantity volatility is also consistent with existing work linking volatility to price elasticities (Atalay, 2017). In emphasizing nominal output volatility, this paper follows the precedent of notable recent papers on the topic (e.g., Burgess and Donaldson, 2017; Caselli et al., 2015)

The pattern of higher volatility with upstreamness at the sector level has macroeconomic implications. Aggregate export volatility is higher for countries with trade portfolios dominated by a large share of upstream sectors. The contribution of export volatility to aggregate GDP volatility makes the finding relevant to other papers in the literature that describe the determinants of GDP or output volatility. The tests that focus on the volatility of exports from sectors can be interpreted to imply that output volatility is higher for upstream sectors, largely due to upstreamness, and not just because they have more volatile export components. Outside of the service sectors, export volatility is on average, twice as high as the volatility of the domestic component of output, with export volatility being larger for 54 of the 56 exporting sectors. The findings for other variables that explain aggregate volatility, including size, are also consistent with the literature. For example, the standard deviation of growth decreases with size, (Simon, 1955; Luttmer, 2007). An extension of the argument relating size to volatility is the idea that more granular economies or sectors are more volatile. Granularity, or unevenness in the distribution of economic activity within an economy or its components has also been shown to explain volatility (e.g., Di Giovanni and Levchenko, 2012).

In the aggregate, low export upstreamness generally predicts low export volatility. Decreasing the country-level export upstreamness by 1, on average, decreases export volatility by about 10%. This finding is relevant to understanding economic differences between countries. While export volatility is only a small fraction of aggregate economic volatility in high-income economies, it explains much of the shocks in developing economies. Previous studies of developing economies show volatility has a negative causal effect on growth (e.g., Turnovsky and Chattopadhyay, 2003; Kose et al., 2005, 2006). Similarly, Imbs (2007) finds that countries with high aggregate volatility experience lower growth (even if the negative relationship is not observed for sector-level analyses). About 80% of the differences in GDP volatility between countries is explained by their differences in export volatility, and 95 of the 220 economies in the UN data have negative covariance between exports and the rest of the economy, so that the contribution of export volatility to aggregate volatility is more than aggregate volatility itself. The results matter, given the documented relationship between nominal output volatility and welfare (e.g., Heathcote and Perri, 2018; McKay and Reis, 2016). Section 3.4 documents the statistically significant relationship between export volatility and a weighted average index of upstreamness.

The rest of the paper is organized as follows: Section 2 interprets the upstreamness measure defined in Antràs et al. (2012), and explains its relevance to economic volatility. The section centers on formal definitions and a simplified model to motivate the paper's empirical analysis. Section 3 describes the data and presents the main findings, and Section 4 has robustness checks, before Section 5 concludes.

2 Framework: An Economy with Intermediate Inputs

This section outlines a simple framework aimed solely at using inter-industry linkages to explain sector co-movement. Given the narrow scope of its function, it leaves out much of the detail described in related papers. The main argument underlying the framework is straightforward: The production of goods require labor and intermediate inputs, so that Y_i, the output of a sector i, is linked to the demand for final goods (and all downstream sectors) that rely on intermediate goods from sector i as inputs.

The paper will focus on the propagation of demand shocks. It is clear that both for production and preferences, elasticities of substitution matter, as highlighted in recent work (e.g., Arellano et al., 2018, 2009; Annicchiarico and Pelloni, 2013). That said, for simplicity, this paper will follow the most common precedent for production functions in this branch of the literature (e.g., Acemoglu et al., 2016, 2012). The Cobb-Douglas form of the production functions used in these papers constrains demand shocks to travel in only one direction – the shocks shift the demand curves for producers upstream in the supply chain. So, a positive income shock from a tax cut for example, increases demand for final goods, and in turn, demand for the intermediate goods required to make those final goods, and so on. The functional form does not allow positive demand shocks to travel downstream, so a technology improvement that stimulates demand for renewable energy over coal for example, will yield no demand shock in the model for items produced with renewable energy, nor for the items that those are used in turn to produce. The reasoning in the cited papers that highlight elasticities of substitution is largely consistent with this paper's main findings. Nevertheless, assuming the Cobb-

Douglas form, even if implicitly, leaves room for future work on simultaneous analyses of demand and production shocks, as well as on the extent to which the propagation of shocks and volatility depend on elasticities of substitution.

If we focus on shocks from final demand and their propagation through the production linkages in an economy, upstreamness - the 'economic distance' of a sector from final demand, becomes important enough to measure.

2.1 Upstreamness

To define *upstreamness*, consider an economy made up of only one supply chain. The N products or sectors in the economy are linked in stages such that *all* the output of sector N is absorbed by sector $N-1$ to create its own output, all of which is absorbed for intermediate uses by sector $N-2$, and so on, until we get product 1, which is consumed for final uses. If the economy was represented as an I-O matrix, the matrix elements Y_{ij} will show the output of sector i consumed in the production process of sector j. In this simplified economy, upstreamness, the distance from the final consumer is simply the sector number, with sector 1 having the lowest upstreamness, as it is the closest to final consumers, while sector N has an upstreamness value of N, being N steps from final uses.[3]

The oversimplified single supply chain economy provides a meaningful description of input-output processes in real economies. Hypothetically, it is possible to deconstruct all firms into input-output processes, and recombine the processes into synthetic sectors (or firms) that follow a strict input-output sequence. The thought experiment here is to place each productive process in the economy inside a matrix $\mathbf{A}$ that transforms inputs to outputs. The set of final outputs $\mathbf{F} = \mathbf{AX}$, where $\mathbf{F}$ represents the vector of outputs for final uses for all sectors and $\mathbf{X}$ represents the vector of all primary inputs into the

[3]From the Spectral Theorem, we know that a diagonal matrix equivalent exists for every normal matrix A (Halmos, 1963). This supports the idea that any input-output matrix may be represented as an equivalent off-diagonal single-supply chain matrix. Note that final uses as defined in this setup could be investment or government spending.

economy. The transformation matrix A is effectively, a scaled input-output matrix, which can be simplified to the matrix (product decomposition) that corresponds to the single chain of effective transformations that make up the economy. Two facts define this simplified economy as a matter of principle: [1] upstreamness is 1 for firms or sectors serving customers that are all final users, either as household consumers, firms or government, and [2] the upstreamness of a sector reflects the upstreamness of sectors linked to it.

Input-output linkages in real economies can provide useful measures of upstreamness or distance from final uses, even if the inter-sectoral input-output linkages look more like a network, than a simple supply chain. Traditionally, descriptions of the economy have mining and agriculture as the most upstream sectors, sending their output to the manufacturing sector, which in turn sends its output to a service sector that serves final uses. In practice, the mining sector uses inputs from the service sector and some agricultural outputs are transferred directly to final uses. Nevertheless, as long as there is an equivalent simplified form for the matrix of transformation (or Input-Output Use Tables), each sector and firm has an estimable upstreamness value.

Measuring upstreamness U_i requires knowing each sector i's position relative to others in the network of input-output linkages, as well as the output allocations of the sectors to which it is linked. One way to capture this requires creating the $N \times N$ matrix $\mathbf{W}$ from benchmark input-output tables, scaled to show the fraction of each sector i's output used as inputs by sector j. By definition, sectors selling a disproportionate share of their output to relatively upstream sectors are themselves, relatively upstream.[4]

Formally representing this intuition, as outlined in Antràs et al. (2012), for all

[4] Antràs et al. (2012) explain the measurement of upstreamness U_i in detail. This paper follows their logic. The measure resembles indexes of total forward linkages in supply-side Input-Output models of earlier papers (e.g. Miller and Blair, 2009; Ghosh, 1958). One must also note that the upstreamness is an analog of Bonacich centrality in a directed network. A node in a network has a higher Bonacich centrality measure if the nodes to which it is linked also have higher Bonacich centrality measures (Bonacich, 1987). This section only summarizes the explanation of how upstreamness is defined in Antràs et al. (2012). The goal of this paper is to establish the relationship between upstreamness and shock transmission through buyer-supplier linkages.

sectors i and j of N sectors:

$$U_i = 1 + \sum_{i=1}^{N} \left(\frac{\theta_{ij} Y_i}{Y_j} \right) U_j$$

where $\theta_{ij} Y_j / Y_i$ is the share of sector i's total output absorbed by sector j, and θ_{ij} captures the dollar value of sector i's output required as inputs to create a dollar of sector j's output.

In sum, the vector of sector upstreamness $\mathbf{U}$:

$$\mathbf{U} = [\mathbf{I} - \mathbf{W}]^{-1} \mathbf{1} \tag{1}$$

$\mathbf{1}$ is a column vector of ones and $\mathbf{I}$ is the identity matrix, so that the vector $\mathbf{U}$ shows the row sums of the inverse matrix. Each element $w_{ij} \in [0, 1]$ of W is $\theta_{ij} Y_j / Y_i$, the fraction of sector i's output used by sector j.[5]

U effectively represents the number of production stages (including fractional hypothetical production stages) between a sector's inputs and the average final consumer.

Interpreting Demand Shocks and Upstreamness: Every sector's output Y_i must be sent ultimately to a final consumer or used by another sector as an intermediate input. Formally:

$$Y_i = F_i + \sum_{j=1}^{N} \theta_{ij} Y_j \tag{2}$$

Benchmark input-output tables show the linkages between sectors and define the link weight elements w_{ij} in matrix $\mathbf{W}$, such that $w_{ij} = 0$ where there are no direct buyer-supplier linkages between sectors i and j. As explained in the lines following equation (1), link weights w_{ij} represent the share of sector i's output consumed by sector j. This formalizes the idea that the output for each sector reflects the final demand from

[5]($[\mathbf{I} - \mathbf{W}]^{-1}$ is recognizably the Leontief inverse, described in Leontief (1944, 1947).

sectors that use the sector's output. Putting (2) in matrix format:

$$\mathbf{Y} = \mathbf{F} + \mathbf{WY}$$

so that

$$\mathbf{Y} = [\mathbf{I} - \mathbf{W}]^{-1}\mathbf{F} \tag{3}$$

or, in clearer terms, using (1):

$$\mathbf{Y} + \delta\mathbf{U} = [\mathbf{I} - \mathbf{W}]^{-1}(\mathbf{F} + \delta\mathbf{1})$$

From (3), it is clear that if final consumption for every sector increased by one dollar (i.e. a vector of ones was added to $\mathbf{F}$), and input-output linkages $\mathbf{W}$ remained unchanged, the output Y_i of each sector would increase by an amount equal to its upstreamness, as defined in equation (1).

