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The Role of Production Networks in Price Stability

by

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ABSTRACT

Between the pandemic and the war in Iran, inflation has become a central issue facing the US economy that is compounding a broader affordability crisis. However, the sector-specific nature of these recent inflationary episodes means that movements in the price level are not evenly distributed and statistics such as consumer price indexes aggregate away meaningful information. These index movements present inflation as an aggregate process when it can be better understood as a structural feature of the economy facilitated by its production networks. This article builds on a new literature using input-output price models to simulate the relative price movements that result from sector-specific price shocks to demonstrate that inflationary processes entail relative price shifts as both their cause and their consequence. It is argued that these relative price movements begin in systemically significant upstream industries and propagate through production networks to produce differential price outcomes that are not captured by price indexes. The conclusions of this article refine the classification of the systemically significant industries found in Weber et. al (2024a) by clarifying the differential relative price movements from a set of systemically significant industries. The implication of these findings is that monetary policy cannot adequately address the causes of recent inflationary episodes and instead policies that target the structural features of the economy are necessary.

JEL Codes: E31, E52, E62, C67.

Keywords: Inflation; Production Networks; Input-Output Analysis; Relative Prices; Price Stability

INTRODUCTION

The global pandemic triggered the "first inflation problem of the 21st century" and reignited theoretical interest in inflation and price stability (DeLong 2023). Since then, the U.S. has contended with an ongoing affordability crisis, chaotic tariff policies, increased use of AI in pricing, and now a war in Iran, which all suggest that the issue of price stability is here to stay (Kuttner 2025); Dayen (2025)]. While many explanations of the pandemic inflation relied on familiar causes such as excess aggregate demand (Giannone and Primiceri 2024) and tight labor markets (Blanchard and Bernanke 2023), a new approach to modeling inflation informed by the pandemic's supply chains disruptions offers the potential to reorient our understanding of inflation and expand our policy approach. This new literature, following the foundational work of Weber, Lara Jauregui, et al. (2024), takes a "production networks perspective" that disaggregates the causes of inflation and locates them in sector-specific price shocks that propagate through production networks. Input-output models are used to simulate sectoral price shocks and isolate the sectors that create the most significant general price instability. The identification of systemically significant sectors suggests new policies to support price stability that operate outside of the conventional channels of monetary policy, such as commodity buffer stocks or targeted price controls. This article contributes to that literature by extending their disaggregated approach to the analysis of inflationary outcomes to demonstrate the role of relative price changes in the inflationary process.

In nearly all theoretical treatments of inflation, instability in the price level is approximated by the movements in a consumer price index. Similarly, the method introduced in Weber et. al (2024a) for classifying systemically significant sectors is based on aggregating their downstream impacts into a synthetic price index and comparing the index movements to estimate impacts on the price level. However, this approach suffers from the same shortcomings of price indexes generally in that, by design, they aggregate away meaningful information. This paper draws on the distinction between the *price level* and the *price system* and argues that the latter provides a stronger conceptual basis for research on inflation dynamics. This conceptual shift leads to an analysis of sectoral shocks through their disaggregated impacts on relative prices. This approach allows for the identification of transmission pathways in which different price shocks propagate through production networks and create relative price changes. This procedure is demonstrated on three different industries identified as systemically significant in Weber, Lara Jauregui, et al. (2024), and one additional industry missed by the original identification strategy.

The methodological extension proposed here provides two principal benefits over the original results: (1) it gives a more structured approach to analyzing production networks and better identifies the ordering of upstream-downstream relations, and (2) it allows for empirical verification of the price relations predicted by the model by matching the their transmission pathways in the model to their real-world price movements in the Producer Price Index (PPI). Based on this procedure, this paper finds that several sectors experience inflationary conditions that originate from price shocks to raw materials and other upstream industries that drive up the cost structure for final commodities. In particular, the "Petroleum and coal products" sector is found to be the single largest contributor to overall price instability in production networks, followed by "Primary metals" and "Chemical products". These findings have clear policy implications that broadly support and expand on the those advocated by the production networks perspective literature, most notably the use of strategic resource buffer stocks. They also suggest that more research is needed to better understand the relationship between production network vulnerabilities and inflationary outcomes.

The paper proceeds as follows: Section 1 details the theoretical foundations of the price system as an alternative conceptual foundation for studying inflation and the shortcomings of relying on consumer price indexes; Section 2 presents the Leontief Price Model used to simulate sectoral price shocks and addresses the issues with the index method utilized in the model; finally, Section 3 presents the results of the model extension through the disaggregated outcomes of sectoral price shocks and their respective transmission pathways. The paper concludes with a brief discussion of the policies suggested by these results.

SECTION 1: RE-CONCEPTUALIZING INFLATION AND ITS MEASUREMENT

The widespread disruption of supply chains during the pandemic in 2021 and the surge in energy prices from the war in Iran are just two of many possible examples of threats to price stability that arise from sectoral price shocks. In the future, disruptions from climate change in the form of resource shortages and supply bottlenecks are likely to produce many similar scenarios (Semenova 2024). The fact that these factors lie outside of the conventional theoretical explanations of inflation and are unable to be addressed by monetary policy strongly suggests there is a need to develop alternative approaches to price stability. A central argument of this paper is that articulating those policies and their effectiveness requires a new conceptualization of inflation that goes beyond explaining inflation as an aggregated process captured by price indexes.[1] The production networks perspective put forward in Weber, Lara Jauregui, et al. (2024) takes a significant step in this direction by treating sectoral shocks as the main cause of inflation rather than exogenous events, leading to their advocacy for commodity buffer stocks and target price controls. In contrast, the contemporary approach to achieving price stability almost exclusively relies on monetary policy as a means to adjust aggregate demand, even in the case of idiosyncratic price shocks.

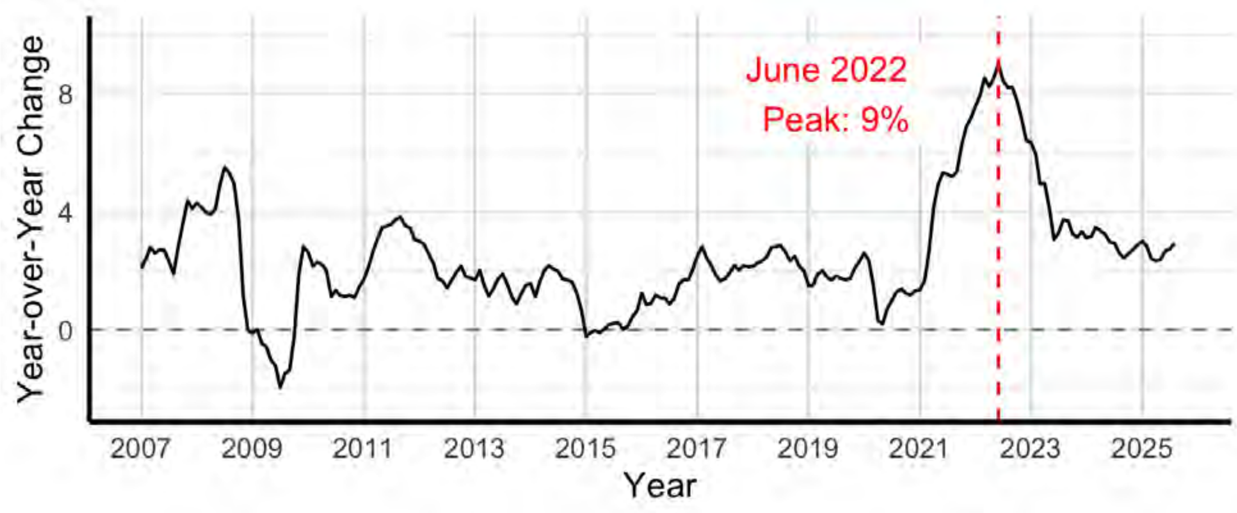
The understanding of inflation justifying the reliance on central banks and monetary policy to produce price stability aligns very closely with New Keynesian theory wherein inflation is caused by a combination of excess capacity utilization and inflation expectations (Galí 2018). This understanding guides the policy response of raising interest rates in an attempt to suppress aggregate demand, and by extension, ease pressure on prices. For this policy to be effective, it requires increasing unemployment to bring it in line to the perceived long-run "neutral" rate, which has the result of suppressing aggregate demand. Inherent to this approach is the idea that a theory of inflation explains its dynamics during a 'normal' state of affairs. However, as suggest by a policy advisor to the Board of Governors, that past half-century history of monetary policy and inflation are severely lacking in episodes that could be described as normal, and rather, good policymaking has always addressed the complexities and nuances of historical episodes (Faust and Leeper 2015).[2] Despite that fact, the contemporary approach as understood by policymakers is broadly guided by generalized lessons from Volcker's response to the inflation crisis of the 1970s and has gone more or less unchanged since then despite the idiosyncrasies of recent years (Powell 2022;

[1] Their critique of aggregate processes is based on the insights of Mitchell (1913) and Leontief ([1986] 2010) rather the MMT and Institutionalist scholars listed here.

[2] The continue doubting the ability of headline statistics to capture these rich and complex events: "Aggregate inflation and real-side dynamics reflect disparate and persistent movements in myriad variables, and the policy implications of these movements are not well captured by two (or any very small number of) conventional summary statistics for headline aggregates" (Faust and Leeper 2015, 2).

Comin et al. 2023). When inflation reached its highest level in decades during the pandemic inflation, many economists resorted to conventional explanations for the surge in prices: large government deficits (Andolfatto and Martin 2025), tight labor markets (Blanchard and Bernanke 2023), or some combination of the two (Lansing 2025; Comin et al. 2023).

Figure 1: U.S Consumer Price Index (Monthly Data)



Within this framework, inflation arising from supply chain disruptions, sectoral shocks, or the potential for isolated resource shortages from climate change, do not systematically factor into either the theory of inflation or the approach policy. However, even before the pandemic inflation some members within the Fed some members have expressed reservations about the sufficiency of the prevailing theoretical explanations of inflation that inform policy. Former Board of Governors member Daniel Tarullo (2017) argues that "we do not, at present, have a theory of inflation dynamics that works sufficiently well to be of use for the business of real-time monetary policy-making." He specifically cites some issue with important considerations for setting monetary policy arising from unobservable variables, some of which are "not data at all, but are instead conceptual constructs" such as potential GDP, the natural rate of unemployment, and the neutral real interest rate (p. 4).[3] This systematic reliance of mainstream inflation theory on unobservable theoretical constructs has itself been the object of heterodox critique since they started being used in policymaking (Papadimitriou and Wray 1994, 2021).

[3]Tarullo (2017) takes particular issue with the notion that inflation expectations play a significant role in determining inflation citing issues with both the myriad of problems involved in the measurement such an ambiguous concept and the lack of a coherent mechanism through which they impact prices (pgs. 10-12).

Beyond the issue of unobservable variables, heterodox economists have been far more critical of this policy approach than the internal reflection of policymakers. Economists working from an MMT and Institutionalist perspective have posed broader critiques based on the ineffectiveness of monetary policy as an instrument for managing the real economy (Fullwiler and Allen 2007), the unethical treatment of labor in the deliberate creation of unemployment (Tcherneva 2010), and the use of an index as an adequate measure of inflation (Papadimitriou and Randall 1996; Wray 1996). These critiques were only amplified by the widespread supply chain disruptions and the resulting inflation beginning in 2021 (Nersisyan and Wray 2022; Tcherneva and Tymoigne 2025). These events led Galbraith (2023) to argue that "the theoretical construct of pure inflation is of no use in understanding the price events of 2021 and 2022 in the United States." Weber, Lara Jauregui, et al. (2024) offer critique on similar grounds taking issue with the "aggregative" conception of inflation that informs policy that takes issue with the treatment of inflation as driven by these unobservable macro variables.[4] As an alternative, they suggest approaching inflation from a "production networks perspective" (p. 299) that centers sectoral price increases and production relations as an alternative causal explanation to aggregate variables.[5]

They model these production relations with an input-output model that captures the cost-push dynamics from increasing input costs that lead to generalized inflationary outcomes. Disaggregating the causes of inflation to the sectoral level allows them to identify sectors that serve as "particular point[s] of vulnerability in a measurable form to identify prices that matter most for inflation" (ibid, p. 300). The inflationary impact of each sector is assessed based on its total contribution to a synthetic consumer price index (CPI), detailed in Section 2. This synthetic CPI is constructed as a weighted aggregate of the downstream price increases in the model. When comparing relative inflation contributions, "the most systemically significant prices are those that have the greatest impact on the general price level defined in terms of the CPI" (ibid, p. 300). This procedure for identifying systemically significant sectors set forth in Weber, Lara Jauregui, et al. (2024)

[4]Their critique of aggregate processes is based on the insights of Mitchell (1913) and Leontief ([1986] 2010) rather the MMT and Institutionalist scholars listed here.

