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Supply and Demand in Disaggregated Keynesian Economies with an Application to the COVID-19 Crisis[†]

By David Baqaee and Emmanuel Farhi*

We study supply and demand shocks in a disaggregated model with multiple sectors, multiple factors, input-output linkages, downward nominal wage rigidities, credit-constraints, and a zero lower bound. We use the model to understand how the COVID-19 crisis, an omnibus supply and demand shock, affects output, unemployment, and inflation, and leads to the coexistence of tight and slack labor markets. We show that negative sectoral supply shocks are stagflationary, whereas negative demand shocks are deflationary, even though both can cause Keynesian unemployment. Furthermore, complementarities in production amplify Keynesian spillovers from supply shocks but mitigate them for demand shocks. This means that complementarities reduce the effectiveness of aggregate demand stimulus. In a stylized quantitative model of the United States, we find supply and demand shocks each explain about one-half of the reduction in real GDP from February to May 2020. Although there was as much as 6 percent Keynesian unemployment, this was concentrated in certain markets. Hence, aggregate demand stimulus is one quarter as effective as in a typical recession where all labor markets are slack. (*JEL* E12, E23, E24, E31, E32, E62, I12)

COVID-19 is an unusual macroeconomic shock. It cannot easily be categorized as an aggregate supply or demand shock. Rather, it is a messy combination of disaggregated sectoral supply and demand shocks. These shocks propagate through supply chains to create different cyclical conditions in different parts of the economy. Some sectors are tight, constrained by supply constraints, and struggling to keep up with demand, whereas other sectors are slack, shedding workers and reducing excess capacity because of lack of demand.

Separating demand shortfalls from supply constraints is important because supply- and demand-constrained sectors respond very differently to policy. For example, policies that boost demand, like lowering interest rates or increasing government spending, exacerbate problems of inadequate supply, leading to shortages

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and inflation. Similarly, policies that boost supply, like relaxing lockdowns or providing liability exemptions, are ineffective at restoring activity when applied to demand-constrained sectors.

We model the outbreak of the pandemic as a combination of supply and demand shocks. We define demand shocks to be changes in households' indifference curves over goods, and we define supply shocks to be changes in the economy's production possibilities. Clearly, the COVID-19 crisis contained elements of both shocks.

On the one hand, even fixing budget constraints, households rebalanced their current expenditures across sectors because they feared infection or disliked the experience of consuming certain goods during a pandemic. Households also rebalanced expenditures across time, reducing current expenditures in favor of a future when conditions for consumption are back to normal.

On the other hand, the epidemic also triggered supply shocks that shrank the economy's production possibilities frontier. For example, lockdowns, desire for social distancing in the workplace, and insurance and liability concerns reduced the supply of labor, the capacity with which firms could safely operate, and firms' productivity.

To analyze this situation of divergent sectoral outcomes, we use a general disaggregated model and aggregate up from the micro to the macro level. We allow for an arbitrary number of sectors and factors, as well as unrestricted input-output linkages and elasticities of substitution. We incorporate downward nominal wage rigidities, credit constraints, and a zero lower bound on nominal interest rates. While the economics of supply and demand shocks are well understood in one-sector models, this paper provides a comprehensive analysis of these forces in models with multiple sectors and input-output linkages.

In this paper, we provide analytical results on how disaggregated supply and demand shocks affect output, employment, and inflation. We show that negative sectoral supply shocks are stagflationary, whereas negative demand shocks are deflationary, even though both can cause Keynesian unemployment.[1] Furthermore, complementarities in production amplify Keynesian spillovers from supply shocks but mitigate them for demand shocks. This means that complementarities reduce the effectiveness of aggregate demand stimulus. We use a calibrated version of the model to decompose the supply and demand sources of the COVID-19 recession. We also use the model to answer counterfactual questions about the effects of aggregate demand stimulus. The following paragraphs describe these results and outline the paper in more detail.