The foregoing suggests a new interpretation for upstreamness: the dollar increase in a sector's output associated with a *uniform* increase in final consumption across all sectors. This complements existing uses of the concept. The two economic interpretations of upstreamness that Antràs et al. (2012) provides are: [1] the semi-elasticity of a sector's output to a uniform change in input-output linkages between sectors, and [2] the dollar increase in aggregate output for a one dollar increase in value added for a given sector. From (2) one can deduce the first interpretation. If all θs were increased uniformly, the change in output would differ by sector, depending on each sector's upstreamness. For the second definition, one must consider the outputs Y_i as the sum of value added and intermediate inputs. Increasing value added in sectors with higher upstreamness corresponds to higher levels of aggregate output, due to the higher corresponding levels of value added in downstream sectors.

The new interpretation of upstreamness as a measure of responsiveness to common exogenous changes in final uses, emphasizes demand shocks in explaining sectoral volatility. By this interpretation, greater changes in output growth rates are expected for upstream sectors, compared to changes in downstream sectors, if demand shocks across sectors share any common component. The rest of this section will show that upstreamness, as it describes the position of a sector relative to others in the full set of demand and production processes that describe the economy, can also explain how production and demand shocks are accumulated and dispersed. The pattern of these growth shocks over time for sectors, or their *volatility*, must therefore reflect sectors' upstreamness.

2.2 Volatility

This section outlines the relationship between a sector's upstreamness and the volatility of its output, using the identity in Equation (2) and a conceptual framework based on the propagation of demand shocks.[6]

Starting from Equation (3), then parsing final demand into two components – a constant μ that is common to all sectors, and idiosyncratic elements $\tilde{f}_i$ of final uses for each sector, represented by the vector $\tilde{\mathbf{F}}$. (The simple two-component approach for final demand clearly over-simplifies and abstracts away from systematic differences in the relationships between the output vector and aggregate demand shock factors like financial conditions and policy. However, the approach is enough for the present purpose of showing demand shocks being propagated upstream.)

$$\mathbf{F} = \mu + \tilde{\mathbf{F}} \tag{4}$$

Combining Equations (3) and (4).

$$d\mathbf{Y} = [\mathbf{I} - \mathbf{W}]^{-1} d\mathbf{F}$$

Defining the vector of output growth shocks, properly scaled by sector output, as $d\hat{\mathbf{Y}}$,

[6] Recent evidence in the literature argue for the relevance of demand shocks to sectoral and aggregate volatility (e.g. Kelly et al., 2013; Di Giovanni and Levchenko, 2012).

and $d\hat{\mathbf{F}}$ the final use shocks, scaled by each sector's final uses.

$$d\hat{\mathbf{Y}} = \underbrace{[\mathbf{I} - \mathbf{W}]^{-1}[\hat{\mu} + \hat{\mathbf{F}}]}_{size} \underbrace{d\hat{\mathbf{F}}}_{shocks} \tag{5}$$

Where $\hat{\mathbf{F}}$ represents each sector's final uses' share of total output, (after adjusting for $\hat{\mu}$, the common demand shock). $\mathbf{F}$ is itself a measure of sector size.

Defining volatility $\sigma^2_{Y_i}$ as the variance of the sectoral output growth shocks in (5), $var(d\hat{\mathbf{Y}})$, and representing the Leontief inverse as $\mathbf{H}$:

$$\text{Volatility} = \sigma^2_{Y_i} = \left(\hat{\mu}\mathbf{U} + \mathbf{H}\hat{\mathbf{F}}\right)^2 \sigma^2_F$$

taking logs

$$ln(\sigma^2_{Y_i}) = 2[ln(\hat{\mu}\mathbf{U} + \mathbf{H}\hat{\mathbf{F}})] + ln(\sigma^2_F) \tag{6}$$

σ^2_F is the vector of final use volatility by sector.

Exogenous demand shocks to final consumption could be due to exchange rates for exports, or income shocks for domestic demand.[7]

LEMMA 1: *A sector's volatility will generally be less than the volatility of the sector upstream from it: (considering only downstream/demand shocks.)*

$$\frac{\partial \sigma^2_Y}{\partial U} > 0$$

Equation (6) provides the rationale for this statement. It should also be clear from equation (3) that any non-zero common element μ for final uses across sectors in an economy contributes $\mu\mathbf{U}$ to the vector of sectoral growth shocks. Larger growth shocks translate to a pattern of higher volatility. Table 14 in Appendix section A.1 provides illustrative evidence on the correlation between the growth rates for a sector, and the average growth rates of sectors directly upstream or downstream from it. The regres-

[7] Foster et al. (2008) and Olabisi (2015) among many others, discuss demand shocks in greater depth.

sions in that table also include estimates that use prices as a control variable to mitigate concerns about endogeneity. In sum, the theoretical argument that links nominal output volatility to upstreamness is captured in equations (2) to (6). The scale of shocks to the nominal value of final consumption is directly reflected in the corresponding changes to the output of linked sectors upstream from the final consumers.[8]

2.3 Size and Concentration

Equation (6) reflects the contribution of sector size to output volatility. The $\hat{\mu}$ term in the equation captures sectoral output Y, and common shock for all sectors μ. The second part of the term, $\hat{\mathbf{F}}$ includes the final uses share of sectors' output, (which includes sector size by definition). Sectoral volatility is expected to decrease with sector size, and to increase with higher shares of output consumed for final uses in this model. It should be no surprise that higher shares of output consumed for final uses also mean higher correlation between the volatility of final uses, and the volatility of a sector's output. Altogether the framework recognizes that demand shocks in final uses exist, and that they propagate upstream into their supply chains.

LEMMA 2: *Sectors with high output value will on average have lower output volatility, and sectors with a high share of final uses, high volatility that reflects the volatility of final uses*

Formally, from equation (6):

$$\frac{\partial \sigma_Y^2}{\partial Y} < 0$$

which implies, given that $\dfrac{\partial \hat{F}}{\partial Y} < 0$

$$\frac{\partial \sigma_Y^2}{\partial \hat{F}} > 0 \tag{7}$$

[8] The link between common shocks to final uses and volatility in the model fits the finding in previous work that nearly all of the variability in industrial production is associated with common factors (Foerster et al., 2011).

The contribution of the volatility of final uses to sectoral volatility also provides a rationale for expecting a positive correlation between volatility and trade openness (measured as export share). The higher volatility of exports relative to the rest of the economy is an established finding in the literature. The difference motivates the inclusion of an export share variable in the empirics that follow this section. Furthermore, if domestic consumption competes with volatile imports, in estimating sectoral volatility, it may be necessary to control for import share, if imports represent a notable share of absorption (imports and production less exports).[9]

There is also a diversification effect in this framework. Sectors that serve multiple, uncorrelated or negatively correlated sources of demand are expected to have lower output volatility. The concept is a corollary to the correlation between the volatility of final uses and sectoral output in (6), (and Lemma 2). In addition to the differences in demand volatility for domestic final uses and exports, productivity shocks or differences in inventory practices may lead to differences in the volatility of demand from downstream sectors - for sectors with more than one downstream destination. The correlation between shocks from each of the sectors, as well as the concentration of output destinations for each sector will contribute to its observed volatility. Similarly, volatility is expected to increase with use-concentration − sectors serving only one other sector will be more exposed to its idiosyncratic demand shocks d_j, relative to sectors with a broadly diversified portfolio of users. The empirics include variables that represent these contributions, in addition to the others mentioned in this section.

3 Empirics

The section first describes the data, before estimating the relationship between upstreamness and volatility.

[9] The expectation of higher volatility with trade exposure is consistent with results in previous work (Di Giovanni and Levchenko, 2009).

3.1 Data and Descriptives

3.1.1 Data

The three datasets uses to test the paper's main hypothesis are the BEA input-output tables, BEA industry output tables, and UN GDP by sector data. I describe each of these data sources in turn. First, the input-output tables provide the **W** matrix that generates the upstreamness measure - the key variable. I use two versions of this table: first is the summary input-output table series from 1997-2016. The 71 sectors in the table roughly match the North American Industry Classification System (NAICS) at the 3-digit level, with a few exceptions where the sectors are aggregated to broader summary groups. The second version is the detailed 2007 benchmark table with 403 narrowly-defined industries, corresponding roughly to the six-digit NAICS industry definition. The Tables also provide estimates for the final uses of each sector, as well as the share of the final output that is exported. Imports as a share of total absorption are provided in these tables.[10]

The second BEA table captures total output at the summary and detailed levels for the years 1947-2016 (and 1997-2016 respectively). Sectoral output volatility is derived from the reported output growth in these tables. The summary table shows 71 sectors, while the detailed output table reports 389 industries using the BEA Code for 2007. 19 of the 71 (238 out of 389) sectors at the summary (detailed) level are in manufacturing. The output tables use categories that are broadly similar to the categories in the I-O tables, with less detail. The small discrepancy in the number of sectors between the I-O table and the output tables reflects the use of summary groups to avoid disclosure for some sectors. For example, Tobacco farming (111910) and Cotton farming (111920) are reported separately in the I-O tables, but lumped into Other crop farming (111900) in the output tables. (Note that the paper focuses on gross output, not value added).

[10]For convenience, the language in the paper will generally refer to the summary classification into 71 groups as sectors, and the detailed classification to 403 groups as industries – the terms industry and sector are otherwise used interchangeably.

Third, UN tables show aggregate-level real GDP data, and its components at the broad sector-level for more than 180 countries between 1970 and 2016. The analysis was limited to the years 1997-2016, to match the other datasets. While no set of input-output tables are available for estimating for the countries' upstreamness separately, the data enable estimates of GDP volatility at the aggregate level, as well as the volatility of output for broad sectors, in addition to import and export volatility. Calculating export volatility required the use of UN COMTRADE data on exports at the country-product level (Gaulier and Zignago, 2010). The HS6 trade categories were concorded to NAICS six-digit industries, to derive a trade-weighted average upstreamness, from the upstreamness of the corresponding detailed sectors.

3.1.2 Descriptives: Input-Output Linkages and Upstreamness

Table 1 shows the 10 sectors with the highest volatility measures, as well as the 10 with the lowest volatility, with sectors defined at the summary level. The table also shows upstreamness for the 20 sectors. Volatility is calculated as the standard deviation of year-on-year growth between 1997 and 2016 for each sector, and growth is measured as the mid-point rate between successive years. The calculation of upstreamness substantially follows the approach in Antràs et al. (2012) (for both the sector and detailed industry data). The square matrix W is calculated as the ratio of a commodity's usage to the total output of the using sector. The numerator of the (i, j)-th entry of W, is the value of commodity i used in producing j the (i, j)-th entry from the I-O Use Table. The denominator $Y_i - X_i + M_i$ is the sum of values in row i of the Use Table, after removing net exports and net changes in inventories. The formula $[I - W]^{-1}\mathbf{1}$ gives the column vector whose i-th entry is the upstreamness measure for sector i, as defined in Section 2.