[5]They situate their analysis more in terms of conventional Post-Keynesian conflict inflation following Rowthorn (1977) than the Institutionalist literature, and in some cases contributed to debates among Post-Keynesian debates on the merits of profit-led inflation. They do, however, insist that the relative price analysis of the Institutionalist Wesley Mitchell is a significant motivation.

is now foundational to an emerging literature on the supply-side causes of inflation, sometimes dubbed as the "shockflation" approach (van 't Klooster and Weber 2024). This literature adopts the same model and applies it to a variety of alternative contexts such as identifying systemically significant sectors across the EU (Ferreira et al. 2024), the structure of production networks across the EU (Ipsen et al. 2025), as well as simulating the effects of carbon price shocks in Germany (Weber, Thie, et al. 2024).

The production networks perspective and its modeling strategy is built on the idea that all prices are apart of the same interrelated system, and thus "actual inflation is both a change in relative prices and in the average price level" (Weber, Lara Jauregui, et al. 2024, 299). The historical antecedents of this idea are found in both the work of Leontief and, before that, the insights of the American Institutionalist literature on relative prices. These same foundations motivate this article's argument that movements in index numbers are not the most reliable way to assess inflationary processes or capture the relative price shifts inherent to them. Following Galbraith (2023), it could be argued that the "price level" itself, usually approximated by an index of final consumer prices, is an unreliable basis for conceptualizing inflation. A more suitable alternative is the conception of the *price system* put forward by Mitchell (1913) and Mills (1927). Instead, they define the price system as a concept encompassing a greater array of price relations across all stages of the production process.

Mitchell (1913) is a foundational analysis of the business cycle that established many of the early stylized facts of relative prices that exist in "a bewildering diversity of fluctuations" (p. 94). In this work, Mitchell documents the prevailing system in which all prices are connected to one another. He describes consumer prices as having a "genetic" relationship to one another wherein they are only "loosely connected" via substitution effects but "more closely related to the price for the same goods which shop-keepers pay to wholesale merchants, and the latter to manufacturers" (p. 27-29). In the case of manufacturers, the relation is based on whether those commodities are made of the same materials. In other words, greater than the relationship between similar or different final goods is the relationship between their production processes and what he calls the "series of prices" that exist between the production and final delivery of commodities. This series of prices composes the price system where each part of that series has its own margin by which the price of a good is marked up at each step.

It is based on this conception of the price system and its "endless chain" of relations that the analysis of relative prices takes shape (p. 31). Mitchell (1913) documents how the price system contains a dispersion of relative prices that is generally unstable while the scale of the dispersion at different stages of the process remains relatively consistent. He finds industries that provide raw materials and minerals for production have prices which are far more volatile than those of finished products and much more dependent upon immediate business conditions. This responsiveness to short-term conditions makes them much more reflective of the state of the business cycle than finished products which are subject to rigidities introduced by series of margins in the chain of production (pgs. 96-102). His conclusion that raw materials have much greater levels of price volatility suggests that products early on in the supply chain have greater potential to serve as a source of input cost increases that propagate to downstream industries. The high relative volatility of input costs suggests the existence of some shock-propagation process that originates in the production network and drives the increases in final prices. This process is considered more closely in Section 3.

Frederic Mills (1927) builds on the insights of Mitchell (1913) on relative prices and argues that the movement of "general prices" appears through changes in the established relations of individual prices that compose the index; together, those prices form an elaborate network spanning the economy in a near infinite set of relations. While Mitchell (1913) finds the dispersion of relative prices within an index to be large but stable, Mills argues that changes in general prices drive shifts in the established structure of relative prices. While this appears to be a reversal in causality, Mills uses "general prices" to refer to the movements of the broader business cycle captured by movements across the various stages of production (Ch.1, Section 4). From this perspective, it is the swings in the business cycle that drive shifts in relative prices. Coupled with the insights of Mitchell (1913), the more volatile material inputs to production, moving in sync with the business cycle, provide the initial price increase during the expansion. This dynamic gives rise to price fluctuations that do not affect relative prices evenly over the course of the business cycle and work through the price system with various time lags for different industries and products. This dynamic of upstream cost-shocks followed by propagation through the price system across the business cycles is essentially the underlying mechanism captured by the price model in Weber, Lara Jauregui, et al. (2024), albeit tailored to match specific scenarios rather than business cycle dynamics.

Taken together, Mitchell's analysis of the volatility of raw materials and differential margins in production combined with Mill's description of price divergence across cyclical swings creates a picture of the business cycle in which "smooth and unmistakable cyclical movements are conspicuously absent" (Mills 1927, 77). By extension, both Mitchell (1913) and Mills (1927) describe a price system without fixed price relations and caution against the use of general indexes to meaningfully describe such a system. While both use indexes for the purpose of cursory summary at different stages of the process, frequently combining the analysis of producer prices and consumer goods indexes, the broad price dispersion within each imposes severe restrictions on their interpretation. Mitchell (1913) argues that "to expend much labor in refined elaboration of data subject to a broad margin of error is pedantic" (p. 94). In Mitchell ([1915] 1938), a work specifically addressing the use and interpretation of index numbers, he cautions against broad interpretations of their movements. In particular, he is skeptical of index numbers' ability to accurately reflect changes in the purchasing power of money, a skepticism he extends to universal concepts more generally as the basis for their construction. Instead, indexes apply only to context-specific purposes, with separate metrics for different types of output and stages in the production process (p. 24). Mills (1927) expands these insights and argues that:

> "The conception of prices as a system has been introduced, and the internal structure of this system has become an object of scientific inquiry. *Once the significance of this conception is appreciated, it is clear that no single index number of commodity prices can yield the information concerning the behavior of prices and the shifts in price relations which economists and businessmen require. For many important aspects of price behavior quite elude measurement by such an index*" (p. 218, emphasis added).

In the analysis of both figures, individual index numbers are improperly suited to demonstrate the necessary information about relative price movements within them.

These works are instructive for the present issues of describing inflation as arising from the cost structure in production networks. Today it is an unspoken convention to treat movements of a consumer price index as reflecting inflation conditions, so much so that the two are often treated as synonymous. The notion of the 'price level' itself as the object of measurement is inadequate and leads to a false equivalence that inherently treats final consumer prices as a reasonable approximation of more complicated set of relations. In reality, the vast network of interrelated prices across the economy consists of shifting relative prices, each moving according to their own conditions of production. Taking seriously the complexity of the price system and its implications for empirical study suggests that treating the outcomes of price shocks in a similarly disaggregated way can prove instructive. The shock-propagation structure of the model presented in Weber, Lara Jauregui, et al. (2024) makes a novel and insightful contribution to studying the disaggregated origins of cost shocks and inflation, but the assessment of those disaggregated cost shocks based on their aggregated effects places limitations on the results.

In the next section, the price model and method of impact assessment is described in more detail, which is followed by a demonstration of the analytic benefits of disaggregation analysis on the conception of price system rather than a price level.

SECTION 2: THE LEONTIEF PRICE MODEL & THE ORIGINAL FINDINGS

This section details the input-output price model and the method of assessing inflationary impacts as put forth in Weber, Lara Jauregui, et al. (2024) and utilized throughout the shockflation literature. While innovative in its treatment of inflation's causes, the arguments outlined in Section 1 suggest that the way their model measures inflation by approximating index movements can be improved. Those improvements are detailed in section 3. The structure of this model defines the cost of output in a cost-of-production approach that allows for the simulation of cost-push price dynamics based on the technical relations of production at a given point in time.[6] The specifica-

[6]The model as specified in Weber, Lara Jauregui, et al. (2024) uses data at 71 industry level from the 2019 input-output accounts to capture the technical relations prior to their disruption by the pandemic. The 2019 technical relations are used to test the sectors that had the largest impact during the post-pandemic price increases. All cost increases in the base model assume complete cost passthrough to output prices, while other extensions in the model

tion in Weber, Lara Jauregui, et al. (2024) divides industries into two groups of exogenous and endogenous industries. The industries set as permanently exogenous are those that the authors argue have prices better captured by supply and demand conditions rather than the cost of production, as well as rent-extraction industries such as finance, insurance, and real estate.[7] As each industry is individually shocked, it is set as exogenous and the downstream price changes for endogenous industries is determined by the core equation:

$$\Delta P_E = (I - A'_{EE})^{-1} A'_{XE} \Delta P_X$$

In this equation, P_E and P_X are the respective price vectors for endogenous and exogenous industries where $(I - A'_{EE})^{-1}$ is the Leontief Inverse capturing total input requirements of endogenous industries from endogenous industries and A'_{XE} is the direct input requirements of endogenous industries from exogenous industries. The derivation of this equation, as well as the full list of exogenous and endogenous industries, are detailed in Appendix A.1 and A.4. The total inflationary impact of each industry is determined by the price shock and the resulting change in output prices for the endogenous industries. These effects are aggregated into a synthetic price index by weighting each industry's price change by the ratio of consumption expenditures on its output over total consumer expenditures.

Within this setup there are three factors that determine a sectors' total inflation impact, which are "the size of the price shock, the extent to which the shocked industry's output is used as direct and indirect inputs throughout the economy, and the weights of the affected industries in consumers' baskets as captured by the synthetic CPI" (p. 304). The first factor, the size of the price shock, is determined by each industry's *sectoral price volatility* defined as the standard deviation of its average annual output price change from 2001 to 2019. This is the price shock used in their

in their paper capture conflict tensions between wages and prices. The latter aren't considered in this paper.

[7] They draw on Kaldor (1985) and Kalecki (1956) in specifying exogenous industries as rent extraction industries in finances, insurance, and real estate; they also include raw material extraction such as mining, as well as commodity markets with the justification that they function more like auction markets determined by supply or demand conditions more than direct reliance on costs. While raw material costs are important considerations for price shocks in this paper, the extensions to their model still rely on this specification for the purposes of demonstrating the unexplained relative price movements in their results.

base model and is the model used for analysis in this paper, while alternative models change the shock value to match alternative scenarios. The second factor is the use of an industry's output as direct and indirect inputs to production captured by the technical coefficients matrices, A_{EE} and A_{XE}. A price shock to one industry creates a direct increase in costs for those using its output and an indirect cost on those industries further down the production chain that purchase output from the impacted industries. The third factor is the relative weights of the impacted industries in the synthetic price index. This index weight is defined by the ratio of an industry's output consumed in final demand over total final output demand. The change in the endogenous industry price vector, P_E, is summed together by multiplying each element by its respective weight.

These three pieces are used to assess the direct and indirect effects of each sector as they are individually shocked. The *direct impact* of a sector is the size of its price shock multiplied by its consumption weight and represents the direct contribution of the price shock to the movement of a price index. The *indirect impact* is the effect of the shock on all downstream industries aggregated together through their relative weights and represents the movements of all of the other industries in the CPI resulting from the shock. The two inflation impacts together create the total inflation impact of an industry that is used to classify "systemically significant" industry in U.S . The larger the total impact, the more latent systemic significant the price contains.[8] The equations defining these direct and indirect impacts that compose the synthetic CPI are:

$$IP_{dir} = c_x \Delta P_x$$

$$IP_{ind} = \sum_{i \neq x} c_i \Delta P_E^i$$

$$IP_{tot} = \sum_{i \neq x} c_i \Delta P_E^i + c_x \Delta P_x$$

[8]In the original paper, the output of the model using sectoral price volatilities as the shock is compared to the results using price shocks from alternative scenarios found in the pandemic and the war in Ukraine.

where c_x is the consumption share weight, IP_{DIR} is the direct impact, IP_{IND} is the indirect impact, and IP_{TOT} is the total impact as the sum of the two.