After setting up the environment and equilibrium in Section I, we provide *local* comparative statics under very general conditions in Section II, characterizing the response of aggregates such as output, inflation, and unemployment, as well as of disaggregated variables. Whereas both supply and demand shocks reduce output and cause Keynesian unemployment, their effect on the price level is dissimilar. Negative demand shocks are generically deflationary and negative supply shocks are

[1] Keynesian unemployment measures the amount of slack in a given factor market. It captures underemployment due to lack of demand for the good that the factor is producing because of downwardly rigid wages. Measured unemployment in the data reflects not only Keynesian unemployment but other forms of supply-driven underemployment due to the pandemic. See Section IB for a discussion.

generically inflationary, even in the presence of arbitrarily complicated production networks and highly incomplete markets. This result, which is obvious in a one-sector model, is not immediate in a multisector model because supply shocks in one industry can reduce demand in other industries, and in principle, one might imagine that this effect could be so strong as to overturn the intuition from the one-sector model.

Section II shows that the production network matters only in so far as it plays a role in determining how factor income shares respond to shocks in equilibrium. To build more intuition for this result, in Section III, we focus on a Cobb-Douglas special case where the behavior of factor shares is simple to understand. Using the Cobb-Douglas model, we demonstrate that credit-constraints magnify the unemployment and output effects of both supply and demand shocks. If unemployed households are unable to borrow against their future income, then unemployed workers are forced to cut back their spending more aggressively than they would if they could borrow. Therefore, credit constraints magnify spending reductions given income losses, and this acts as an endogenous negative demand shock.

In Section IV, we use a constant elasticity of substitution (CES) special case to understand the role of complementarities. We show that complementarities in the production network amplify negative supply shocks to some markets by causing Keynesian spillovers in other markets. Intuitively, negative supply shocks raise the relative price of the shocked sectors, and because of complementarities, redirect expenditures toward the shocked sectors. This reduces demand in other sectors and causes Keynesian unemployment. In contrast, we show that these complementarities also mitigate demand shocks. In response to a negative aggregate demand shock, flexible factor prices fall relative to rigid factor prices. Due to complementarities, expenditures are then redirected away from flexibly priced factors and toward the Keynesian factor markets, stabilizing employment.

The fact that complementarities mitigate demand shocks is a double-edged sword, since for the same reason, complementarities also mitigate the potency of aggregate demand stimulus. Intuitively, aggregate demand stimulus raises the price of non-Keynesian markets, and substitution toward these markets due to complementarities dissipates the efficacy of stimulus.

In Sections III and IV, we also provide *global* comparative statics showing that the qualitative nature of our local results remain valid for large shocks. These global comparative statics allow us to capture the nonlinearities of the model and in particular, how the shocks interact with each other and get amplified or mitigated. Under some conditions, we show that output is globally decreasing in negative supply and demand shocks, whereas inflation is globally increasing in negative supply but decreasing in negative demand shocks.

In Section V, we provide a quantitative illustration of the model applied to US data from February to May 2020. We use this model to decompose the relative importance of supply and demand shocks, and study the role of complementarities across sectors in shaping the response of output to the initial shocks and to changes in policy.

The benchmark model predicts that real GDP falls by 8 percent, inflation is around -1 percent and there is around 6 percent Keynesian unemployment. Negative supply shocks on their own reduce output by around 6 percent, cause mild Keynesian unemployment of around 1 percent, and imply inflation should be close to 6 percent.

On the other hand, negative demand shocks on their own reduce output by 5 percent, cause 10 percent Keynesian unemployment and predict inflation of around -4 percent. Hence, *both* supply and demand shocks are necessary to match the data, which feature large reductions in real GDP but only mild deflation.

We use the model to classify sectors as supply constrained (tight) or demand constrained (slack). In both the model and the data, supply-constrained sectors experienced mild price inflation, and demand-constrained sectors experienced mild price deflation over our sample period. Furthermore, in the data, wages of workers in sectors the model classifies as being supply constrained rose whilst those in demand-constrained sectors fell.

We use the model to quantify the importance of complementarities, and find that they amplified negative supply shocks and mitigated negative demand shocks by roughly an equal amount. Therefore, complementarities do not have strong effects on the overall aggregate response of inflation or output. However, they do change the breakdown between the relative importance of supply versus demand, making supply shocks relatively more important.

As mentioned before, an important reason for separating supply-constrained sectors from demand-constrained ones is that they respond very differently to interventions. Demand-side policies are counterproductive in supply-constrained markets, and supply-side policies are unhelpful in demand-constrained markets. In this vein, we consider policy counterfactuals for social insurance and monetary policy.