[Table 1 to go here]

The table shows a pattern of high upstreamness for the sectors with the highest output volatility. The third-highest level of upstreamness in the data belongs to the sector with the highest observed output volatility – Oil and gas extraction (211). The two sectors with the highest levels of upstreamness do not appear in this table – other real estate services (ORE) and technical services (5412OP). From the three-digit sector-level estimates, the oil and gas extraction sector's output is almost four sector-linkage steps away from the average final consumer. On the contrary, housing, hospitals and other customer-facing services sectors have the lowest-possible upstreamness value, and some of the lowest levels of output volatility observed in the data.

Figure 1 previews the paper's main finding, showing a pattern of higher output volatility on the vertical axis for sectors with high upstreamness. Upstreamness on the horizontal axis ranges from a minimum value of 1 (10 of 71 sectors that directly serve final users) to 5.25 (Miscellaneous professional, scientific, and technical services). The average upstreamness for sectors is 1.71 (with the first and third quartiles being 1.07 and 1.95). Using the more detailed input-output table with 389 industries - corresponding to six-digit NAICS industries, gives different estimates for upstreamness as expected. The range of observed upstreamness with the disaggregated definition is 1 to 49.3, with 1.1 and 2.6 as the quartiles. Section 4 revisits the use of more detailed industry definitions to estimate upstreamness and volatility.

[Figure 1 to go here]

Output volatility varies considerably between sectors. Output volatility for Oil and gas extraction (IO code 211), at 0.28, is 28 times larger than for the least volatile sectors (e.g., Hospitals). The mean output volatility for this period is 0.07. There is no clear division between broad sectoral groups in terms of output volatility. The most volatile sectors include financial services (IO code 523), and sectors with the lowest output volatility include a subset of manufacturing – Food, beverage and tobacco products, (at 0.03). Manufacturing sectors, with the diamond markers in the graph, span nearly the entire range of both upstreamness and volatility. As expected, primary sectors like oil and gas extraction have high upstreamness, while direct service sectors like Hospitals have some of the lowest upstreamness values. All 71 sectors are in the graph.

3.2 Upstreamness and Volatility

To formally test the relationship between upstreamness and output volatility, the following specification closely mirrors equation (6):

$$
\begin{aligned}
ln(\sigma^2_{Y_i}) &= \alpha_0 + \alpha_1 ln(Upstreamness_i) + \alpha_2 ln(Size_i) + \alpha_3 ln(TradeShare_i) \\
&\quad + \alpha_4 ln(\sigma^2_{F_i}) + +\alpha_5 ln(HHI^{use}_i) + \varepsilon_i \qquad (8)
\end{aligned}
$$

$\sigma^2_{Y_i}$ represents the volatility of sector i's output, calculated as the standard deviation of the annual sectoral output growth. $Size$ represents the log of total sectoral output in the baseline year (1997) as well as the share of the sector's output that is directly absorbed by final uses. $Tradeshare$ is a vector of the import and export share for each sector i's domestic output, included here because of the consistent pattern of higher export volatility for most sectors. $\sigma^2_{F_i}$ is the volatility of final uses for each sector, corresponding to σ^2_F in equation (6).

Table 2 summarizes the key variables estimated in equation (8). To help interpret the regressions that follow, the table also shows logs of variables. First, it is noteworthy that sectoral output volatility is generally low in the US, with significant dispersion. (The volatility of final uses follows the same pattern). Upstreamness also follows an expected pattern, starting from 1 for sectors linked downstream to only final users, to just above 5. That is, if the economy was defined as 71 sectors, production is never more than an average of five inter-sector linkages from a final user, and less than two steps for most sectors.

[Table 2 about here]

Furthermore, the import, export and final use shares for sectors also vary significantly, with some sectors exporting nothing – unsurprisingly, while others have exports accounting for more than 30% of output, e.g., other transportation equipment. Imports as a share of absorption also span a wide range, from zero to 42%. The average for both of these variables is 6%, which is consistent with the numbers reported in the literature for aggregate imports and exports for the period spanning 1997 to 2016. The Herfindahl Hirschmann Index of the uses for sectoral output is similarly high, with a mean of 0.44, which may reflect the prevalence of service sectors that send large shares of their output to final uses. The logs of the volatility, upstreamness and share variables fit the expected values observed in levels. The total sectoral output in logs is roughly centered about the mean value of 15.38, with minimum and maximum values about 2 above and below the mean.

Table 3 presents the estimates from equation (8). Column (1) reports a simple OLS regression of volatility on upstreamness, with no additional controls. Column (2) regresses volatility on size and the volatility of final uses, as well as use concentration and final uses' share of output. Size is measured as the log of total output from each sector between 1997 and 2016. Columns (3), (4) and (5) use other combinations of control variables, including controls for the share of exports and imports, following Di Giovanni and Levchenko (2009).

All specifications in the table show a positive relationship between the upstreamness of a sector and its volatility. About 14% of the variation in output volatility between sectors is explained by this variable alone. The coefficient on upstreamness is statistically significant in all cases, and suggests that a one-step increase in upstreamness is associated with all else equal, about a 50% increase in output volatility, or 10 standard deviations.

[Table 3 about here]

Final uses also explain a notable share of sector volatility. The share of output sent to final uses, the volatility of final uses, and sector size, put together, explain roughly three three quarters of the variation in sectoral output volatility. (The R^2 values in Column (2) and 4 are instructive for this purpose). As expected, larger sectors have lower levels of output volatility, consistent with earlier work (e.g. Di Giovanni and Levchenko, 2012, 2009), while export and import shares predict higher volatility. The table shows higher volatility levels for sectors with high volatility levels for their associated final uses, as well as sectors that send a large share of output to final uses. Altogether, the reduced-form estimates in the table strongly indicate that explaining volatility requires the use of an upstreamness measure.

Table 4 repeats the results in Table 3 separately for broad sector sub-samples. The first two columns show manufacturing sectors, and the last two, tertiary sectors. Primary sectors are not shown, as running a linear regression with nine observations is usually not advisable. (Nevertheless, Figure 2 in the appendix graphs the volatility-upstreamness relationships separately for all three broad sector groups). The estimates in Table 4 support previous claims about the sources of variation in the key variables, i.e., that there is notable variation between sectors for both upstreamness and volatility, within the broad sector groups. Furthermore, the results show that even within the two largest sector groups, a statistically significant upstreamness-volatility relationship holds.

[Table 4 about here]

Column (1) of Table 4 show that for the 19 manufacturing sectors defined at the summary level, increasing upstreamness predicts higher levels of output volatility. The estimated coefficient for manufacturing is larger, and with a higher level of statistical significance than the coefficient for tertiary sectors in Column (3). The variation in the data explained by a linear model is also higher for the first column, but nonetheless, both sector groups report positive relationships between upstreamness and output volatility with no addition controls. The results for the sub-samples in Columns (2) and (4) look more like the estimates for the full sample. Column (4) shows a coefficient for upstreamness that is statistically significant, and the coefficients on the control variables – final use volatility, use concentration, import share, export share, final use share and sector size, mirror the sign or statistical significance of the main estimates. In sum, the main results hold for these two sub-samples of the data.

Table 5 separately estimates the effects of upstreamness on quantity volatility and price volatility. The BEA output tables for the years 1997-2016 also include chained quantity and price indexes for each sector, so that in addition to output volatility, price or quantity volatility can be estimated as the standard deviation of the price and quantity indexes' growth rates over time. The specification follows Table 3, with columns 1 and 3 using only upstreamness as a control, and the other two columns using the same variables as the full regression specifications in the last columns of Tables 3 and 4.

[Table 5 about here]

The results in the table show *a stronger link between price volatility and upstreamness*, than between quantity volatility and upstreamness. The estimate in Column (1) is positive, as in previous tables, but is not statistically significant. Adding other control variables in Column (2) does not improve the estimated effects of upstreamness, as the standard error of the estimated coefficient increased, compared to the first column. The estimates suggest that changes to quantity volatility can be explained by the volatility of final uses, which has positive and statistically significant coefficient. Import share, and the share of output sent to final uses are the other variables in the specification that coefficients distinguishable from zero. Interestingly, more of the variation in quantity volatility is explained in Column (2) by the linear model, compared with the variation in price volatility in Column (4). Columns (3) and (4) of the table show a positive and statistically significant relationship between upstreamness and price volatility. The estimates imply that a one step increase in upstreamness ls associated with all else equal, more than a doubling of price volatility. It is also noteworthy, that the share of sectoral output sent to final uses has a stronger correlation with quantity volatility than with price volatility. The estimates are consistent with expectations that in the face of demand shocks, price adjustments are more likely than quantity adjustments at the sectoral level.[11]

[11] As described in the previous section, Table 14 in Appendix section A.1 provides supportive, even if

3.3 Export and Domestic Output Volatility at the Sector-Level

Exports and imports are more volatile than domestic production and consumption for most economies (Engel and Wang, 2011). This pattern may be explained in part by the upstreamness of exports. For the U.S. and other high-income economies, a notable share of imports and exports remain upstream goods that serve as inputs into other production processes. The average upstreamness for all U.S. sectors is 1.7, compared with 1.9 for the 56 of 71 sectors that export goods and services. Understanding how much upstreamness explains the volatility of imports and exports can help explain the pattern of higher volatility for export-intensive sectors relative to the rest of the economy.

For comparison, Table 6 includes the volatility of domestic output, that is, output consumed domestically. The comparison highlights differences between how upstreamness captures demand shock propagation for domestic final uses, and how changes to export upstreamness affects the volatility of total outputs. For similar reasons, the table includes the volatility of imports, which could reflect the pattern of shocks to domestic demand, with imports used as a buffer, or the volatility of foreign output, reflected in the demand for imports for a given sector.

For this section, I adopt the specification:

(9)

$$
\begin{aligned}
ln(\sigma^2_{Xi}) = \alpha_0^{export} &+ \alpha_1^{export} ln(Upstreamness_i) + \alpha_2^{export} ln(\sigma^2_{Di}) + \alpha_3^{export} ln(Size_i) \\
&+ \alpha_4^{export} ln(TradeShare_i) + \alpha_5^{export} ln(HHI_i^{use}) + \varepsilon_i
\end{aligned}
$$

The X subscript represents either imports, exports or domestic uses. σ^2_{Xi} thus could be the volatility of imports, exports or domestic output for sector i. The σ^2_{Di} variable represents the volatility of final uses for each sector, while the size variables captures

suggestive evidence, using correlation between the growth rates for a sector, and the growth rates of linked downstream sectors.

the size of exports, imports or output domestic uses.