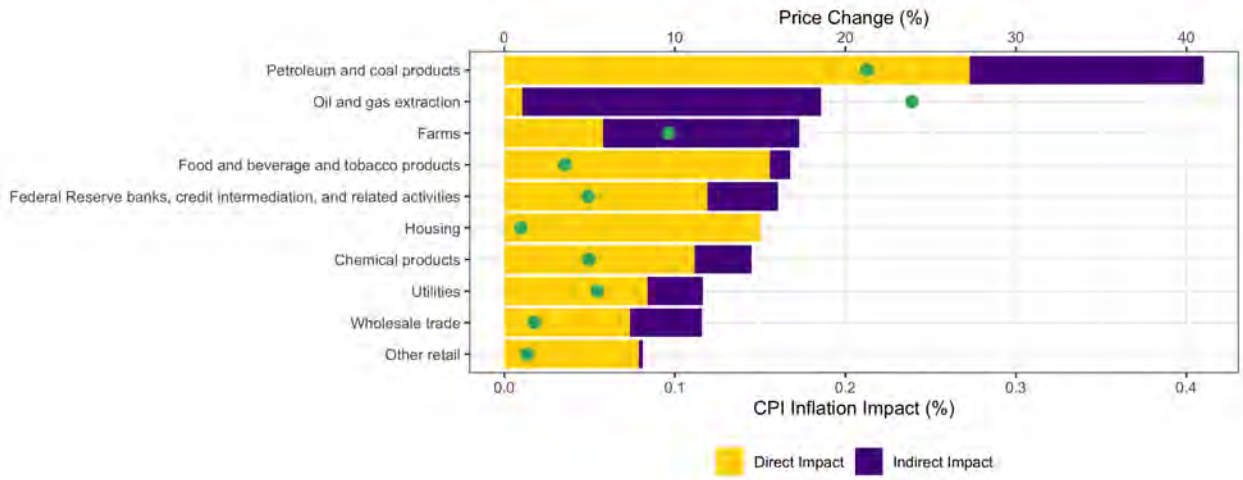
Weber, Lara Jauregui, et al. (2024) use this model to identify 8 systemically significant sectors in the U.S economy. Table 1 below depicts each of these industries and the associated components that determine their systemic significance and Figure 2 is a replication of the results from their base model. The results in Figure 2 show the combination of direct and indirect effects for the top 10 industries to compare their total impacts on the synthetic CPI and demonstrate how relative price movements can create generalized inflation. However, following the arguments laid out in section 1, the price model can also be used to analyze how each industry produces relative prices shifts in the impacted industries based on their technical relations (Miller and Blair 2013). The aggregation of these relative price changes into a synthetic index creates two main problems for understanding the impacts of the sectoral shocks: (1) a significant portion of their results are driven by the direct impact, which does not capture any systemic character of the price shock, and (2) it aggregates meaningful information into the indirect impacts. Moving to a disaggregated approach to inflation assessment centered around the identification of production networks resolves both of these problems.

Table 1: Systemically Significant Industries

Industry	**Price Shock**	**Direct Impact**	**Indirect Impact**	**Index Weight**
Petroleum and coal products	21.26%	0.273	0.137	1.33
Oil and gas extraction	23.89%	0.011	0.175	0.00
Farms	9.65%	0.058	0.115	0.54
Food and beverage and tobacco products	3.57%	0.156	0.012	4.28
Housing	0.98%	0.150	0.000	15.29
Chemical products	4.96%	0.112	0.033	2.03
Utilities	5.45%	0.084	0.032	1.97
Wholesale trade	1.77%	0.074	0.042	4.17

The first problem regards the contribution of the direct impact for most industries. The two components used to compute the direct impact, the sectoral price volatility and its consumption share, do not capture the systemic character of these industries and rather reflect the relative role of their output in consumer goods. While this information may be useful when considering the impact on household budgets, it does not capture the role of the industry in creating generalized disrup-

Figure 2: Base Model Original Results

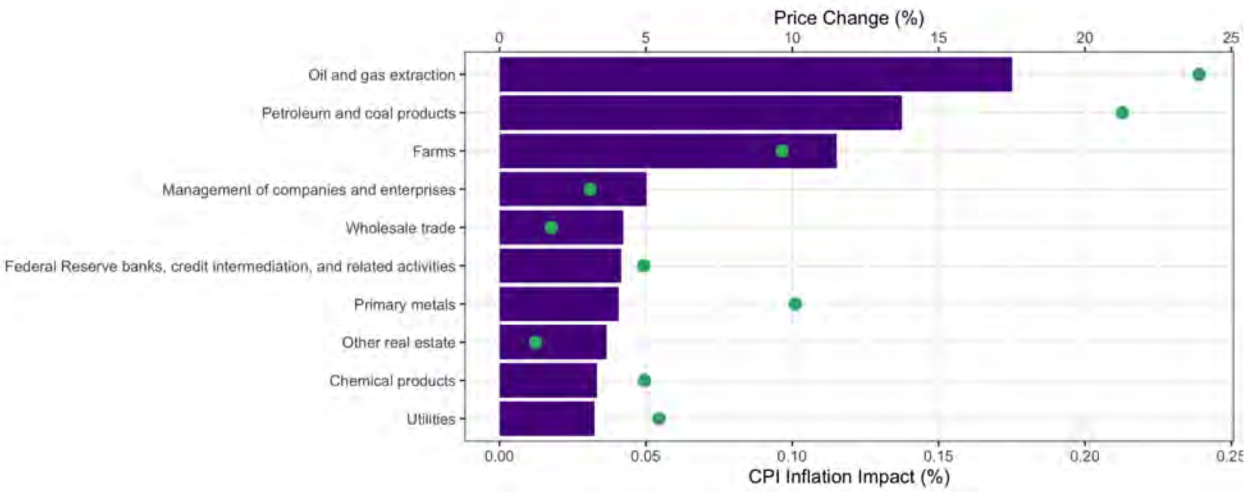


tions in the price system nor how that disruption creates relative price shifts. Due to the large role of these direct impacts, industries which play a significant role in production but do not service consumers directly do not register as having a latent systemic significance. Taking the "Housing" industry as an example demonstrates this point more clearly.

The inflation impact of the "Housing" industry is entirely direct because the industry does not produce output and thus plays no role as an input for any other industries. In other words, it cannot be a common production input because the industry has no output. This does not mean housing is not a significant portion of household budgets, but instead means that it cannot provide insights into systemic significance from a production networks perspective. Weber, Lara Jauregui, et al. (2024) do acknowledge this fact and draw attention to it through the juxtaposition of "Housing" with "Oil and gas extraction" (p. 310) to demonstrate the different channels of systemic significance. However, this does not resolve the issue that for all other systemically significant industries outside of "Oil and gas extraction", the direct effects drive a significant portion of the results. Even for industries which could more clearly be systemically significant under that indirect impact channel, such as "Wholesale Trade" or "Utilities", more than half of their inflation impact does not reflect their systemic character.

When only reporting the inflation impact of the indirect channel directly, there is a slight change in the results, particularly outside of the most significant industries. Figure 3 below replicates the same output from the base model after omitting the direct impact component.

Figure 3: Base Model Results - Indirect Effects Only



Two new industries appear near the top of the results: "Management of companies and enterprises" and "Primary Metals". The latter is understood as an important primary input to production process and the argument is made section 3 that it should be considered systemically significant. The observations of Mitchell (1913) still hold true today that input costs tend to be more volatile than final goods as "Primary metals" has the third largest sectoral price volatility in the group. "Management of companies and enterprises", however, represents a ubiquitous input to the management of large firms and represents an industry dominated mostly by its labor input into those firms in occupations dealing with accounting, financial management, and operations managers. It is important to acknowledge that the results do not significantly change the overall finding of industries, but leaving out the direct effects does slightly shift their relative impacts and places the emphasis more directly on the production relations.

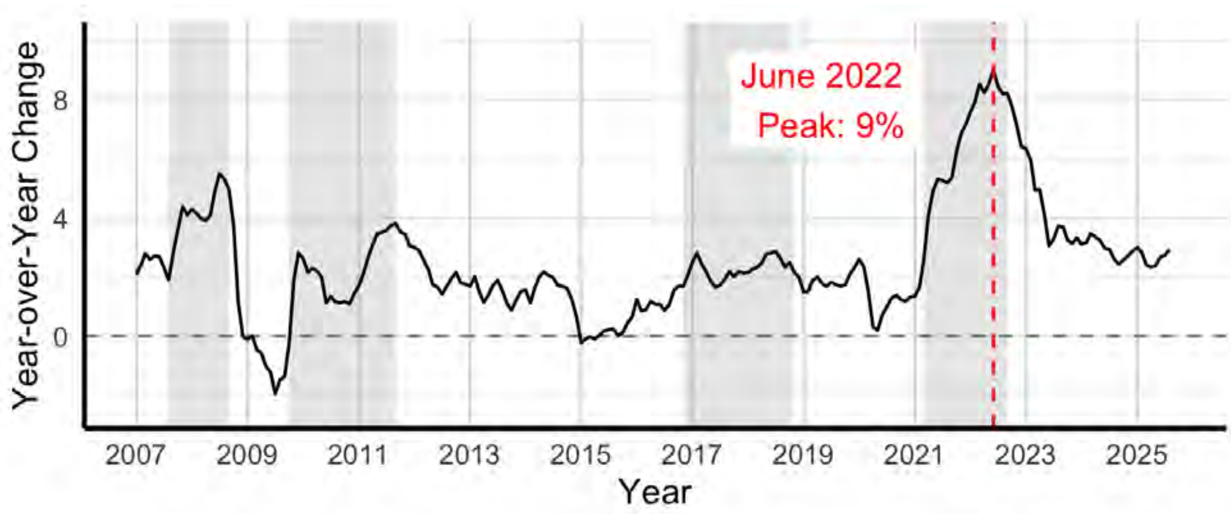
The second problem is similar to the first in that the indirect effects also use the weighted consumption shares but apply them to all of the endogenously effected industries to aggregate their impact. Building on the arguments of Mitchell ([1915] 1938) and Mills (1927), this paper argues that incorporating these weights throughout the aggregated results to approximate a consumer price index cannot capture the effect of these price shocks on production networks. The construction of an index, by design, aggregates away information into a single summary statistic. When the object of analysis is production networks themselves, the valuable information is not just in the total size of the effect but also the *composition* of that effect. For the model extensions offered in this paper, the specific *transmission pathways* through which an industry's price shock creates general price stability is the primary information used for analysis. Specifying these transmission pathways allows for the classifications of industries as systemic based on the composition of their impact on downstream industries and the pathways through which that impact occurs. Section 3 presents the identification of the transmission pathways directly and connects them to patterns in production price data.

SECTION 3: IDENTIFYING TRANSMISSION PATHWAYS IN PRODUCTION NETWORKS

This Section presents the disaggregated output of the base model described above and uses that information to identify the transmission pathways that facilitate the propagation of price shocks. The output of the model detailed in Section 2 is modified to produce these disaggregated by solving for endogenous prices using the power series approximation specified in Miller and Blair (2013). Details on this procedure can be found in Appendix A.2. Identifying these transmission pathways presents three benefits: (1) they shows which individual pathways are the most significant for price stability; (2) they reveal the shifts in relative prices that results from a sector-specific shocks shock; and (3) they allow for the pattern of price increases predicted by the input-output analysis to be cross referenced to production price data in the corresponding subseries of the Producer Price Index (PPI). These benefits are explored through three examples using various sectors identified as systemically significant in Weber, Lara Jauregui, et al. (2024) while also providing evidence that the price of "Primary metals" should be included as a systemically significant. After establishing these findings, this section concludes with a discussion of the policy implications of these findings showing how they support the case for using of strategic resource buffer stocks as suggested in van 't Klooster and Weber (2024), Weber, Thie, et al. (2024), and Weber, Lara Jauregui, et al. (2024) but also allow for the identification of refined policy targets that give necessary depth to the policy proposal.

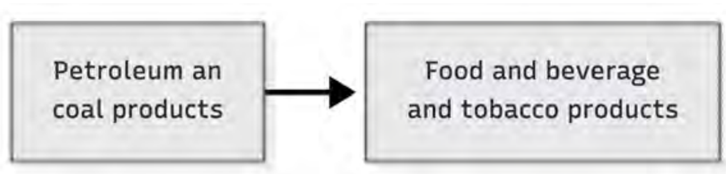
Figure 4 below highlights four different periods where the disaggregated results show upstream cost-shocks propagated through production networks. These four periods correspond to the breakout of the global financial crisis, a two-year period in the aftermath of the crisis beginning in late 2009 through 2011, a brief inflationary period running from 2017-2019, and finally the pandemic inflation starting in March 2023 that is the main episode being considered. In many of the examples that follow, the peak of the price index at 9 percent during June 2022 during the pandemic inflation is demarcated by a horizontal red line and is presented as a basis for comparison to when production prices peaked in many industries. While none of the first three reached the level of severity found in the pandemic inflation, highlighting all four scenarios creates a holistic depiction with many of the processes being present in periods prior to the pandemic.