We find that the power of untargeted aggregate demand stimuli, like monetary policy, is greatly diminished in the current crisis. In our model, aggregate demand stimulus is one quarter as effective in the current crisis compared to a typical, aggregate-demand-driven, recession. There are two reasons for this. First, the sectoral nature of the COVID-19 shock means that around one-half of the labor markets are supply-constrained and do not respond to demand stimulus. Second, realistic complementarities sap the efficacy of demand stimulus by dissipating more of it as inflation.

We also use the model to quantify the importance of social insurance. Our baseline calibration assumes complete markets, and adding credit constraints further depresses output, inflation, and employment. For example, if 50 percent of unemployed workers become credit constrained and receive no income support from the government, then output falls by an additional 1 percent, and Keynesian unemployment increases by an extra 2 percent. As with monetary policy, the importance of social insurance depends on the strength of complementarities, and in a Cobb-Douglas model with weaker complementarities, social insurance is three times more important.

We end the paper by touching upon some extensions of the basic framework in Section VI before concluding in Section VII.

Related Literature

This paper is part of the literature on economic effects of the COVID-19 crisis, as well as the literature on multisector models with nominal rigidities.

Guerrieri et al. (2020) show that negative supply shocks can have negative demand spillovers, under the condition that the intersectoral elasticity of substitution is less than the intertemporal one. They also show that this condition is weaker under incomplete markets. Our paper complements theirs by considering both supply and demand shocks in a model with rich input-output linkages. Our results about supply shocks build on and are related to theirs. We show that complementarities in the production network, rather than consumption, can also amplify negative supply shocks, even if the intersectoral and intertemporal elasticities of substitution in consumption are the same. Furthermore, we also show that these supply shocks, despite causing Keynesian unemployment, are nevertheless still inflationary. We also show that while complementarities amplify negative supply shocks, they also mitigate negative demand shocks. For this reason, in our quantitative exercise, a Cobb-Douglas model, without complementarities, predicts almost the same reduction in output and employment as a model with stronger intersectoral complementarities because of these offsetting effects on supply and demand shocks.

Bigio, Zhang, and Zilberman (2020) study optimal policies in response to the COVID-19 crisis in a two-sector Keynesian model. We differ in both focus and framework, since we are not focused on optimal policy and instead try to understand the importance of the production structure.[2] Fornaro and Wolf (2020) study COVID-19 in a New Keynesian model where the pandemic is assumed to have persistent effects on productive capacity in the future by lowering aggregate productivity growth. The expected loss in future income reduces aggregate demand. They show that a feedback loop can arise between aggregate supply and aggregate demand if productivity growth in turn depends on the level of economic activity.[3] We differ in that we focus on the effects of current disruptions. Caballero and Simsek (2020) study a different kind of spillover, between asset prices and demand shortages.

Our paper also relates to quantitative multisector models. Barrot, Grassi, and Sauvagnat (2020) study the effect of COVID-19 using a quantitative production network with complementarities and detailed administrative data from France. Bonadio et al. (2020) study the effect of COVID-19 in a quantitative international trade model. Bodenstein, Corsetti, and Guerrieri (2020) analyze optimal shutdown policies in a two-sector model with complementarities and minimum-scale requirements. Our approach differs from these papers due to our focus on nominal rigidities and Keynesian effects. Brinca, Duarte, and Faria-e Castro (2020) use a statistical model to decompose sectoral outcomes in the COVID-19 crisis into demand- and supply-side sources. Our classification of demand and supply drivers are conceptually different to theirs for reasons we discuss in Section I. Kaplan, Moll, and Violante (2020) combine an epidemiological model with a multisector heterogeneous agent New Keynesian model to study the economic impact of the pandemic.

This paper is also related to other work by the authors, especially Baqaee and Farhi (2020). Whereas in this paper, we study how exogenous shocks interact with nominal frictions and result in involuntary unemployment, Baqaee and Farhi (2020) is a companion paper where we analyze the nonlinear mapping from changes in hours and household preferences to real GDP. In this companion paper, we find that the

[2] Bigio, Zhang, and Zilberman (2020) study a fully dynamic model specified in continuous time, which allows them to analyze how the effects unfold over time.

[3] This could be because of reduced investment in research and development due to a reduced size of the market à la Benigno and Fornaro (2018).

negative supply and demand shocks associated with COVID-19 are large enough that accounting for nonlinearities is quantitatively important.