Table 6 in Column (1) shows that domestic output volatility is correlated with upstreamness, although Column (2) implies that the statistical significance of the estimated coefficient depends on the controls applied. Columns (3) and (4) show that export volatility is not necessarily higher for sectors with high upstreamness. Finally, Columns (5) and (6) also show that import volatility is not related to upstreamness in a statistically significant sense, although import volatility tends to be higher for upstream sectors, and when final use volatility is high, which is not surprising. The results are useful, in showing that the observed higher levels of output volatility with upstreamness are not simply due to the higher volatility of exports, or the higher average upstreamness of exporting sectors. As expected, when controlling for size, sectors that export more in absolute terms have lower export volatility on average. The same also applies to the portion of a sector's output that is not exported, as well as imports. Column (2) uses the domestic demand or absorption as the measure of size, while Columns (4) and (6) respectively use export and imports. The R^2 values in Columns (1) and (2) of the same table suggest that upstreamness explains more of the variation in the volatility of domestic absorption than the variation of export volatility across sectors.

[Table 6 about here]

The results in Table 6 remain consistent with previous tables and with the findings in Foster et al. (2008) and Di Giovanni et al. (2014) that output fluctuations are higher for economic units whose trade destinations have higher volatility.

3.4 Aggregate Export Volatility and Upstreamness

This section examines how upstreamness explains aggregate export volatility. A notable share of GDP volatility is explained by export volatility, given that exports now account for about 30% of global GDP, while export volatility is about three times the volatility of GDP (Engel and Wang, 2011). The next table builds on the main finding in Tables 3 and 6, but uses country averages for upstreamness. The link to upstreamness is most relevant to export volatility, as exports represent a subset of gross output -with all intermediate inputs included - while GDP measures only value-added, excluding the value of intermediates. GDP volatility is not expected to give a comparable empirical relationship to upstreamness, (unless labor and capital strongly complement the use of intermediates, to give a positive correlation between output and value-added).[12]

The empirical specification includes other control variables: the weighted average of the GDP volatility of export destinations, following the σ_F^2 variable in Equation (8), export concentration by destination HHI^{dest}, export concentration by product HHI^{prod}, GDP per capita in 1997, as a measure of institutional quality, and the sum of GDP over the years 1997-2016 as a measure of size. The literature on co-movement for vertically-linked sectors make a strong case for examining whether sectors serving volatile destinations will in turn be volatile (Di Giovanni and Levchenko, 2010; Shea, 2002). This suggests a specification for estimating export volatility that includes demand shocks from US destinations. Formally:

$$\begin{aligned} (10) \qquad ln(\sigma_{Ec}^2) = \alpha_0^{agg} + \alpha_1^{agg} ln(Upstreamness_c) + \alpha_2^{agg} ln(\sigma_{Di}^2) \\ + \alpha_3^{agg} HHI_c^{dest} + \alpha_4^{agg} HHI_c^{prod} + \mathbf{Z}_c + \varepsilon_c \end{aligned}$$

The country-level upstreamness term, $Upstreamness_c = \sum_{i=1}^{N} (X_{ic}/X_c)^2 Upstreamness_i$ is the export-weighted sum of upstreamness for the trading sectors of country c. This variable ranges from less than 1.3 for Greenland, to 48.5 for Iraq, whose exports are dominated by the upstream oil and gas sector. (Note that the $Upstreamness_i$ measure used are from the detailed industry definitions, which range from 1 to 52.5). I construct

[12] GDP volatility differs across countries because some economies specialize in fewer and more volatile sectors (Koren and Tenreyro, 2007). Few papers have explored the contribution of exports to this pattern (e.g. Di Giovanni et al., 2014; Di Giovanni and Levchenko, 2012, 2009).

the weights from exports for each country-sector combination X_{ic} and X_c, the aggregate exports summed for all the years 1997-2016. Export data is taken from the BACI database (Gaulier and Zignago, 2010), which gives exports at the HS6 product/sector level for more than 200 economies. The HS6 product categories are matched to IO categories using the concordance provided by the U.S. Census for mapping HS10 trade categories to six-digit NAICS industries.

The destination volatility term is the export-weighted average of the GDP volatility of the countries to which the US exports from a given sector ($\sigma^2_{Di} = \sum_i \frac{GDP_i}{\sum_k GDP_k} \sigma^2_i$). If US exports from the logging sector are sent only to China for example, then the variable takes the value of China's GDP volatility - just for the logging sector, while other sectors with different destinations use other sets of values for destination-country GDP volatility. Using this variable addresses the possibility that the prevalence of aggregate level shocks in the destinations that import US goods affect the volatility of US exports for a sector. Note that I use GDP volatility for the destinations to avoid concerns about reverse causation- it is unlikely that production shocks in a US sector accounts for all the GDP volatility in the countries that import from that sector. The HHI variables measure diversification of exports, as the sum of squares of export shares by destination and product, while $\mathbf{Z_c}$ represents other country-level variables like GDP per capita.

The results in Table 7 remain consistent with the earlier findings in the paper. Export volatility is higher for economies with a larger share of trade from upstream sectors. Decreasing the country-level export upstreamness by 1 is expected to *decrease export volatility by at least 10%.* The coefficient of GDP per capita is negative, as expected. Similarly, larger economies, as measured by GDP also tend to have lower levels of export volatility. Concentration is measured with the Herfindahl Hirschmann Index (HHI). Concentration variables like destination HHI and product HHI have the expected sign, without controlling for upstreamness and economic size. However, in a specification that controls for upstreamness, GDP and GDP per capita, the coefficients, along with that of destination volatility, lose statistical significance, and make no clear prediction for export volatility.

[Table 7 about here]

The results show a negative correlation between GDP per capita and aggregate export volatility,with a statistically significant coefficient of -0.12 for the 189 countries with data on GDP per capita and upstreamness. As expected, larger economies also had lower levels of export volatility, but there is no clear statistical relationship between export volatility and the volatility of GDP in the export destinations. As mentioned earlier, this may simply reflect the imperfect correlation between output and the value-added terms that sum up to GDP.

These findings complement existing published work on the contributions of export volatility to aggregate GDP volatility. About 80% of the differences in GDP volatility between countries is explained by their differences in export volatility. (The regression of the variables is not shown in the paper to conserve space). In following Shea (2002), I also estimate the volatility of exports, the volatility of GDP minus exports, as well as the covariance between the export and other components of GDP. More than 160 of the countries in the UN data had negative covariance between exports and the rest of the economy, and the contribution of export volatility to aggregate volatility was more than aggregate volatility itself for 95 of these countries. That is, export volatility did not just contribute to GDP volatility, it contributed more volatility than the rest of the economy, as well as the comovement between exports and domestic value added. The results in Table 7 show a clear link between the upstreamness of a country's export portfolio and the volatility of its aggregate exports.

In sum, the negative correlation between volatility and GDP per capita in Koren and Tenreyro (2007) may be explained in part by the prevalence of upstream sectors in the production and export portfolio of low-income countries.

4 Robustness Checks

The findings are robust to whether industries are defined at the detailed 6-digit NAICS level, or as sectors at the 3-digit summary level. The findings also remain broadly unchanged for specifications that use stages of production as a proxy.

4.1 Industry Definition, Prices and Quantities

Table 8 shows estimates of the volatility upstreamness relationship using the detailed output (and input-output) data. The 403 industry groups in the output data were matched and collapsed to the 389 industries in the detailed 2007 IO table. As a crude but necessary approximation, final use volatility values for which detailed data remain unavailable, were replaced with the equivalents from the summary-level data. (For example, oilseed farming and grain farming have the same value for the variable, taken from the estimates for Farming (111CA) at the summary level.) Import and export share, as well as final use share and total output, had values in the benchmark year used for this regression. Import and export shares in this table were calculated using the imports and exports in the benchmark input-output tables, and so was the share of output sent directly to final uses. Size was still measured as the log of the sum of output over all the years.[13] [Table 8 about here]

The result in Tables 8 and 3 are remarkably similar, despite the fact that upstreamness ranges up to 5.25 for the first, while it goes beyond 49 in the second. The detailed industry groups show more of the linkages between sectors and therefore allow for more steps to be identified between raw materials and final uses. The estimates in Table 8 suggest that a one-step increase in upstreamness adds four standard deviations to the volatility of an industry, on average. Increasing import shares and export shares also contribute to higher output volatility, as in Table 3. Similarly, higher shares of output

[13] Four of the 389 industry categories in the IO table are largely informative, and do not feature in the regressions as productive sectors: Scrap, Used and secondhand goods, Noncomparable imports, Rest of the world adjustment.

sent to final uses, and higher final uses volatility also contribute to higher volatility in the detailed industry data estimates. In sum, the paper's main findings do not depend on the level of detail at which industries are defined.

Table 9 shows the corresponding table for estimating the effect of upstreamness on quantity volatility and price volatility for detailed six-digit NAICS industry equivalents. Just as in Table 5, upstreamness is not a statistically significant predictor of quantity volatility, while it has a strong and clear relationship with price volatility. Using the narrow industry group definitions does not change the previous indication that demand shocks tend to translate more into price shocks upstream than quantity changes. The other variables, including import and export share, final use share, output size and final uses volatility all remain broadly similar in sign with the results in Table 5.

[Table 9 about here]

4.2 Cost Shocks and Data Subsets

To address concerns that sectors like oil and gas production may be more sensitive to cost shocks, (rather than demand shocks), we exclude four sectors most at risk of getting policy- or other cost-driven changes to production. The four sectors are: Oil and gas extraction (211), Support activities for mining (213), Funds, trusts, and other financial vehicles (525) and Federal Reserve banks, credit intermediation, and related activities (521CI). Excluding these sectors provides the opportunity to see whether the main results hold, even after excluding these large, traditionally volatile sectors that are subject to policy-driven, or other aggregate cost shocks (as opposed to demand shocks).

Table 10 shows estimates for the 67 remaining 3-digit sectors. The upstreamness-volatility relationship remains negative and statistically significant, with an estimated coefficient of approximately 0.6. Size, final use volatility, as well as export, import and final use shares all feature in the regressions, in the same format as Table 3. [Table 10 about here]

The estimates in Table 10 are remarkably similar to those in Table 3. Upstreamness still predicts higher levels of output volatility, with nearly the same estimated coefficient as Table 3 (0.61 in column 5, compared to 0.64 in column 5 of the original table). The estimated effects of size (-0.13 vs. -0.15 in the original), final use volatility (0.76 vs. 0.78), import share (0.92 vs 0.80) and final use share (0.08 vs. 0.10), are all statistically indistinguishable between the two tables. The statistical significance of the results match exactly on the three key variables in the column 5 specification across the two tables, even if there are small differences for some other specifications or variables. In sum, the results in Table 10 support the main findings, and suggest that cost-driven shocks to production do not explain the headline findings of relationship between upstreamness and nominal output volatility.