Figure 4: U.S Consumer Price Index (Monthly Data)



Presenting the disaggregated results entails a redefinition of direct and indirect impacts according to the proximity of the shock impact. A *direct effect* is now defined as the result of a direct reliance on inputs from the shocked sector. Figure 5 below demonstrates the transmission of a direct effect from "Petroleum and coal products" on "Truck transportation" that is based on the direct use of its input for its production:

Figure 5: Direct Effects



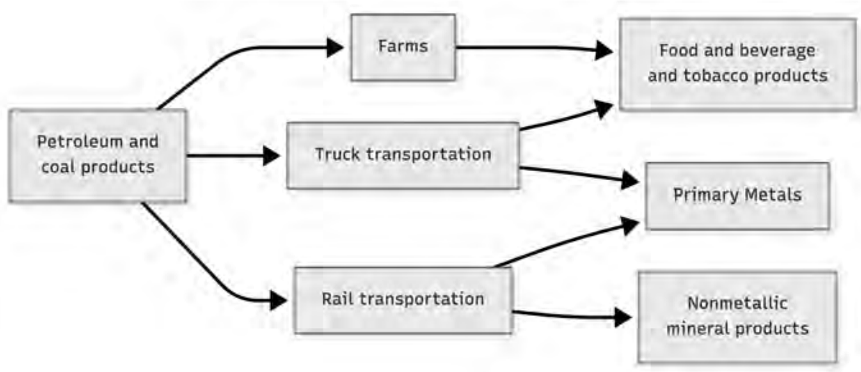
Indirect effects are now only the impacts on downstream industries that happen through other industries. In the original definition, indirect impacts contained the immediate relation between two industries that is now only captured by the direct effect. For example, a shock to "Petroleum and coal products" has an indirect effect on "Food and beverage and tobacco products" that happens *through* the effect on "Truck transportation." This is represented by a slightly longer chain of effects such as:

Figure 6: Direct and Indirect Effects

The presence of these indirect effects does not exclude the direct effect of "Petroleum and coal products" on "Food and beverage and tobacco products" but happens in addition to it. These transmission pathways can be built up into more complex pathways based on the strength of direct effects, revealing those industries with the greatest relative price shifts. Figure 7 presents an example of these more complex pathways.

Once established, the direct transmission pathways identified in these examples are compared to the price trends in closely related industries in subseries of the Producer Price Index (PPI). This exercise is used to confirm the input-cost dependence between industries predicted by the IO shock simulation.

Figure 7: Complex Transmission Pathways

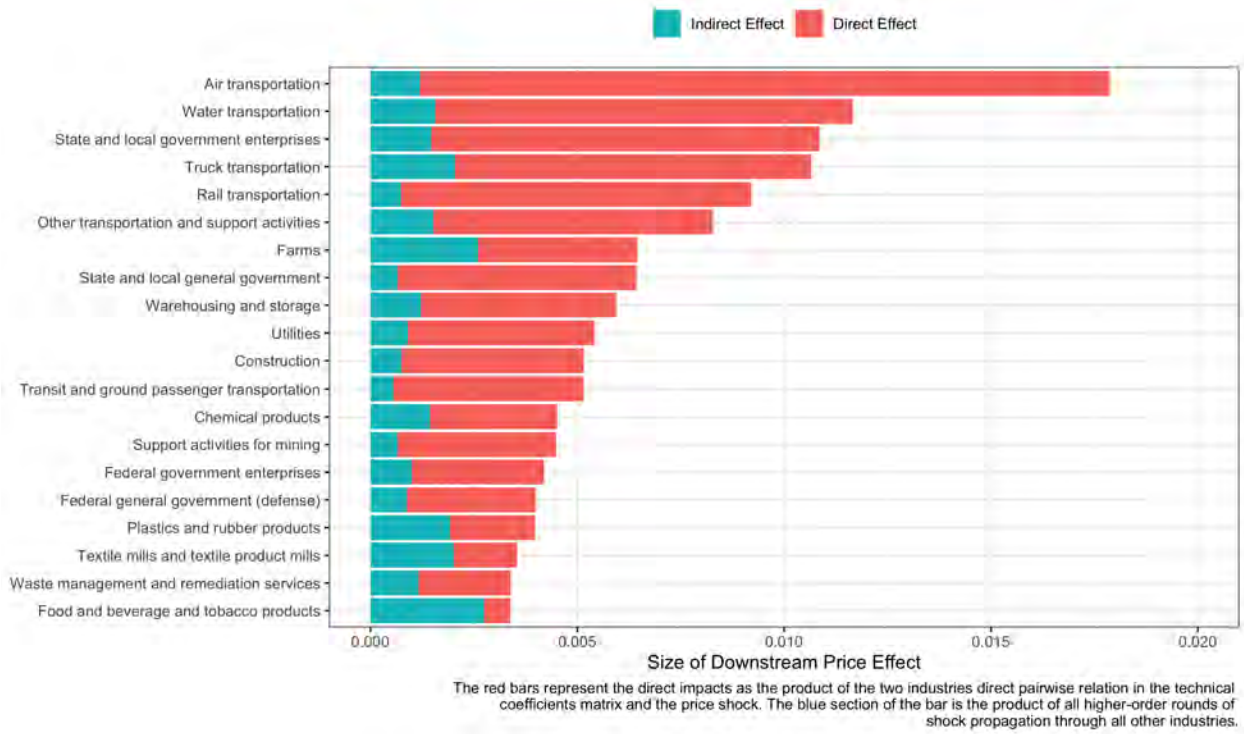


Starting with "Petroleum and coal products" makes a straightforward case due to its large and direct impacts on a set of closely related industries. In the results below, the price shock is set following the base model specification in Weber et. al (2024a) using its average volatility over the period from 2000-2019. Figure 8 below depicts the results of a shock as appeared in the original model with the interindustry price increases represented by the purple section of the bar. Figure 8 depicts the relative price changes to the top 20 downstream industries that is aggregated away in the original results, as well as the relative proximity of those impacts as measured by the direct and indirect effects. The x-axis represents the percent increase of that industry's price as a result of the shock assuming a full cost pass-through. If the price shock were increased to match some specific inflationary scenario, as done in Weber, Lara Jauregui, et al. (2024), the magnitude of the price changes would increase while the order of the impacted industries would remain the same.

Figure 8: Aggregated Results for Petroleum and Coal Products

Figure 9 shows that a price shock to "Petroleum and coal products" has fairly predictable impacts, producing large relative effects on transportation and energy dependent industries. This is similar to the observation of the close relation this industry has with "Oil and gas extraction" in Weber, Lara Jauregui, et al. (2024), but differs in both degree and number of downstream connections.

Figure 9: Price Shock to Petroleum and Coal Products

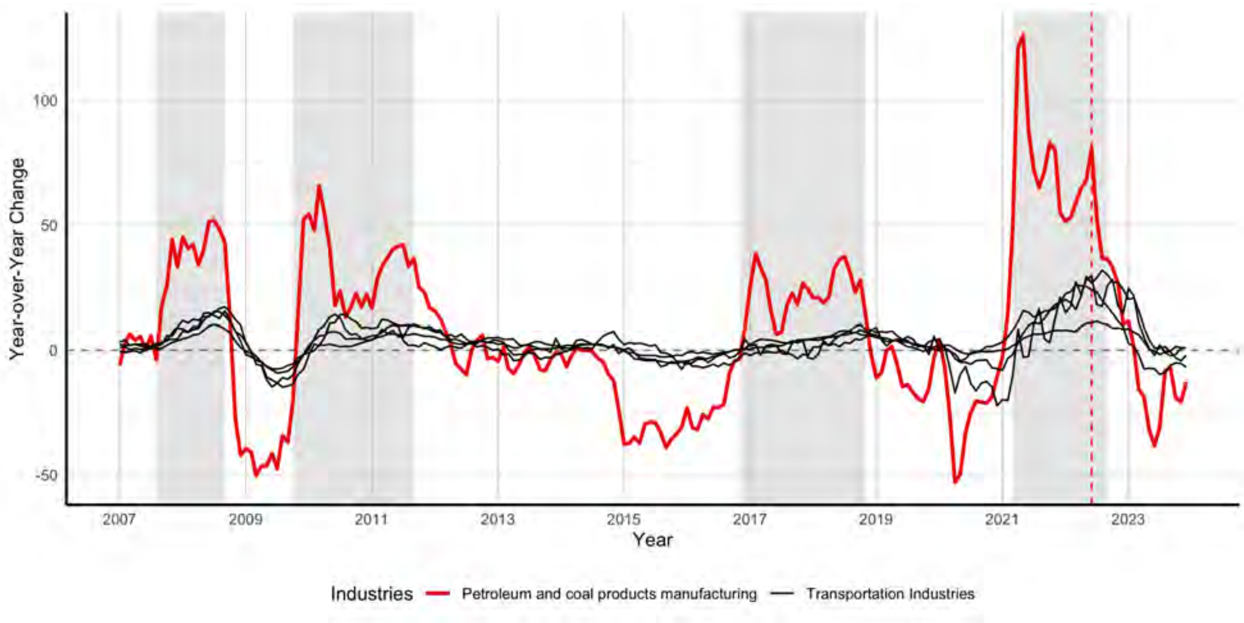


Outside of those top six, the next most affected industry is “Farms”, most likely due to fertilizers that are derived from petroleum and the operation of farm equipment. Two other systemically significant industries, “Utilities” and “Chemical products”, also appear near the top of the list.

The large direct dependence of transportation sectors on inputs from “Petroleum and coal products” captured in the results of the IO simulation can be directly seen in their real output prices. Figure 10 depicts the producer prices from the related industries in their respective subseries data from the Producer Price Index (PPI). Simple inspection shows that price shocks to petroleum and coal product manufacturing produced gradually increasing prices on four different transportation industries. Those industries covering water, air, rail and truck transportation and all move together following oil price shocks very closely. While these results themselves are predictable and unsurprising, it shows a pattern of price increases based on the input dependency predicted by the IO model.

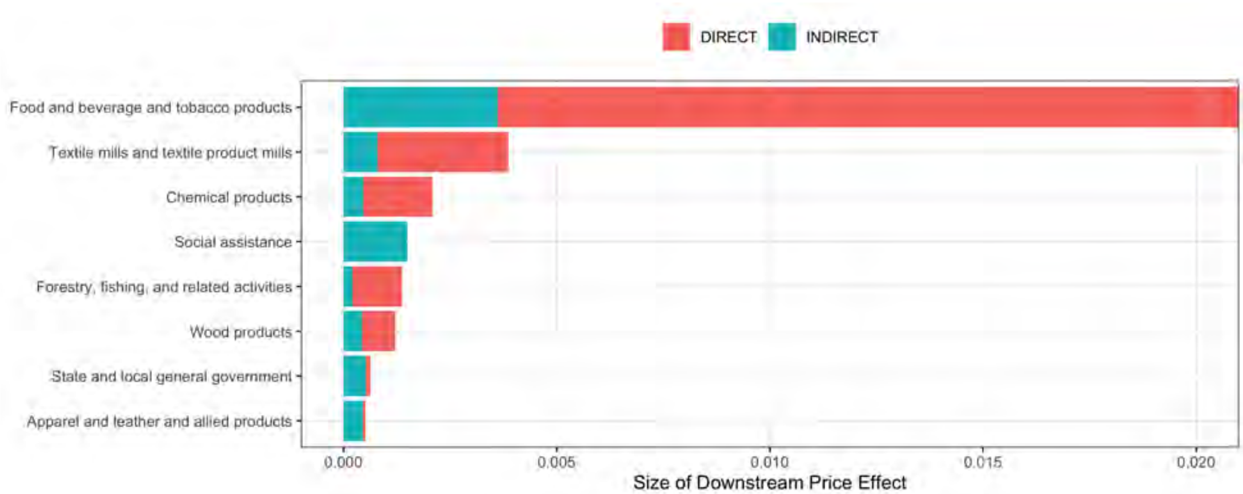
This example shows that, in some cases, the indirect effects can also be significant. Further down the list of impacted industries in Figure 9 is “Food and beverage and tobacco products” which

Figure 10: Output Prices of Petroleum and Transportation Industries



has a higher indirect portion relative to most industries, meaning that nearly all of the impact is happening *through* other industries. Following intuition, Figure 11 below represents a shock to "Farms" with "Food and beverage and tobacco products" being the most affected industry due to their obvious direct relationship.