Our analysis is also related to production network models with nominal rigidities, like Baqaee (2015), who studies the effect of targeted fiscal policy and shocks to the sectoral composition of demand in a production network with downward wage rigidity; Pasten, Schoenle, and Weber (2017) and Pasten, Schoenle, and Weber (2019) who study propagation of monetary and total factor productivity shocks in models with sticky prices; Ozdagli and Weber (2017) who study the interaction of monetary policy, production networks, and asset prices; and Rubbo (2020) and La'O and Tahbaz-Salehi (2020) who study optimal monetary policy with sticky prices.

I. Setup

In this section, we set up the basic model. We describe the problem faced by households and firms, the equilibrium notion, and the shocks that we will be studying.

A. *Environment and Equilibrium*

There are two periods, the present denoted without stars, and the future denoted with stars, and there is no investment.[4] We take the price level in the future as given. As in Krugman (1998) and Eggertsson and Krugman (2012), this is isomorphic to an infinite-horizon model where after an initial unexpected shock in period 1, the economy returns to a long-run equilibrium with market clearing and full employment.[5]

There is a continuum of households, a set of producers $\mathcal{N}$, and a set of factors $\mathcal{G}$. The economy has the same set of households, producers, and factors in both the present and the future.

Consumers.—There is a continuum of consumers who collectively own all the primary factors. The quantity of factor f supplied is $L_f \in [0,1]$. Full employment occurs when $L_f = 1$ for every $f \in \mathcal{G}$. When the quantity of factor f employed falls, we assume this change comes about via the extensive margin; that is, some fraction $1 - L_f$ of the owners of factor f become unemployed while the remaining fraction L_f continue to receive payment and are fully employed. Some fraction, $1 - \phi_f$, of the unemployed factor is owned by households that derive their entire income solely from f and cannot borrow against their future income. The remaining fraction ϕ_f can borrow against their future income. This means that a fraction $(1 - \phi_f)$ of the unemployed factor $(1 - L_f)$ is owned by households that cannot consume anything in the present and are credit constrained. We refer to these households, that are unemployed and cannot borrow or consume, as the *hand-to-mouth* (HtM) households, and we refer to the rest of the households, who are not credit constrained, as the *Ricardian* households.

[4] We abstract from investment in the main body of the paper in order to keep the exposition manageable. We show in online Appendix F how our approach generalizes to environments with investment.

[5] Our analysis extends to situations where the crisis lasts for multiple periods without change, as long as we maintain the assumption that there is no investment and no credit constraints; see footnote 13 for more information.

All households have the same intertemporal utility function

$$(1-\beta)\frac{y^{1-1/\rho}-1}{1-1/\rho}+\beta\frac{y_*^{1-1/\rho}-1}{1-1/\rho},$$

where ρ is the intertemporal elasticity of substitution (IES), $\beta \in [0,1]$ captures households' time-preferences, and y and y_* are current and future consumption. The intertemporal budget constraint for an unconstrained household is

$$p^Y y+\frac{p_*^Y y_*}{1+i} = I+\frac{I_*}{1+i},$$

where I, I_*, p^Y, and p_*^Y are the income of the household and the price of the consumption good in the present and future, and $(1+i)$ is the nominal interest rate. We omit the HtM households' budget constraint since they simply spend their exogenous future income on the future good and cannot consume in the present.

Now, we turn to the within-period problem. The consumption bundle in the present period is given by

$$Y = \mathcal{C}(c_1, \ \ldots \ , c_{\mathcal{N}}; \omega_{\mathcal{D}}),$$

a homothetic final-demand aggregator of the final consumptions c_i of the different goods i. The parameter $\omega_{\mathcal{D}}$ is a preference shifter capturing changes in the sectoral composition of final demand. We normalize shocks to the composition of demand so that, at the initial allocation, they do not directly affect the level of present utility relative to future utility.[6] Throughout the rest of the paper, we refer to Y as *output*.[7]

The price p^Y of the consumption bundle Y is denoted by

$$p^Y = \mathcal{P}(p_1, \ldots, p_{\mathcal{N}}; \omega_{\mathcal{D}}),$$

where $\mathcal{P}$ is the ideal price index of the quantity index $\mathcal{C}$. We also denote by

$$E = p^Y Y,$$

final expenditure in the present period (i.e., nominal GDP). Since the price and quantity of the consumption good in the future is exogenous, we represent these by $\bar{Y}_*$, and $\bar{p}_*^Y$. Future final income and expenditure is then $\bar{E}_* = \bar{p}_*^Y \bar{Y}_*$.