Section 4.3 continues the robustness checks with tests of alternative upstreamness measures, in addition to using controls for input prices.

4.3 Alternative Upstreamness Measures and Input Prices

The upstreamness measure described in this paper has a crude analog in available data. The Bureau of Labor Statistics developed a stages of production classification system that broadly represents the same idea with a categorical variable − all goods are classified as raw materials and intermediate goods used for other intermediate goods (Stages 1 and 2), intermediate goods used for final goods (Stage 3) or final goods (Stage 4). In these broad categories, raw materials would have the highest levels of upstreamness, and intermediate goods would generally fall between raw materials and final goods. For simplicity, Stages 1 and 2 in the BLS classification were coded into one group representing raw materials, and used as the baseline for the two stages closest to final demand.

Table 11 shows that this paper's predictions hold when using the broad Stages of

Production categories as a proxy for upstreamness. Sectoral output volatility is lower on average by 0.24 for final goods compared with raw materials. The results are not statistically significant for intermediate goods sectors, compared to the baseline, but the sign in Columns (3) to (5) point in the direction that fits the earlier findings in the paper. The control variables are final use volatility, sector size, and use concentration measured the same way as in previous tables, in addition to the import and export share for the sector. Column (1) suggests that the BLS stages of production groupings are only a crude proxy for upstreamness, explaining about 1% of the variation in sectoral output volatility. Size and trade shares in Columns (2) and (3) of the table behave as expected, correlating negatively and positively in that order with output volatility. The specifications in Columns (4) and (5) with a more robust set of controls yield estimates that show statistically significant differences between final goods and raw materials in terms of output volatility. In the full specifications, the final goods categories have the lowest volatility estimates, and the categories farther upstream have relatively higher volatility levels on average. The estimates are consistent with previous tables that use a continuous variable to measure upstreamness.

To address the concern that the volatility of input prices lead to higher output volatility in upstream sectors, Table 12 includes estimates from specifications with a proxy for input price volatility. The proxy is calculated in two steps: an input-price index is calculated for each sector-year, using the share of inputs from the input-output tables as weights, on the price index data for each on the sectors directly upstream. Then, the volatility of the input-price index is estimated as the standard deviation of mid-point growth rates over the 1997-2016 period. Therefore sectors whose main inputs are primarily from providers with volatile prices will have high values of this proxy. (The correlation between input price volatility and upstreamness is not statistically significant). The specifications in Table 12 also include a measure of output use concentration. The concentration variable, as in Table 3, addresses concerns that the final use volatility term in the main specification does not capture the diversification of demand shocks across users downstream of a sector – final uses as well as intermediate uses. Use concentration is calculated as the Herfindahl Hirschmann Index of the distribution of each sector's output to other sectors in the input-output tables, and to final uses, (with final uses as one category). [Table 12 about here]

Unsurprisingly, including these variables does not alter the main findings of the paper. The input price volatility variable explains much less of the variation in output volatility in a simple correlation,, and its coefficient is not statistically significant in the full specification with all control variables in Column (5). Nevertheless, the results change when industries are measured at the detailed 6-digit NAICS level, as shown in Table 13 of the Appendix, although the changes do not alter the main conclusions of the paper.

5 Conclusion

This paper uncovers evidence of an empirical regularity in the U.S. economy: sectors far removed from final consumers experience higher levels of output volatility. The distance from final consumers is measured as upstreamness, and output volatility is measured as the standard deviation of growth for sectors. From the main findings in the paper, volatility for sectors at the median upstreamness level of 1.3 will be about 35% higher than for sectors closest to final uses, like housing and local government services. A unit increase in upstreamness will on average, come with an increase in output volatility of 10 standard deviations. This empirical regularity contributes to the existing literature on *why output from some sectors are more volatile*, a topic that is necessary for understanding the sources of aggregate volatility. The pattern of higher output volatility with upstreamness is robust to specifications that control for the volatility of input prices, for the export share of sectoral output, for sector size, for final use uses share, and for the volatility of final uses for each sector's output. The statistical significance of upstreamness, after including these additional controls, highlights the paper's contribution to the body of work that explains sectoral volatility with trade share and sector size (e.g., Di Giovanni and Levchenko, 2009, 2012). Upstreamness explains a non-trivial share of the variation in output volatility between sectors, even after controlling for sectors' import and export shares. Furthermore, the volatility of domestic demand also increases with upstreamness. The response of outputs to demand is consistent with the findings of previous studies of demand shocks, including fiscal shocks (e.g., Auerbach and Gorodnichenko, 2017, 2012). Appendix section A.1 further illustrates the argument using basic empirical tests.

Upstreamness predicts higher levels of output volatility, even within broad sector groups like manufacturing and services. The data show notable variation in upstreamness and volatility within these groups (as highlighted in Figure 2). While consumer-facing manufacturing sectors like food, beverage and tobacco have low output volatility and upstreamness, service sectors providing inputs for other sectors many steps away from final uses have both high output volatility and upstreamness, (e.g., administrative and support services). In testing the manufacturing and service sector groups separately, the paper shows a statistically significant relationship between upstreamness and volatility for both groups, with sharper estimates for the set of manufacturing sectors.

We find the relationship between upstreamness and nominal output volatility, to be more significant than the relationship between upstreamness and quantity-based output volatility. The finding is unsurprising, given the prediction in Section 2 that as demand shocks propagate upstream, the successive suppliers adjust in response. Price adjustments are more likely than quantity adjustments in response to demand shocks, (as menu costs are usually lower than the costs of production scale adjustments). These set of findings particularly complement previous work that highlight the importance of price elasticities, and elasticities of substitution in explaining sectoral shocks (Baqaee and Farhi, 2019; Boehm et al., 2015; Atalay, 2017).

Aggregate export volatility is also higher with upstreamness, that is, the weighted average upstreamness of exports at the country-level. The finding supports claims that aggregate export volatility and its contribution to GDP volatility are related to the composition of the national export portfolio. Export volatility is higher by about 13% for each unit increase in the upstreamness of the aggregate export portfolio. For the US economy, sectoral export volatility is not consistently linked with upstreamness in any statistically significant manner. This helps to make the argument that aggregate export volatility is higher because of the items exported, not just because of export-related factors. In sum, countries with exports portfolios dominated by upstream sectors tend to have higher levels of export volatility. This finding of a consistent pattern addresses a gap in the literature. While Koren and Tenreyro (2007) and Carvalho and Gabaix (2013) argue that some sectors inherently have higher levels of volatility than others, this paper explains the differences, using a model of demand shocks propagating through input-output linkages. It is also relevant to economic development, given how export volatility is closely linked to GDP volatility, and how GDP volatility is linked to lower GDP per capita.

The findings are robust to how sectors are defined - summary groups of 71 sectors, or detailed groups of 389 industries. They are also robust to how upstreamness is measured - formally, using the IO table, or the less formal stages of production groups defined by the BLS. The upstreamness measure is robust to changes in the input-output tables over time: the correlation between upstreamness for sectors at the summary level in 1977 and 2002 is a remarkable 95.1%. The sign of the relationship between output volatility and upstreamness is also consistent over time - even if the more recent data provides a starker, and more statistically significant estimate.

The consequences of sectoral volatility are non-trivial, especially for labor outcomes. The paper contributes a novel explanation for nominal output volatility that complements existing research on the determinants of sectoral and aggregate volatility, and can inform future research into theoretical and empirical frameworks that link the structure of production to micro- and macroeconomic behavior and outcomes.

The findings are particularly relevant to policymakers in developing countries, faced with choices about *how* to diversify the economy. Paths to economic diversification that do not consider the relative upstreamness of sectors may be limited in their ability to reduce the aggregate volatility of exports and GDP for those economies. On the other hand, selecting a path to diversification that emphasizes downstream sectors should lower the expected levels of economic volatility – for output, exports and GDP.

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Table 1: Top 10 and Bottom 10 Industries by Output Volatility

Code	Description	Volatility	Upstreamness
	Highest Output Volatility		
211	Oil and gas extraction	0.28	3.78
324	Petroleum and coal products	0.23	3.27
213	Support activities for mining	0.22	1.08
331	Primary metals	0.20	2.74
441	Motor vehicle and parts dealers	0.19	1.01
22	Utilities	0.12	2.38
3361MV	Motor vehicles, bodies and trailers, and parts	0.12	1.63
321	Wood products	0.11	1.52
523	Securities, commodity contracts, and investments	0.10	2.71
212	Mining, except oil and gas	0.10	1.53
	Lowest Output Volatility		
81	Other services, except government	0.03	1.67
GSLG	State and local general government	0.03	1.00
445	Food and beverage stores	0.02	1.00
722	Food services and drinking places	0.02	1.38
61	Educational services	0.02	1.03
HS	Housing	0.02	1.00
621	Ambulatory health care services	0.02	1.03
623	Nursing and residential care facilities	0.01	1.01
622	Hospitals	0.01	1.00
GSLE	State and local government enterprises	0.01	1.02

Volatility is the standard deviation of year-to-year sectoral output growth and upstreamness is the distance of each sector from final use, as described in Antràs et al. (2012).

Table 2: Descriptive Statistics

	Mean	St. Dev.	Min	Max
Upstreamness	1.71	0.90	1.00	5.25
Output volatility	0.07	0.05	0.01	0.30
Final use volatility	0.07	0.06	0.01	0.28
Use HHI	0.44	0.32	0.05	1.00
Final use share	0.53	0.32	0.001	1.00
Import share	0.06	0.10	0.00	0.42
Export share	0.06	0.07	0.00	0.34
ln(Output volatility)	−2.97	0.67	−4.51	−1.21
ln(Upstreamness)	0.43	0.43	0.00	1.66
ln(Final use volatility)	−2.92	0.71	−4.37	−1.26
ln(Use HHI)	−1.15	0.90	−3.04	0.00
ln(Final use share)	−0.99	1.18	−7.49	0.00
ln(Output)	15.38	0.95	13.16	17.15

N = 71

Table 3: Output Volatility and Upstreamness

	Dependent variable:				
	ln(Output Volatility)				
	(1)	(2)	(3)	(4)	(5)
ln(Upstreamness)	0.57^{***}		0.70^{***}	1.21^{***}	0.64^{***}
	(0.17)		(0.15)	(0.28)	(0.14)
ln(Final use volatility)		0.92^{***}	0.83^{***}		0.78^{***}
		(0.06)	(0.06)		(0.06)
ln(Output)		0.06	-0.16^{***}	-0.40^{***}	-0.15^{**}
		(0.04)	(0.06)	(0.10)	(0.06)
ln(Use HHI)		0.02	0.20^{***}	0.30^{**}	0.18^{***}
		(0.06)	(0.07)	(0.13)	(0.07)
ln(Final use share)		0.09^{*}	0.10^{**}	-0.06	0.10^{**}
		(0.05)	(0.04)	(0.08)	(0.04)
Import share				1.65^{**}	0.80^{**}
				(0.74)	(0.38)
Export share				1.78^{*}	0.38
				(1.07)	(0.55)
Constant	-3.22^{***}	-1.02	1.93^{**}	2.70^{*}	1.51^{*}
	(0.11)	(0.63)	(0.83)	(1.61)	(0.81)
Observations	71	71	71	71	71
R^2	0.14	0.80	0.85	0.46	0.87

Note: *p<0.1; **p<0.05; ***p<0.01

The table shows OLS estimates for the volatility-upstreamness relationship for sectors defined to correspond broadly with 3-digit NAICS industry groups. Upstreamness represents the number of production stages (including fractional hypothetical production stages) between a sector's inputs and the average final consumer. Volatility is the standard deviation of year-to-year industry output growth (or of final uses growth) for the sector. Use HHI captures the concentration of uses for sectoral output. Output as sector size is measured in trillions of US dollars, the sum of output between 1997 and 2016. The final use and export shares represent the fraction of total output assigned to each each, while import share is obtained by dividing each sectors imports with the sectors output added to imports. See text for details.