Figure 11: Price Shock to Farms



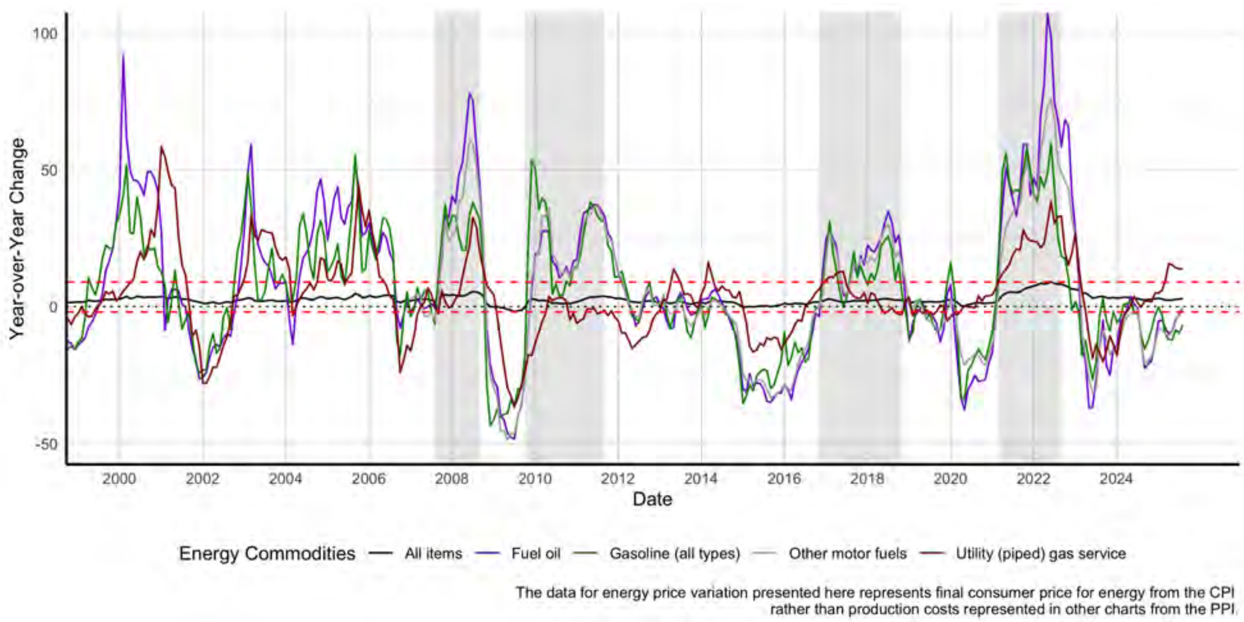
A large and direct effect also occurs in the relations between "Oil and gas extraction" and "Petroleum and coal products" as acknowledged above but to an even more extreme degree. Out of these general relations arises a much fuller picture of the relationship between industries in production networks. If we were to follow these shocks out further we would get increasingly complex transmission pathways.

These direct price relations between specific industries revealed by the disaggregation can be extracted from the price shocks to each industry and compared to show the strongest price-dependencies in the economy. Table 2 below shows the 10 highest individual cost-shock pathways that result from the base model simulations. Out of the top 10, downstream impacts resulting from “Petroleum and coal products” make up five of them, with a sixth coming from the large direct impact of “Oil and gas extraction” on its own price. When extended to the top 50 downstream impacts, it makes up 18 of them, three times the number of the next most common industry. Petroleum and coal product price shocks exhibit such a large impact not just because of the direct dependence of so many industries on it for inputs, but also because petroleum, alongside other energy sectors, is one of the most volatile prices in the economy. Figure 12 below compares the year-over-year change of various energy prices in monthly data compared to the change in the overall CPI, with two red bands marking the highest and lowest value of the CPI during the period.

Table 2: Strongest Cost Pass-through Relations

Industry Shock	**Price Shock**	**Impacted Industry**	**Price Change**
Oil and gas extraction	24.2%	Petroleum and coal products	6.08%
Farms	9.5%	Food and beverage and tobacco products	1.92%
Petroleum and coal products	21.2%	Air transportation	1.68%
Primary metals	10.1%	Fabricated metal products	1.60%
Petroleum and coal products	21.2%	Water transportation	1.00%
Petroleum and coal products	21.2%	State and local government enterprises	0.94%
Chemical products	5.0%	Plastics and rubber products	0.92%
Petroleum and coal products	21.2%	Truck transportation	0.86%
Petroleum and coal products	21.2%	Rail transportation	0.84%
Primary metals	10.1%	Electrical equipment, appliances, and components	0.82%

Figure 12: Energy Commodities Price Variation Relative to CPI (Monthly Data)

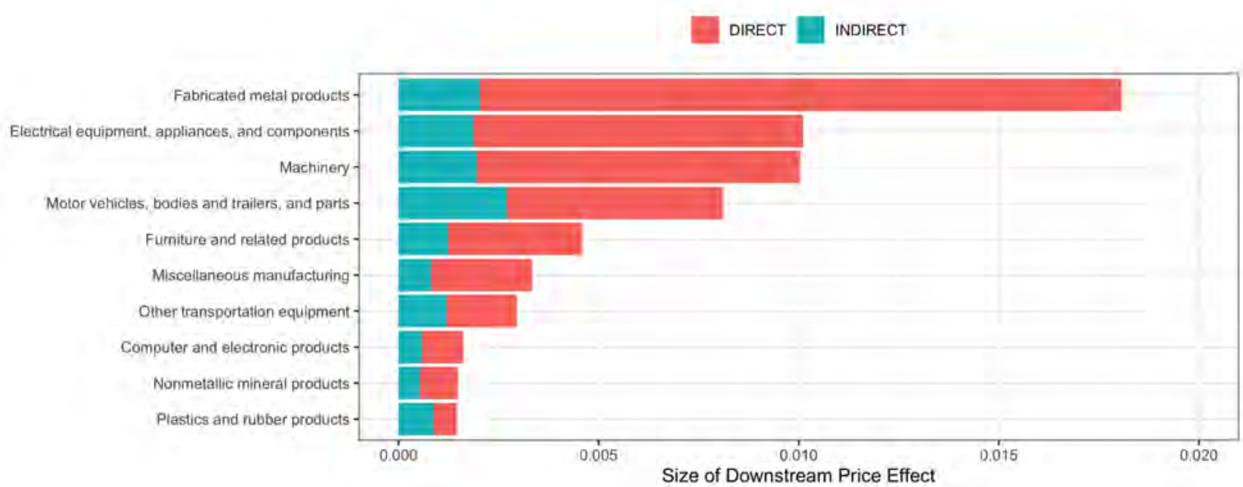


These prices have fluctuations several times greater than that of the CPI, reaching high peaks that are at times over 50 percent year-over-year change while oil occasionally nears 100 percent. While it is predictable that their fluctuations would be greater than the overall index, the size of these spikes in light of the results above further emphasizes the disruptions they create in production networks. In typical analyses of inflation, both in policymaking and in conventional theory, there is an understanding that monetary policy will not have a meaningful impact on these prices and due to this fact, combined with their extreme volatility, they are excluded along with food in core measures of inflation. However, the results of the input-output simulations demonstrate that removing them from the index cannot meaningfully isolate these price movements from their impact on downstream prices.

It is important to note that these volatile price swings seen in energy prices become more asymmetric as they move through production networks, meaning that while large oil price increases are at some point followed by large decreases, the same is not true of the industries that are impacted by the price shock. Although transportation sectors do exhibit small price declines, they are both more infrequent and of a much smaller magnitude than their price increases from the shock to petroleum products. While the original price shock may dissipate and be partially reversed, its effects become embedded into the cost structure. In the context of the regularity and magnitude of petroleum price shocks, this appears to exhibit regular upward pressure on prices with no meaningful policies to mitigate it. These findings both support and refine the results established in Weber, Lara Jauregui, et al. (2024) that petroleum products, and energy prices in general, are the most significant contributors to price instability in the economy.

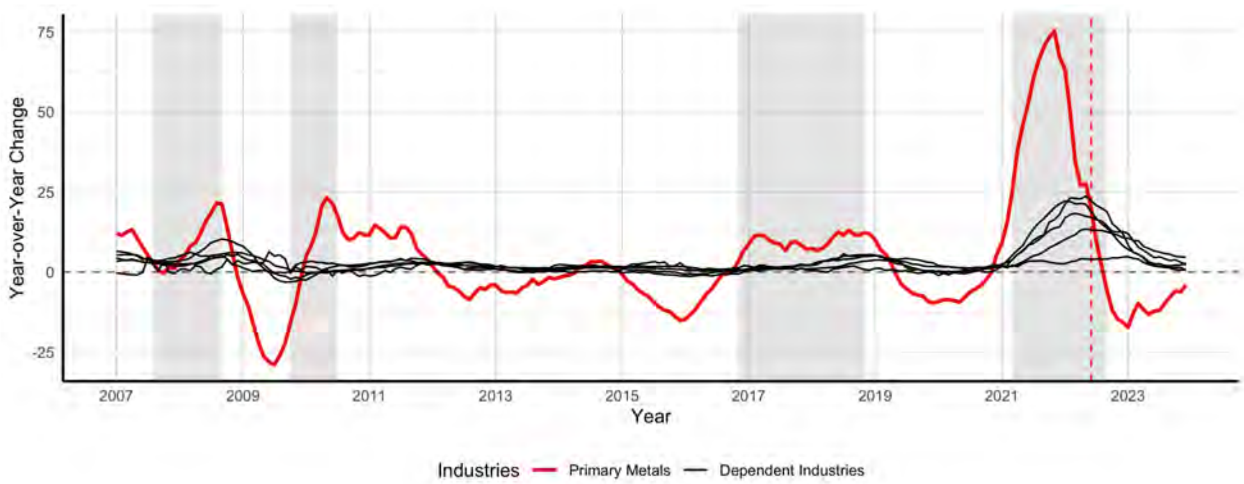
Second to petroleum and coal product among the top transmission pathways of price shocks is the price of “Primary metals”. “Primary metals” appears twice in the top 10 but, unlike “Petroleum and coal products”, was not among the industries designated as systemically significant by the original model. Out of the top 50 impacts, primary metals appears 6 times, the second most next to petroleum products. This industry did not register as systemically significant in the aggregated results due to its extremely small share in final demand expenditures. Despite this, when considering only its indirect impacts from the original results shown in Figure 3, it appeared as the 7th most impactful industry. This is due to its large role in providing direct inputs for production for several important industries. Figure 13 below shows the disaggregated results of a shock to primary metals.

Figure 13: Price Shock to Primary Metals



There are 4 main industries that experience large price pressures from increasing primary metal costs: “Fabricated metal products”, “Electrical equipment, appliances, and components”, “Machinery”, and “Motor vehicles, bodies, trailers, and parts”. Repeating the procedure from above, Figure 14 below presents the subseries of those affected industries with the same pattern found above: a price shock to primary metals is regularly followed by production price increases in those industries.

Figure 14: Price Shock to Primary Metals



The trend across all four of the specified inflationary periods preceded the peak of the CPI during the pandemic inflation.

The third most frequent industry in the top 50 strongest connections is "Chemical products", appearing 4 times (tied with Oil and gas extraction). Figure 15 below shows the disaggregated result of a price shock to chemical products. The top four industries impacted by a shock to chemical products are: "Plastics and rubber products", "Textile mills and textile product mills", "Petroleum and coal products", and "Farms". While Petroleum and coal products is unlikely to be significantly driven by the cost of chemical products (its price spikes usually precedes spikes in chemical products), and farm products are not captured in the PPI, the remaining two industries do generally exhibit the same established trend, albeit with much shorter lag times.