Table 4: Output Volatility and Upstreamness by Broad Sector Group

	Dependent variable: ln(Output Volatility)			
	Manufacturing		Services	
	(1)	(2)	(3)	(4)
ln(Upstreamness)	0.70**	0.86**	0.34*	0.49***
	(0.29)	(0.32)	(0.18)	(0.17)
ln(Final use volatility)		0.65***		0.81***
		(0.11)		(0.07)
ln(Output)		−0.11		−0.12*
		(0.14)		(0.06)
ln(Use HHI)		0.17		0.20**
		(0.18)		(0.09)
ln(Final use share)		0.02		0.07
		(0.15)		(0.05)
Import share		0.94		−0.54
		(0.84)		(1.98)
Export share		−0.18		1.27
		(0.82)		(0.83)
Constant	−2.98***	0.56	−3.37***	1.20
	(0.18)	(2.22)	(0.11)	(0.96)
Observations	19	19	45	45
R^2	0.25	0.88	0.07	0.84
Note:		*p<0.1; **p<0.05; ***p<0.01		

The table shows OLS estimates for the volatility-upstreamness relationship for sectors defined to correspond broadly with 3-digit NAICS industry groups. The estimates are reported separately for two broad sector groups, manufacturing in Columns (1) and (2), and tertiary sectors in columns (3) and (4). Other variables are as in Table 3.

Table 5: Quantity and Price Volatility vs. Upstreamness

	Dependent variable:			
	ln(Quantity Volatility)		ln(Price Volatility)	
	(1)	(2)	(3)	(4)
ln(Upstreamness)	0.28	0.27	0.64^{***}	1.11^{***}
	(0.17)	(0.22)	(0.21)	(0.35)
ln(Final use volatility)		0.60^{***}		0.44^{***}
		(0.09)		(0.14)
ln(Output)		−0.13		-0.33^{**}
		(0.08)		(0.13)
ln(Use HHI)		−0.07		0.40^{**}
		(0.10)		(0.16)
ln(Final use share)		0.21^{***}		−0.11
		(0.07)		(0.10)
Import share		1.48^{**}		−0.35
		(0.57)		(0.90)
Export share		0.09		1.04
		(0.83)		(1.31)
Constant	-3.23^{***}	0.61	-4.20^{***}	2.27
	(0.10)	(1.24)	(0.13)	(1.95)
Observations	71	71	71	71
R^2	0.04	0.64	0.12	0.45

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

The table shows OLS estimates for quantity and price volatility. Variables are as described in Table 3.

Table 6: Domestic, Export and Import Volatility vs. Upstreamness

	Dependent variable:					
	ln(Output Volatility)		ln(Export Volatility)		ln(Import Volatility)	
	(1)	(2)	(3)	(4)	(5)	(6)
ln(Upstreamness)	0.42*	0.12	−0.02	0.37**	0.15	0.48**
	(0.23)	(0.10)	(0.16)	(0.14)	(0.23)	(0.24)
ln(Final use volatility)		0.98***		0.27***		0.45***
		(0.04)		(0.09)		(0.14)
ln(Use HHI)		0.19**		0.20**		0.27*
		(0.07)		(0.08)		(0.15)
ln(Final use share)		−0.21**		0.08		−0.13
		(0.10)		(0.07)		(0.14)
ln(Domestic output)		−0.09**				
		(0.04)				
ln(Exports)				−0.18***		
				(0.03)		
ln(Imports)						−0.17***
						(0.04)
Constant	−3.04***	1.29**	−2.10***	0.94*	−2.08***	1.26
	(0.14)	(0.50)	(0.11)	(0.52)	(0.15)	(0.78)
Observations	69	69	56	56	47	44
R^2	0.05	0.94	0.0003	0.46	0.01	0.42
Note:				*p<0.1; **p<0.05; ***p<0.01		

The table shows OLS estimates for domestic output volatility, as well as import and export volatility for sectors defined to corresponding with 3-digit NAICS industry groups. The variables use the same definition as in Table 3. Domestic output is total output after removing exports, without including imports. See text for details.

Table 7: Aggregate Export Volatility and Upstreamness

	Dependent variable:				
	ln(Export Volatility)				
	(1)	(2)	(3)	(4)	(5)
ln(Average upstreamness)	0.09*			0.16***	0.13***
	(0.05)			(0.04)	(0.05)
ln(GDP per capita)		−0.12***		−0.12***	−0.12***
		(0.02)		(0.02)	(0.02)
ln(GDP)		−0.08***		−0.10***	−0.09***
		(0.01)		(0.02)	(0.02)
ln(Destination volatility)			0.26**		−0.03
			(0.12)		(0.11)
ln(Destination HHI)			0.17**		−0.02
			(0.08)		(0.07)
ln(Product HHI)			0.20***		0.06
			(0.04)		(0.05)
Constant	−2.46***	0.84**	−0.53	1.16***	0.85
	(0.09)	(0.38)	(0.57)	(0.41)	(0.57)
Observations	195	208	195	189	189
R^2	0.02	0.30	0.17	0.34	0.34
Note:			*p<0.1; **p<0.05; ***p<0.01		

The table shows OLS estimates for export volatility at the country level. Average upstreamness is the export-weighted average for upstreamness index for all goods exported by each country between 1997 and 2016. Destination volatility is the export-weighted average GDP volatility for the export destinations served by each country. See text for details.

Table 8: Detailed Industry Volatility and Upstreamness

	Dependent variable:				
	ln(Output Volatility)				
	(1)	(2)	(3)	(4)	(5)
ln(Upstreamness)	0.10**		0.29***	0.38***	0.25***
	(0.05)		(0.05)	(0.06)	(0.05)
ln(Final use volatility)		0.52***	0.44***		0.42***
		(0.04)	(0.04)		(0.04)
ln(Output)		−0.14***	−0.22***	−0.24***	−0.19***
		(0.02)	(0.02)	(0.03)	(0.03)
ln(Use HHI)		0.01	0.10***	0.11***	0.09***
		(0.03)	(0.03)	(0.03)	(0.03)
ln(Final use share)		0.01	0.01	−0.02	0.0003
		(0.01)	(0.01)	(0.02)	(0.01)
Import share				0.25	0.13
				(0.21)	(0.19)
Export share				0.69***	0.44*
				(0.25)	(0.23)
Constant	−2.56***	−1.03***	−1.40***	−2.91***	−1.52***
	(0.04)	(0.14)	(0.15)	(0.05)	(0.15)
Observations	385	385	385	385	385
R^2	0.01	0.39	0.44	0.32	0.45
Note:			*p<0.1; **p<0.05; ***p<0.01		

The table shows OLS estimates for the volatility-upstreamness relationship for sectors defined to correspond broadly with 6-digit NAICS industry groups. Upstreamness represents the number of production stages between an industry's inputs and the average final consumer. Volatility is the standard deviation of year-to-year industry output growth (or of final uses for the industry). Industry size is measured in trillions of US dollars, the sum of output between 1997 and 2016. The final use and export shares represent the fraction of total output assigned to each category, while import share is obtained by dividing each sectors imports with the sectors output added to imports. See text for details.

Table 9: Industry Quantity and Price Volatility vs. Upstreamness

	Dependent variable:			
	ln(Quantity Volatility)		ln(Price Volatility)	
	(1)	(2)	(3)	(4)
ln(Upstreamness)	−0.03	0.07	0.48^{***}	0.66^{***}
	(0.04)	(0.05)	(0.06)	(0.09)
ln(Final use volatility)		0.38^{***}		0.15^{**}
		(0.04)		(0.07)
ln(Output)		-0.17^{***}		-0.21^{***}
		(0.03)		(0.05)
ln(Use HHI)		0.03		0.08^{*}
		(0.03)		(0.05)
ln(Final use share)		0.01		−0.02
		(0.01)		(0.02)
Import share		0.25		-0.62^{**}
		(0.18)		(0.30)
Export share		0.65^{***}		−0.27
		(0.22)		(0.36)
Constant	-2.58^{***}	-1.73^{***}	-4.08^{***}	-3.71^{***}
	(0.04)	(0.15)	(0.05)	(0.25)
Observations	385	385	385	385
R^2	0.001	0.47	0.16	0.24
Note:		$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$		

The table shows OLS estimates for quantity and price volatility for industries defined to correspond broadly with 6-digit NAICS groups. The variables use the same definition as Table 8. See text for details.

Table 10: MAIN RESULTS WITHOUT OIL AND CORE BANKING SECTORS

	Dependent variable:				
	Log(Output Volatility)				
	(1)	(2)	(3)	(4)	(5)
ln(Upstreamness)	0.59***		0.66***	0.93***	0.61***
	(0.17)		(0.17)	(0.29)	(0.16)
ln(Final use volatility)		0.89***	0.83***		0.76***
		(0.07)	(0.06)		(0.06)
ln(Output)		0.04	−0.15**	−0.26**	−0.13**
		(0.04)	(0.06)	(0.10)	(0.06)
ln(useHHI)		−0.03	0.19**	0.12	0.17**
		(0.07)	(0.09)	(0.15)	(0.08)
ln(Final use share)		0.13**	0.10**	−0.03	0.08
		(0.06)	(0.05)	(0.09)	(0.05)
Import share				1.73**	0.92**
				(0.71)	(0.40)
Export share				2.22**	0.49
				(1.00)	(0.57)
Constant	−3.27***	−0.99	1.77*	0.52	1.20
	(0.10)	(0.66)	(0.92)	(1.63)	(0.90)
Observations	67	67	67	67	67
R^2	0.16	0.77	0.82	0.47	0.84
Note:			*p<0.1; **p<0.05; ***p<0.01		

The table replicates the estimates in Table 3, except that four potentially cost-shock sensitive sectors are excluded. The sectors are: Oil and gas extraction (211), Support activities for mining (213), Funds, trusts, and other financial vehicles (525) and Federal Reserve banks, credit intermediation, and related activities (521CI). The OLS estimates for the volatility-upstreamness relationship for sectors defined to correspond broadly with 3-digit NAICS industry groups. The table shows that the main results are *robust* to excluding these sensitive sectors.