All three of these industries serve as primary inputs early on in their relative production networks that spike first and produce price increases in dependent industries. For "Petroleum and coal products" and "Primary metals", they both exhibit a price volatility both positive and negative that is not mirrored in the dependent industries. The implication of this is the same as described above: each price shock becomes embedded into the cost structure of production and is not mitigated by later price declines to match its own.

Figure 15: Price Shock to Chemical Products

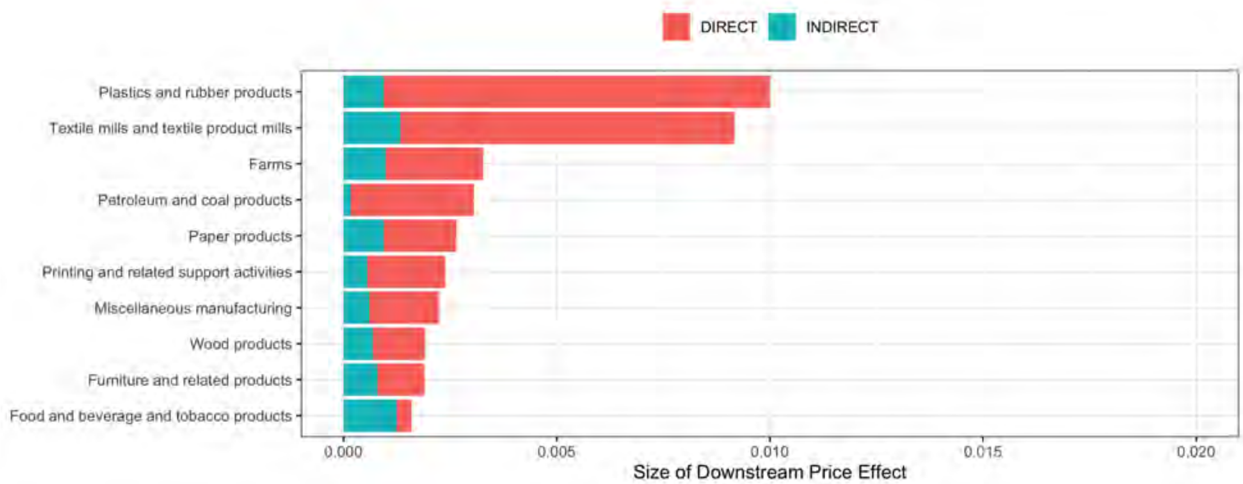
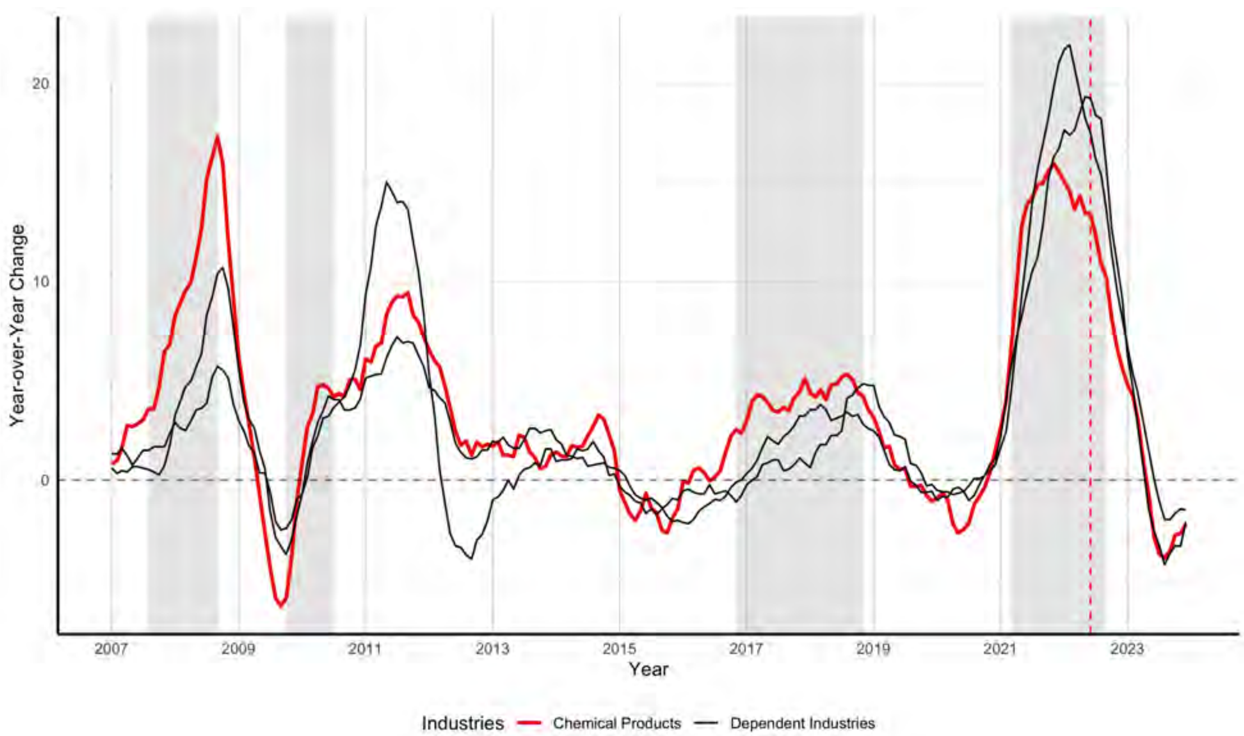


Figure 16: Chemicals products and downstream industries



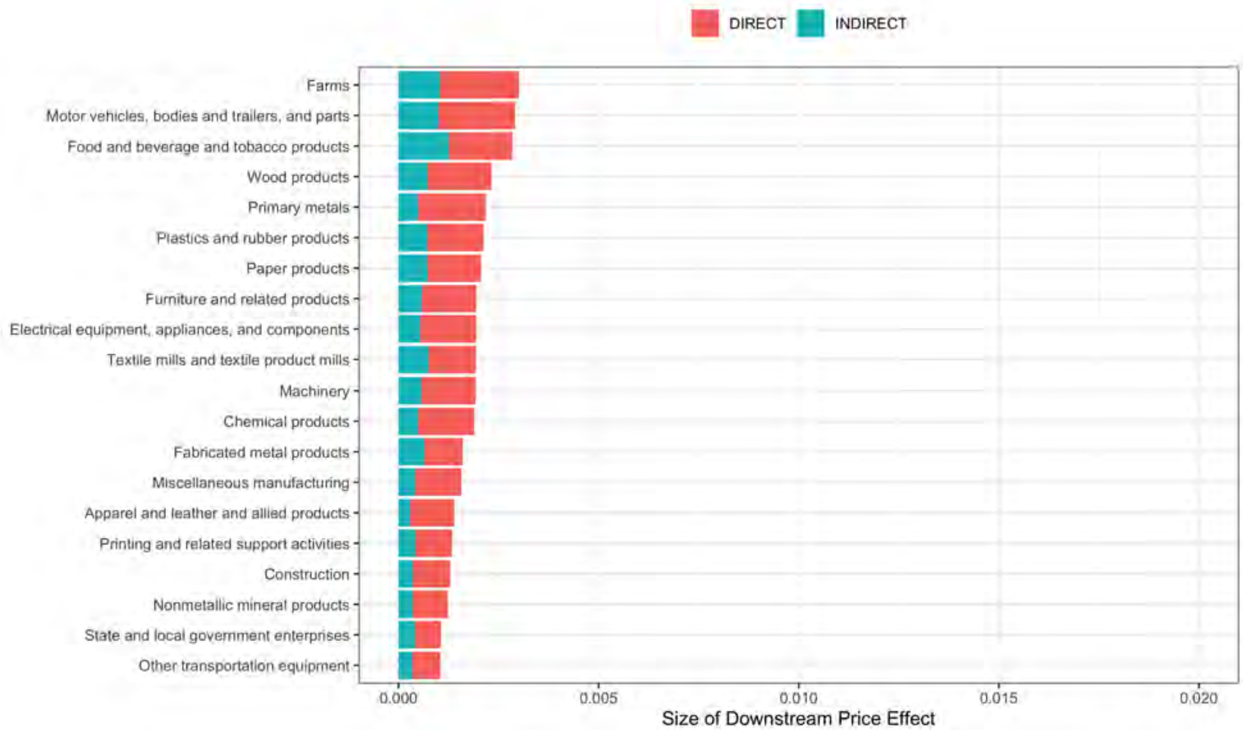
Moving on to the final industry under consideration, "Wholesale trade" presents a comparatively more complex example than those presented above but that complexity also raises additional points of interest, particularly for the pandemic inflation. As originally described in Weber, Lara Jauregui, et al. (2024), the sectoral price volatility of wholesale trade is much lower and more stable than other industries, at least at the current level of aggregation. Despite the relatively small magnitude of the price shocks, it still registers as systemically significant due to its services being a direct input to many different industries. However, unlike the industries discussed above, "Wholesale trade" does not provide a common production input but rather a common intermediary role. This difference in the character of its relations to other industries raises the issue of whether "Wholesale trade" should be treated as a distinct industry on its own versus an intermediary part of the production network of other industries. The practical consequence of this distinction is that, rather than originating price shocks, wholesale trade may propagate price shocks from other industries further upstream in those networks in a similar way to the schema suggested in Weber and Wasner (2023).

Figure 17 below shows the disaggregated results of a shock to wholesale trade. It has a much smaller but relatively more evenly distributed impact when compared to the other industries being discussed. However, this outcome suggest a slightly different story than the input-cost increase of petroleum and coal products.

The institutions of the wholesale trade industry are such that the entire industry is unlikely to undergo the simultaneous price shock as suggested by the model suggests. Firms in this industry typically operate by taking title to the merchandise that they sell, meaning they purchase it outright and take ownership of the product.[9] This fact means that cost increases to wholesale trade would likely occur on a an industry-by-industry basis rather than the industry as a whole. Due to their role as an intermediary, the increased cost of acquiring merchandise raises the cost of their output as they sell that product to retailers or consumers. While the port disruptions during the pandemic might suggest an industry-wide price shock, Figure 18 below shows that wholesale trade costs for different industries experienced price peaks at different times over the pandemic

[9] From the 2022 Naics handhook, page 307: "Merchant wholesalers generally take title to the goods that they sell; in other words, they buy and sell goods on their own account."

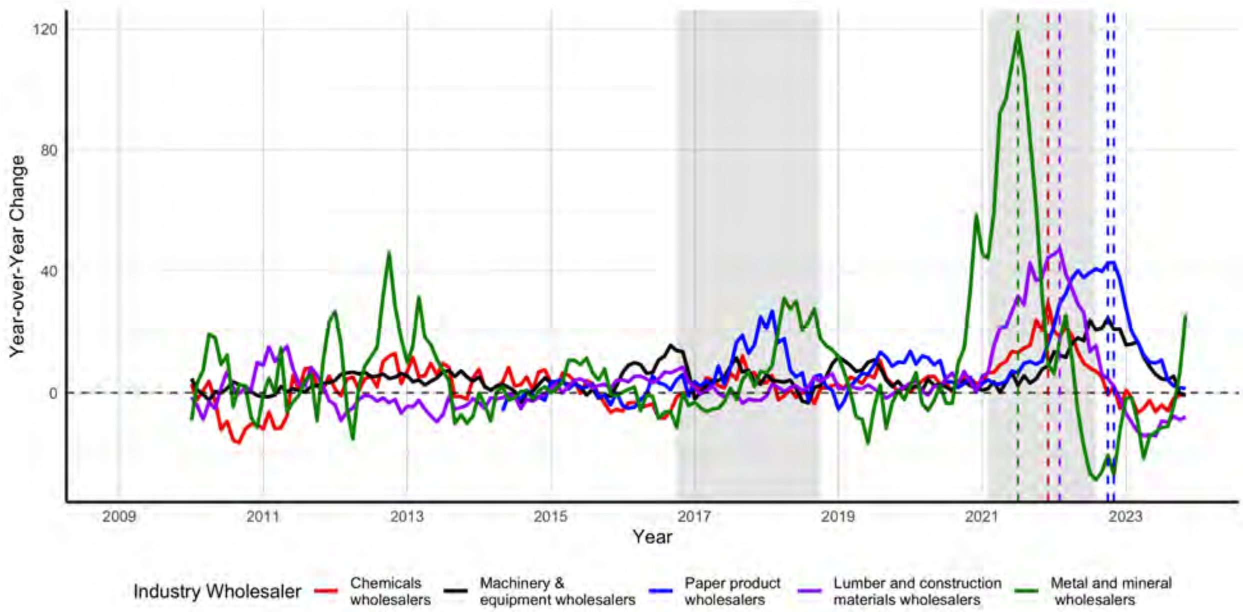
Figure 17: Price Shock to Wholesale Trade



inflation period. The timing of their peaks appears to match their relative positions in production networks with those industries more upstream, such as metal and mineral, lumber, and chemical product wholesale costs peaking first, and more finished products such as paper products and machinery almost a year later.