Table 11: Volatility and Stages of Production

	Dependent variable:				
	ln(Output Volatility)				
	(1)	(2)	(3)	(4)	(5)
Stage 3: Intermediates	0.004		−0.06	−0.12	−0.06
	(0.08)		(0.07)	(0.08)	(0.07)
Stage 4: Final goods	−0.12*		−0.23**	−0.27**	−0.24**
	(0.07)		(0.10)	(0.11)	(0.10)
ln(Final use volatility)		0.52***	0.52***		0.46***
		(0.04)	(0.04)		(0.04)
ln(Output)		−0.14***	−0.13***	−0.11***	−0.09***
		(0.02)	(0.02)	(0.03)	(0.02)
ln(Use HHI)		0.01	0.08**	0.07*	0.08**
		(0.03)	(0.04)	(0.04)	(0.04)
ln(Final use share)		0.01	0.02	−0.03*	−0.002
		(0.01)	(0.01)	(0.02)	(0.01)
Import share				0.56***	0.32*
				(0.21)	(0.19)
Export share				0.99***	0.59**
				(0.26)	(0.23)
Constant	−2.44***	−1.03***	−0.84***	−2.59***	−1.12***
	(0.05)	(0.14)	(0.16)	(0.11)	(0.17)
Observations	380	385	380	380	380
R^2	0.01	0.39	0.39	0.24	0.42
Note:			*p<0.1; **p<0.05; ***p<0.01		

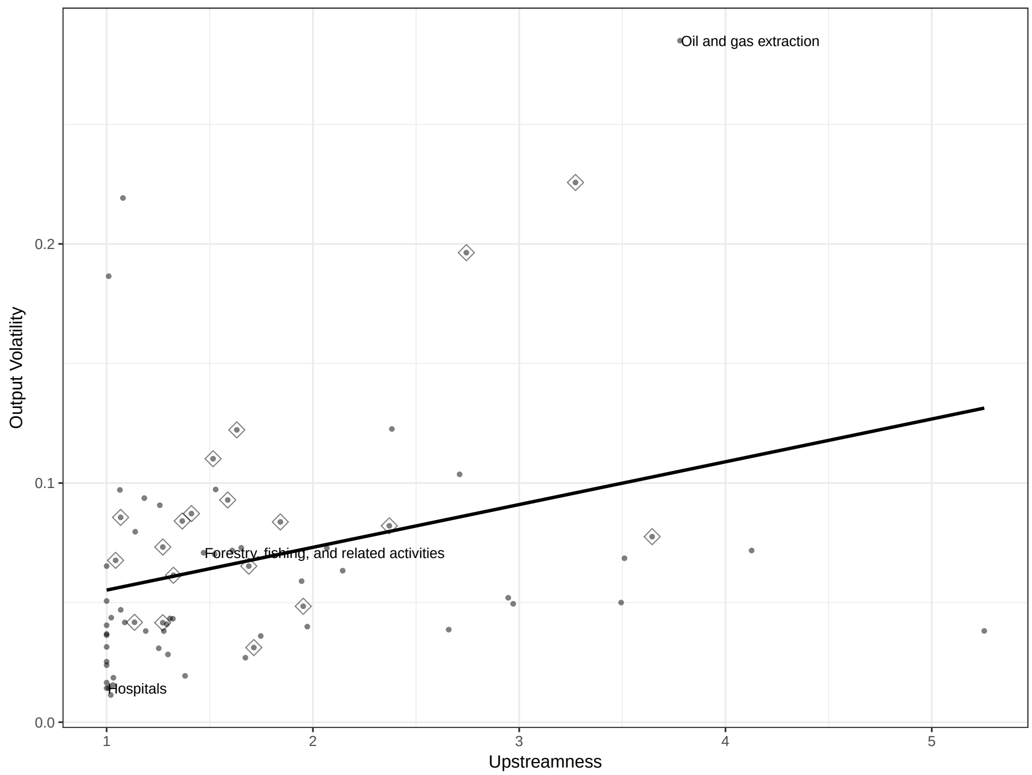
The table shows OLS estimates for the volatility-upstreamness relationship for sectors defined to correspond broadly with 6-digit NAICS industry groups. Upstreamness is measured using the BLS stages of production codes, with stages 1 and 2 combined to represent raw materials, as the baseline category. Volatility is the standard deviation of year-to-year industry output growth. Industry size is measured in trillions of US dollars, the sum of output between 1997 and 2016. Export share represents the fraction of total output shipped overseas, while import share is obtained by dividing each sectors imports' with the sectors output added to imports. See text for details.

Table 12: Industry Volatility and Upstreamness: Controls for Input Prices

	Dependent variable:				
	ln(Output Volatility)				
	(1)	(2)	(3)	(4)	(5)
ln(Upstreamness)	0.10^{**}		0.01	−0.03	0.15^{**}
	(0.05)		(0.04)	(0.04)	(0.06)
ln(Input price volatility)		0.46^{***}	0.45^{***}	0.33^{***}	0.23^{***}
		(0.05)	(0.05)	(0.04)	(0.04)
ln(Final use volatility)				0.50^{***}	0.39^{***}
				(0.04)	(0.04)
ln(Output)					-0.13^{***}
					(0.03)
ln(Use HHI)				0.04	0.08^{***}
				(0.03)	(0.03)
ln(Final use share)					−0.01
					(0.01)
Import share					0.16
					(0.18)
Export share					0.49^{**}
					(0.22)
Constant	-2.56^{***}	-0.91^{***}	-0.92^{***}	0.18	-0.73^{***}
	(0.04)	(0.16)	(0.17)	(0.18)	(0.21)
Observations	385	384	384	384	384
R^2	0.01	0.21	0.21	0.42	0.49
Note:			*p<0.1; **p<0.05; ***p<0.01		

The table shows OLS estimates for output volatility using sectors defined to broadly correspond with 6-digit NAICS industry groups. The variables use the same definition as Table 8, and include input price volatility as an additional control. See text for details.

Figure 1: Sector Volatility and Upstreamness



The graph plots volatility on the vertical axis against upstreamness for all U.S. sectors at the summary level using BEA data. Volatility is the standard deviation of year-to-year sectoral output growth and upstreamness is the distance of each sector from final use, as described in Antràs et al. (2012). Manufacturing sectors are flagged with a diamond marker.

A Appendix

In continuing from the robustness checks section, Table 13 shows that input price volatility may contribute to output volatility in looking at detailed sectors. Nevertheless, the contribution of input price volatility to output volatility still leaves a statistically significant relationship between upstreamness and output volatility. The coefficient of input price volatility is statistically significant in all specifications that use the detailed industry tables, and its correlation with output volatility is non-trivial compared with the other explanatory variables, including upstreamness, final use volatility and use concentration, as represented in Column (4) of the table. The full specification in Column (5) suggests that while input price volatility may predict higher levels of output volatility for sectors defined as narrow industry groups, increasing upstreamness remains a statistically significant predictor of high output volatility.

[Table 13 about here]

The rest of the appendix explains upstreamness, provides illustrative evidence for why upstreamness should lead to higher output volatility, given the correlation of shocks between vertically linked sectors, and discusses possible changes to upstreamness over time.

A.1 Correlation of Growth Shocks for Linked Sectors

This next table illustrates the expected co-movement of growth shocks for sectors with direct input-output linkages. The regression explains each sector's growth in a given period by the weighted average growth of sectors directly upstream from it (as a partial proxy for production shocks), and the weighted average growth of its linked downstream sectors, as a similar proxy for *demand shocks*. To mitigate concerns about endogeneity, columns (4)–(6) of the table regress the growth rates of the quantity index (not value), and use the the growth rates of prices as controls. The shares of flows to, or from the downstream and upstream sectors are used as weights for the growth variables. The regression estimates in the table, largely illustrative, helps to address concerns that upstream sectors are volatile *only* because of production shocks, e.g., claims that demand plays no notable part in the volatility of the oil mining sector.

[Table 14 about here.]

Table 14 shows that output fluctuations are correlated with *both* growth shocks from upstream and downstream sectors. The preliminary results are consistent with papers that link growth to upstream shocks, (e.g. Boehm et al., 2015; Acemoglu et al., 2012; Carvalho, 2008) and those that argue for downstream shocks, or backward propagation, (e.g. Acemoglu et al., 2016; Kelly et al., 2013). In Column (1), one sees a nearly one-for-one increase/decrease in output growth for a corresponding change in the weighted downstream growth. In Column (2), the expected relationship in terms of sign and statistical significance is present, even if the size of the estimated coefficient is smaller than the previous column, (there are more observations in column (2) because downstream growth is missing for more sectors than upstream growth). Column (3) shows that both sources of growth have statistically significant relationships with output growth, and the share of output growth variation that is explained by the inclusion of both variables is slightly more than either variable in Columns (1) and (2).

The coefficient on downstream growth in columns (1), (4) and (6) is larger than one, unsurprisingly. This means that a one percent growth in final demand, is expected to come with growth greater than one percent in the sectors directly upstream of the demand shock. A pattern of scaled up shocks further away in the supply chain from final uses, implied higher volatility over time for those upstream sectors. Columns (4), (5) and (6) fit the expected pattern, with negative quantity growth associated with price shocks for a sector's output. The focus on demand shocks in the paper, is motivated in part by the results in column (6) where price changes for upstream sectors show no statistically significant correlation to sector growth, but changes to prices for downstream sectors predict changes to sectoral output with the same sign.

A.2 Did Upstreamness Change Over Time?