These differences in both the timing and magnitude of the various wholesale trade cost increases suggests that there are some unexplored upstream-downstream dimensions based on the role of the commodities they are trading in production networks. For example, paper product wholesalers and machinery and equipment wholesale experience their peak almost a year after metal and mineral wholesalers. Digging deeper into the price increases of each industry reveals more detail. The two figures below shows two different cases using the production network information gathered through the input-output relations of industries. Figure 19 uses PPI subseries data on producer costs for forestry products and show the price patterns for manufacturers and wholesalers at two different stages in the production network. The upstream industries suggest that, while there was no clear pattern prior to the onset of the pandemic, during the pandemic infla-

Figure 18: Divergences in Wholesale Costs

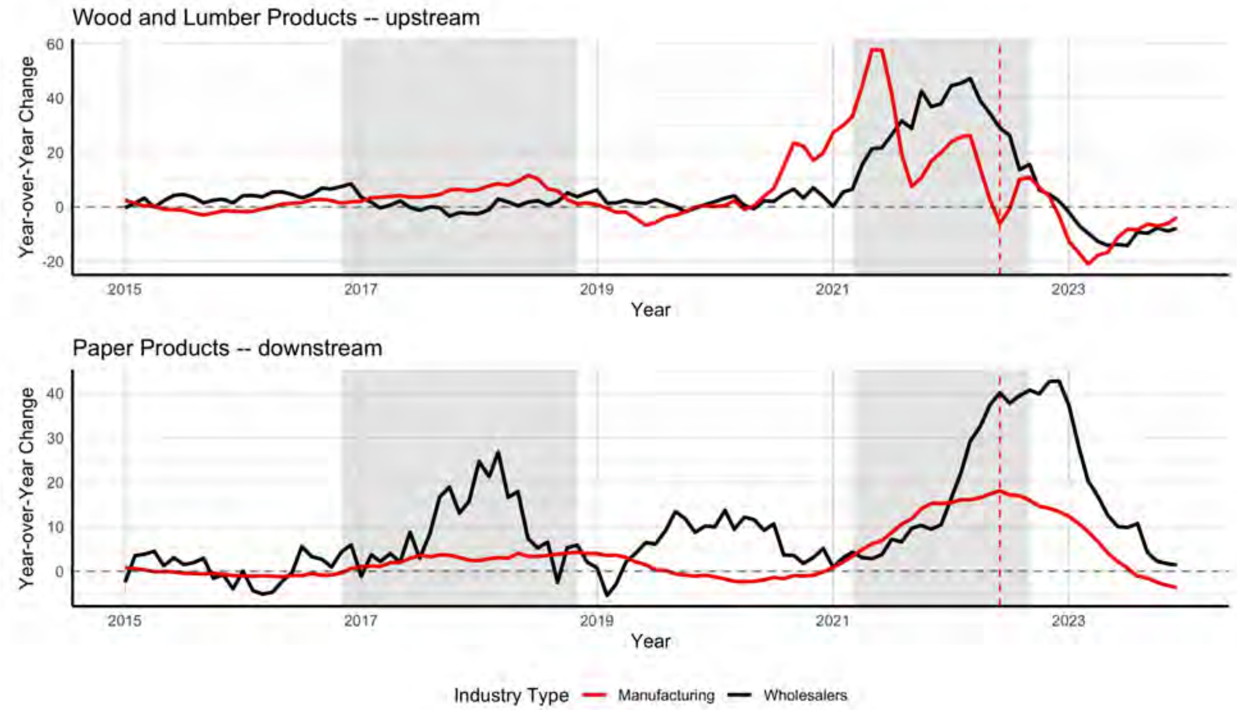


tion wholesale costs for wood and lumber products increased only after production costs for the materials themselves.

The process not occurring prior to the pandemic could be caused by the level of data aggregation or industry specific reasons. Whatever the case, the transmission mechanism becomes more clear during the spike in lumber prices in 2020. Further down the supply chain with some lag, those wood and lumber production costs drove increases in the cost of paper product production. However, in the downstream case, there was only a very short lag and the prices of manufacturing and wholesalers had a near-contemporaneous increase. It is very possible they underwent cost increases simultaneously as a result of the initial increase in production costs.

Figure 20 tells another story focusing on "Primary metals" as discussed above. In the top panel, wholesale costs for minerals and metal increased first with primary metal manufacturing costs following. However, the broad category used for the wholesale industry classification captures both the wholesale trading costs of mining and raw ores as well as iron and steel mills. In this case, the increase in ore mining costs that started before the pandemic and preceded both manufacturing and wholesaler cost increases could have been a contributing cause to price increase in both. The bottom panel with the associated downstream industries appears to tell a similar story

Figure 19: Manufacturing-Wholesaler Price Relations — Forestry Products

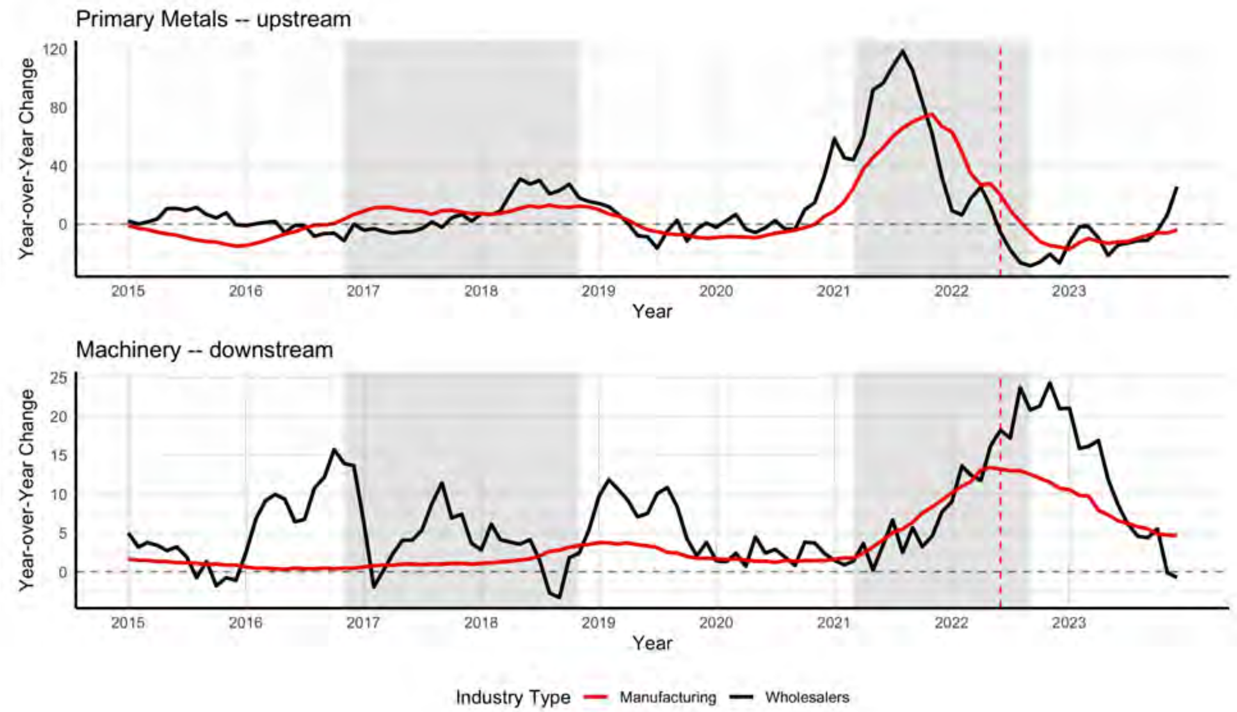


as Figure 19 with a near-contemporaneous rise in manufacturing and wholesale costs in the production of machinery. Again, this may be because they both being driven by the upstream production costs that experience a peak in price increases first, but no matter the case the increasing production costs clearly lag that of ore mining and metal manufacturing.

Across these examples, there are a few preliminary conclusions that can be made:

1. **Inflation is not just an aggregate movement in consumer prices, but a structural feature of the economy**. In nearly all scenarios, production costs for raw materials and upstream industries started increasing before and in significantly greater magnitude to the movement of consumer prices. These production costs increases were certainly passed on to consumers. This procedure outlines a very clear pattern wherein the prices of raw materials and far upstream industries increase first and propagate to closely connected downstream industries.
2. **Energy prices, particularly those related to oil and gas, are the most significant indi-**

Figure 20: Manufacturing-Wholesaler Price Relations - Industrial Products



vidual drivers of inflation. Energy prices are not just the most volatile prices, they also exhibit the largest downstream impacts. This suggests that transitioning to more environmentally sustainable energy production will not just mitigate the impacts of climate change but could also provide substantial benefits for price stability.

3. **Primary metals should be considered an industry with significantly significant prices**. These simulations show that primary metals have the second greatest individual impact on downstream industries in a baseline price volatility scenario. When moving past industry assessment that utilizes consumption weights, its significant impact on production networks becomes clear.

The results obtained from the disaggregated inflation assessment follow directly from the alternative theoretical conception of inflation rooted in the price system and the structural characteristics of production networks. Three main implications for inflation policy follow from this analysis: first, building structural resilience to inflation is an important precursor to achieving price stability; second, the use of strategic resource buffer stocks has potential to mitigate the impact of volatile prices for upstream production resources; and third, long-term policy objectives to ensure price stability have significant overlap with the transition to an environmentally sustainable economy. The main theme underlying these suggestions is that inflation outcomes are inherently tied to the structural features of an economy. Inflation does not represent a uniformly changing set of prices or value of money but shifting set of relative relations in production networks. By extension, policies for price stability do not always need to be reactive to price increases but instead can proactively build a structural resilience to price increases. The viability of these proactive policy measures will inherently rely on the extensive use of fiscal policy which has long been treated as, at best, irrelevant to price stability.

The first policy implication is that the current reliance on reactive monetary policy and demand management cannot stabilize the volatile prices that drive cost increases. Heterodox critics, a member of the Board of Governors, and some of advisers have all found the theoretical understanding of inflation embedded in this approach to be insufficient in various ways. As former board member Tarullo (2017) suggested, the approach to inflation should follow the data. The IO model of price increases presented in Section 2 and the disaggregated extensions give a reliable guide to follow that data. The series of price increases predicted by the model were found to be true in several contexts for petroleum, metals, chemicals, and their associated products. That data presents strong evidence that price shocks to production networks in the pandemic preceded the peak of headline consumer price indexes and a similar pattern was found in preceding periods. When considering the nature of future climate-related price shocks from resource shortages or production disruptions, it is clear that monetary policy will be of little use in resolving the inflation arising from these issues.

The second policy implication is that utilizing buffer stocks for strategic resource is a serious policy alternative that can mitigate the effect of cost shocks to production networks before the result in rising consumer prices. This policy was initially advocated by Keynes (1938) to mitigate the impacts of fluctuating demand, but the evidence provided here suggests that it can also be used to alleviate the significant price volatility in raw materials and associated products identified by Mitchell (1913). In the context of isolated sectoral disruptions and increasing economic and environmental uncertainty, buffer stocks offer the potential to mitigate the impact of temporary resource shortages and localized disruptions. Other authors such as Weber and Schulken (2024) have made a convincing case for the use of buffer stocks that highlight their potential to alleviate shortages of food and critical commodities while counteracting the negative effects of economic uncertainty.

The third policy implication addresses the long-term economic objectives in the transition to an environmentally sustainable economy. The level of instability driven by fossil fuels is often hidden in current approaches to inflation but a core finding of Section 3 was that petroleum products are by far the single largest contributor to price instability in the economy. Not only that, the reliance on petroleum and other fossil fuels is driving environmental destruction that poses significant economic and humanitarian risks. These findings suggest that the long-term transformation of the economy can bring shorter-term benefits in the form of increased price stability. With the acknowledgement that monetary policy cannot meaningfully impact important prices like food and oil, important measurements of inflation considered in policy decisions often rely on "core" measures of inflation simply omit them from the calculation. However, as this article demonstrates, the effect of oil prices movements cannot be isolated from the prices that remain. All commodities that share some "genetic relation" to each other through a dependence on petroleum in production will be impacted by its price shocks with various time lags. Suppressing demand through tightened financial conditions is not a reasonable way to address the impacts of volatile energy prices.