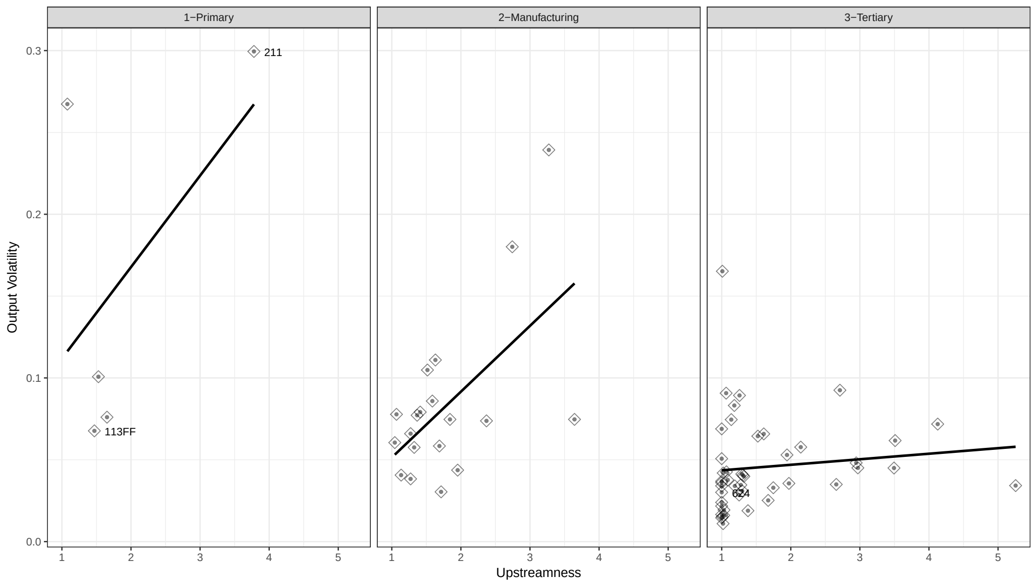
Figure 2 provides the baseline upstreamness-volatility relationship using the 2007 benchmark input-output tables for summary sectors. The baseline is necessary for several reasons: first, it highlights the variation in output volatility and upstreamness between and within broad sector groups, and second, because because of the possible argument that the main findings in the paper depend on the period in which upstreamness and output volatility are measured.

The concern that upstreamness may change over time reflects expectations that technologies changes regularly redefine the input-output matrix that describes the economy. For example, in recent years, a greater share of copper output may be channeled into the production of machinery, which serve as inputs into other manufactured goods, before its absorption by the final consumer. In the past, a larger share of copper may have been used by utilities, which serve consumers directly, so that upstreamness of copper would appear to have increased.

Figure 3 shows the relationship between output volatility and upstreamness for the two selected periods (1972-1989, 1997-2014), when the sectors are defined at this summary level. Even with data aggregated to the summary level, one observes the pattern of higher volatility for sectors with high upstreamness. The estimates should be robust to aggregating sectors into broader categories, given other findings in the paper. One still observes an upward sloping trend for the 1977 graph - even if it does not appear statistically significant, compared with the 2002 figure.

Figure 4 shows that while upstreamness declined slightly for almost all sectors, the relative standings of sectors on upstreamness remained remarkably consistent over time. I use BEA input-output data for 1977 to estimate historical values for sector upstreamness in the graph. This data is only available for sectors aggregated to the summary level (65 sectors, of which 19 are in manufacturing). I repeat the derivation of upstreamness for 2002, using similarly aggregated data. The average upstreamness in 1977 was 2.01, but declined slightly to 1.96 for the 2002 estimates. The maximum upstreamness for any of the 65 sectors at this level of aggregation fell from 3.76 to 3.19.[14]

Figure 2: Volatility and Upstreamness by Sector Groups



The graph plots upstreamness for U.S. sectors, grouped into primary, manufacturing and tertiary sectors. (Construction and Utilities are omitted from the graph for convenience). The pattern of higher output volatility with upstreamness is observed for all sector groups, with the strongest pattern in primary and manufacturing sectors as expected. Upstreamness is clustered near 1 for the services sectors.

[14]Output data at this level of aggregation is available for 1947 to 2016. The BEA also provides annual input-output table estimates at this aggregated level for the years 1997 to 2016.

Table 13: Output Volatility and Upstreamness: Controls for Input Prices

	Dependent variable:				
	ln(Output Volatility)				
	(1)	(2)	(3)	(4)	(5)
ln(Upstreamness)	0.57***		0.58***	0.36***	0.61***
	(0.17)		(0.17)	(0.10)	(0.15)
ln(Input price volatility)		0.22*	0.22*	0.03	0.05
		(0.13)	(0.12)	(0.06)	(0.05)
ln(Final use volatility)				0.85***	0.77***
				(0.06)	(0.06)
ln(Output)					−0.13**
					(0.06)
ln(Use HHI)				0.18***	0.16**
				(0.05)	(0.07)
ln(Final use share)					0.10**
					(0.04)
Import share					0.87**
					(0.39)
Export share					0.41
					(0.55)
Constant	−3.22***	−2.25***	−2.49***	−0.32	1.45*
	(0.11)	(0.42)	(0.40)	(0.24)	(0.82)
Observations	71	71	71	71	71
R^2	0.14	0.04	0.18	0.82	0.87
Note:			*p<0.1; **p<0.05; ***p<0.01		

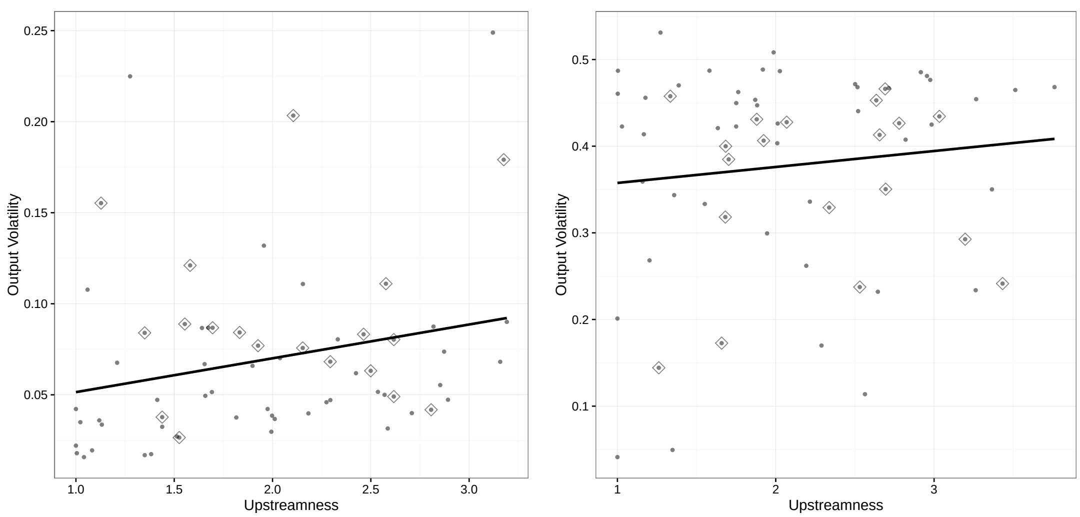
The table shows OLS estimates for output volatility. The variables use the same definition as Table 8, and include input price volatility as an additional control. See text for details.

Table 14: Sectoral Growth vs. Upstream Shocks and Downstream Shocks

	Dependent variable:					
	Output Growth			Quantity Growth		
	(1)	(2)	(3)	(4)	(5)	(6)
Downstream growth	1.13***		0.71***			
	(0.03)		(0.04)			
Upstream growth		0.85***	0.44***			
		(0.02)	(0.03)			
D. quantity growth				1.36***		1.07***
				(0.03)		(0.06)
U. quantity growth					1.03***	0.28***
					(0.03)	(0.05)
U. price growth						−0.01
						(0.04)
D. price growth						0.28***
						(0.04)
Price growth						−0.16***
						(0.04)
Constant	−0.01***	0.004**	−0.01***	−0.01***	−0.005***	−0.01***
	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Observations	1,273	1,349	1,273	1,340	1,420	1,340
R^2	0.59	0.53	0.66	0.54	0.41	0.57
Note:						*p<0.1; **p<0.05; ***p<0.01

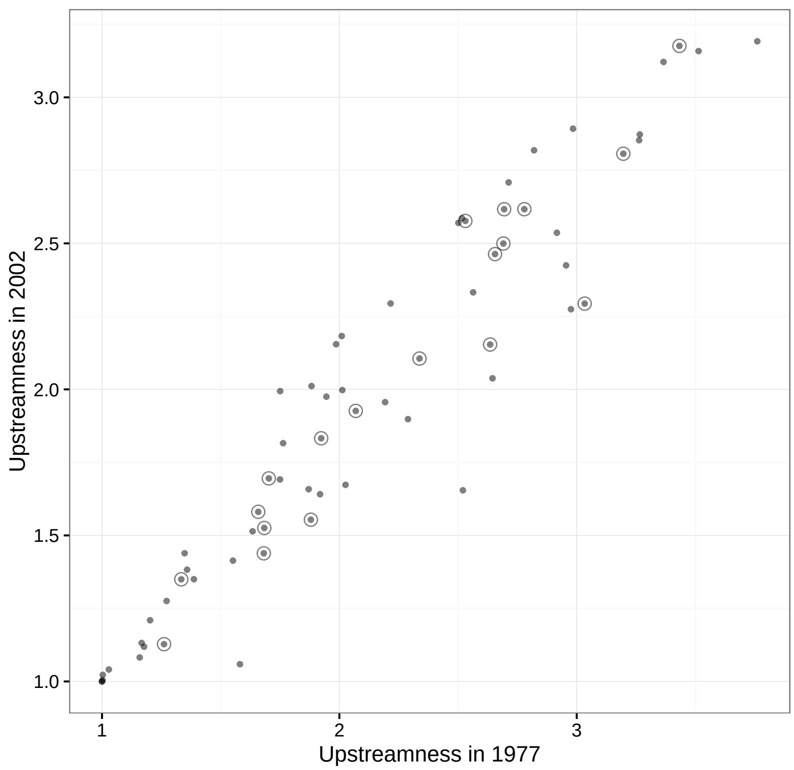
The table show output growth for values and quantities at the sector-year level, with the average growth for each sector's upstream and downstream sectors as control variables. To address concerns about endogeneity, the last three columns of the table use the growth of sector's quantity indexes as the dependent variable, and control for changes in the weighted average quantities and prices of upstream and downstream sectors. U. and D. in the table stand for upstream and downstream.

Figure 3: Sector Volatility and Upstreamness, 1977 and 2002



2002 on the left, 1977 on the right. The graph plots volatility on the vertical axis against upstreamness for all 65 U.S. sectors at the summary level using BEA data, comparing the measures using the 1977 and 2002 benchmark data. Volatility is the standard deviation of year-to-year sectoral output growth and upstreamness is the distance of each sector from final use, as described in Antràs et al. (2012).

Figure 4: Sector Upstreamness in 1977 and 2002



The graph plots upstreamness for all 65 U.S. sectors at the summary level using BEA data. The horizontal axis shows estimates from 1977 IO data, while the y-axis shows upstreamness using 2002 data. Manufacturing sectors are marked with concentric dots.