CONCLUSION

This paper argues that inflationary processes cannot be adequately captured by the notion of the "price level" or measurements based on consumer prices indexes. Instead, inflation is a structural feature of the economy and its production networks. In this approach, inflationary processes arise from cost shocks to raw materials and common production inputs that become embedded into the cost structures of commodities. The disaggregated approach proposed here demonstrated this through the analysis of prices in several systemically significant sectors including "Petroleum and coal products", "Primary metals", "Chemical products", and "Wholesale trade". This analysis suggests that the current approach to price stability that relies on reactive monetary policy and aggregate demand suppression is not able to address these root causes of inflation. Alternative policies such as strategic resource buffer stocks were suggested to build structural resilience in production networks and mitigate the impact of upstream cost shocks before they impact consumers.

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APPENDIX

APPENDIX A.1: MATHEMATICAL DERIVATION OF THE MODEL

The Leontief price model defines the prices of output as the sum of production costs. These costs are specified as input costs, value added, and import costs. This is expressed as:

$$\hat{X}P = \hat{X}A'P + V + M$$

where $\hat{X}$ is the diagonal matrix of total output for each sector, P is the price vector, A' is an industry-by-industry domestic requirements matrix derived following the specification in Medeiros and Howells III (2017), V is the vector of value added, and M is the vector of import values for each sector.

Dividing both sides by total output gives:

$$P = A'P + v + m$$

where v is the vector of value added per unit of output and m is the value of imports per unit of output. Isolating the price vector on the left-hand side yields:

$$P = (I - A')^{-1}(v + m)$$

The term $(I - A')^{-1}$ is the Leontief inverse of direct and indirect requirements of inputs from other industries. This inverse drives the selected price shock through the relations between industries in the model.

However, each component can be split into two groups, with one representing exogenous industries and the other representing endogenous industries, using the notation of Valadkhani and

Mitchell (2002). Once split, the system becomes:

$$\begin{bmatrix} P_X \\ P_E \end{bmatrix} = \begin{bmatrix} A'_{XX} & A'_{EX} \\ A'_{XE} & A'_{EE} \end{bmatrix} \begin{bmatrix} P_X \\ P_E \end{bmatrix} + \begin{bmatrix} v_X \\ v_E \end{bmatrix} + \begin{bmatrix} m_X \\ m_E \end{bmatrix}$$

The four subdivisions of the direct requirements matrix are:

- A'_{XX}: direct input requirements of exogenous industries from exogenous industries.
- A'_{EX}: direct input requirements of exogenous industries from endogenous industries.
- A'_{XE}: direct input requirements of endogenous industries from exogenous industries.
- A'_{EE}: direct input requirements of endogenous industries from endogenous industries.

For the determination of the prices of endogenous sectors, only the bottom row of the partitioned equations with A'_{XE} and A'_{EE} is needed. Solving for the endogenous price vector, P_E, gives:

$$P_E = (I - A'_{EE})^{-1} A'_{XE} P_X + (I - A'_{EE})^{-1} (v_E + m_E)$$

To conduct price shocks, industries are divided into exogenous and endogenous groups based on their perceived price-setting institutions, with industries supplying commodity markets viewed as having prices more determined by market supply and demand than by costs.

Once industries are divided between these two groups, the change in the endogenous price vector generated by a change in the exogenous price vector is defined as:

$$\Delta P_E = (I - A'_{EE})^{-1} A'_{XE} \Delta P_X$$

The change in the industry's price in the ΔP_X vector is multiplied through the input-output relations. The resulting vector ΔP_E contains the disaggregated results for endogenous industries. The selected size of the shock and the designation of permanently exogenous industries both affect model output. Both are preserved in this iteration of the model for the sake of demonstrating the underlying variation in the original results.

APPENDIX A.2: THE POWER SERIES APPROXIMATION

For the separation of disaggregated results into direct and indirect impacts, a power series approximation is used as an alternative to solving with the Leontief inverse. A detailed discussion of the computations in this approach can be found in Miller and Blair (2014, Ch. 2).

For the base equation driving the model:

$$\Delta P_E = (I - A'_{EE})^{-1} A'_{XE} \Delta P_X$$

The power series approximation of the Leontief inverse is:

$$(I - A'_{EE})^{-1} = I + A'_{EE} + (A'_{EE})^2 + (A'_{EE})^3 + \cdots$$

Substituting this into the model gives:

$$\Delta P_E = \left[I + A'_{EE} + (A'_{EE})^2 + (A'_{EE})^3 + \cdots \right] A'_{XE} \Delta P_X$$

Equivalently, the round-by-round effects can be written as:

$$\Delta P_E = \sum_{k=0}^{\infty} (A'_{EE})^k A'_{XE} \Delta P_X$$

where k is the number of rounds after the initial direct transmission from exogenous to endogenous industries.

The direct and indirect effects are defined according to the round-by-round calculation:

- The initial price shock in ΔP_X is round 0.
- The direct effects are captured in round 1 by the direct use of exogenous inputs by endogenous industries:

$$\text{Round } 1 = A'_{XE} \Delta P_X$$

- The indirect effects are the sum of all higher-order effects from round 2 onward:

$$\text{Round } r = (A'_{EE})^{r-1} A'_{XE} \Delta P_X, \quad r \geq 2$$

Thus, round 2 is:

$$\text{Round } 2 = A'_{EE} A'_{XE} \Delta P_X$$

Round 3 is:

$$\text{Round } 3 = (A'_{EE})^2 A'_{XE} \Delta P_X$$

and so on.

While the round-by-round computations can technically continue to infinity, in all cases the computations converge to the values found with the Leontief inverse around round 9. In computations of the indirect effects in the paper, the round-by-round computations were made by summing rounds 2 through 20 to ensure consistency in the results:

$$\text{Indirect Effects} = \sum_{r=2}^{20} (A'_{EE})^{r-1} A'_{XE} \Delta P_X$$

APPENDIX A.3: SECTORAL PRICE VOLATILITY, DIRECT IMPACTS, AND INDIRECT IMPACTS DERIVATION

The size of the shock is determined by what the authors call each industry's sectoral price volatility, denoted as spv. Sectoral price volatility is defined as one standard deviation of the yearly percent change in price between 2000 and 2019.

For industry x, sectoral price volatility is defined as:

$$spv_x = \sqrt{\frac{1}{T} \sum_{t=t_0}^{t_1} \left(\Delta P_t^x - \Delta P_{t_0,t_1}^{\hat{x}} \right)^2}$$

and $\Delta P_{t_0,t_1}^{\hat{x}}$ is the average yearly percentage price change for industry x between the initial date t_0 and final date t_1. In this construction, industries with more volatile prices over the period have larger shock inputs to the model. Industries are shocked one-by-one, with endogenous industries being set as exogenous when shocked and the price shock occurring to only one industry at a time.

In the original model, the effects of those shocks on all other industries in the system are summed together and weighted by each industry's respective share in consumption relative to total consumption. This weighted summation of effects composes what the authors call a synthetic CPI, which is used to estimate the inflation impact of each particular industry. The synthetic index from the original model's inflation assessment is constructed through the addition of two terms that the authors classify as direct and indirect inflation impacts.

The direct impact is:

$$IP_{dir} = c_x \Delta P_x$$

The indirect impact is:

$$IP_{ind} = \sum_{i \neq x} c_i \Delta P_E^i$$

The total impact is:

$$IP_{tot} = c_x \Delta P_x + \sum_{i \neq x} c_i \Delta P_E^i$$

The weights for each industry in this synthetic index are derived from each industry's respective share in final consumption, denoted c_x for the shocked industry and c_i for all other industries.

The direct impact, IP_{dir}, is the direct product of the consumption share and the size of the shock. The indirect impact, IP_{ind}, is the sum of the effects on the prices of the endogenous industries multiplied by their respective consumption share weights. The total effect, IP_{tot}, is the sum of the direct and indirect effects and defines the total movement of the synthetic CPI used to compare the output of shocks to different industries.

The larger the total impact on the synthetic index from the two terms, the more systemically significant the industry is in contributing to inflation.

APPENDIX A.4: FULL LIST OF EXOGENOUS AND ENDOGENOUS INDUSTRIES

The full list of industries designated as exogenous and endogenous are found below alongside their sectoral price volatilities and their consumption share weights.

Table 3: Industry Classification, Sectoral Price Volatility, and Consumption Shares

Industry	Sectoral Price Volatility (%)	Consumption Share
Exogenous industries		
Oil and gas extraction	23.89	0.04
Mining, except oil and gas	6.77	0.01
Federal Reserve banks, credit intermediation, and related activities	4.93	2.42
Securities, commodity contracts, and investments	3.46	1.75
Insurance carriers and related activities	1.00	2.87
Funds, trusts, and other financial vehicles	3.15	1.02
Housing	0.98	15.37
Other real estate	1.23	0.05
Management of companies and enterprises	3.10	0.00
Ambulatory health care services	0.90	7.76
Hospitals	0.82	6.55
Nursing and residential care facilities	1.03	1.80
Amusements, gambling, and recreation industries	0.86	1.24
Food services and drinking places	0.77	5.70
Endogenous industries		
Farms	9.65	0.60
Forestry, fishing, and related activities	3.62	0.06
Support activities for mining	3.44	0.00
Utilities	5.45	1.54
Construction	2.27	0.00
Wood products	4.28	0.03
Nonmetallic mineral products	2.04	0.07
Primary metals	10.10	0.01
Fabricated metal products	2.50	0.13
Machinery	1.19	0.08
Computer and electronic products	2.96	0.66
Electrical equipment, appliances, and components	2.42	0.27

Table 3: Industry Classification, Sectoral Price Volatility, and Consumption Shares *(continued)*

Industry	Sectoral Price Volatility (%)	Consumption Share
Motor vehicles, bodies and trailers, and parts	0.89	1.70
Other transportation equipment	0.89	0.15
Furniture and related products	0.96	0.39
Miscellaneous manufacturing	0.71	0.72
Food and beverage and tobacco products	3.57	4.37
Textile mills and textile product mills	2.17	0.18
Apparel and leather and allied products	0.85	1.02
Paper products	2.51	0.15
Printing and related support activities	1.55	0.04
Petroleum and coal products	21.26	1.28
Chemical products	4.96	2.25
Plastics and rubber products	2.71	0.29
Wholesale trade	1.77	4.18
Motor vehicle and parts dealers	2.46	1.13
Food and beverage stores	1.96	1.54
General merchandise stores	2.90	1.49
Other retail	1.34	5.89
Air transportation	4.04	1.16
Rail transportation	4.14	0.06
Water transportation	4.89	0.18
Truck transportation	2.70	0.69
Transit and ground passenger transportation	1.79	0.30
Pipeline transportation	2.57	0.02
Other transportation and support activities	2.07	0.17
Warehousing and storage	1.96	0.00
Publishing industries, except internet (includes software)	1.00	0.72
Motion picture and sound recording industries	1.81	0.17
Broadcasting and telecommunications	0.84	2.39
Data processing, internet publishing, and other information services	0.73	0.58
Rental and leasing services and lessors of intangible assets	1.19	0.69
Legal services	1.54	0.77
Computer systems design and related services	0.97	0.00

Table 3: Industry Classification, Sectoral Price Volatility, and Consumption Shares *(continued)*

Industry	Sectoral Price Volatility (%)	Consumption Share
Miscellaneous professional, scientific, and technical services	1.00	0.50
Administrative and support services	0.82	0.53
Waste management and remediation services	0.94	0.17
Educational services	0.84	1.91
Social assistance	0.60	1.63
Performing arts, spectator sports, museums, and related activities	1.11	0.58
Accommodation	1.58	1.18
Other services, except government	0.60	4.68
Federal general government (defense)	1.78	0.00
Federal general government (nondefense)	1.14	0.00
Federal government enterprises	1.98	0.09
State and local general government	1.65	2.56
State and local government enterprises	2.26	1.35