[6] That is, we assume $\mathcal{C}(c;\omega_{\mathcal{D}}) = \mathcal{C}(c;\omega_{\mathcal{D}}')$ where c is the vector of consumption goods the household consumes in the no-shock steady state. In other words, we normalize the sectoral preference shocks so that, on their own, they do not alter intertemporal decisions.

[7] Changes in Y are, to a first order, the same as changes in real GDP. To define real GDP, we mimic the chain-weighted procedures used by national income accountants. Local changes in real GDP are defined by the Divisia index $d\log Y^{GDP} = \sum_{i\in\mathcal{N}}(p_i c_i)/\left(\sum_{j\in\mathcal{N}} p_j c_j\right) d\log c_i$. To a first-order approximation, $d\log Y^{GDP} = d\log Y$. Discrete changes in real GDP are defined by integrating the Divisia index $\Delta\log Y^{GDP} = \int d\log Y^{GDP}$. If there are shocks to the composition of final demand $\omega_{\mathcal{D}}$, then real GDP $\Delta\log Y^{GDP}$ and the consumption bundle $\Delta\log Y$ are only equal up to a first-order approximation, and may not be the same at higher orders of approximation. We return to these issues in the quantitative exercise in Section V.

Producers.—Producer i maximizes profits

$$\pi_i = \max_{y_i, \{x_{ij}\}, \{L_{if}\}} p_i y_i - \sum_{j \in \mathcal{N}} p_j x_{ij} - \sum_{f \in \mathcal{G}} w_f L_{if},$$

subject to production function

$$y_i = A_i F_i\left(\{x_{ij}\}_{j \in \mathcal{N}}, \{L_{if}\}_{f \in \mathcal{G}}\right),$$

where A_i is a Hicks-neutral productivity shifter, y_i is total output, and x_{ij} and L_{if} are intermediate and factor inputs used by i. Without loss of generality, we assume that F_i has constant returns to scale.[8]

Market Equilibrium.—Market equilibrium for goods is standard. The market for i is in equilibrium if

$$c_i + \sum_{j \in \mathcal{N}} x_{ji} = y_i.$$

Market equilibrium for factors is nonstandard, the wages of factors cannot fall below some exogenous lower bound.[9] We say that factor market f is in equilibrium if the following three conditions hold:

$$(w_f - \bar{w}_f)(L_f - \bar{L}_f) = 0, \quad \bar{w}_f \leq w_f, \quad L_f \leq \bar{L}_f, \tag{1}$$

where

$$L_f = \sum_{i \in \mathcal{N}} L_{if}$$

is the total demand for factor f. The parameter $\bar{w}_f$ is an exogenous minimum nominal wage. The parameter $\bar{L}_f \leq 1$ is the maximum quantity of the factor that can be employed, and it may be less than full employment (full employment is represented by $L_f = \bar{L}_f = 1$).

In words, there are two possibilities. One possibility is $w_f \geq \bar{w}_f$ and employment of the factor is equal to its maximum value $L_f = \bar{L}_f$. In this case, we say that the market is tight, that it clears, and that it is *supply constrained*. The other possibility is that $w_f = \bar{w}_f$ and employment of the factor is less than its potential $L_f \leq \bar{L}_f$. We then say that the market is slack, that it does not clear, and that it is *demand constrained*. In this case, we call the underemployment $\bar{L}_f - L_f$ of the factor *Keynesian unemployment* since it is caused by a lack of demand for the good that the factor is producing given the rigid wage.

We only consider two cases: the case where $\bar{w}_f$ is equal to its preshock market-clearing value, denoting the set of such factors by $\mathcal{L} \subseteq \mathcal{G}$; and the case where $\bar{w}_f = -\infty$, making the wage of f flexible and ensuring the market for f always clears, denoting the set of such factors by $\mathcal{K} \subseteq \mathcal{G}$. For concreteness, we

[8] Following the replication argument of McKenzie (1959), we can treat every production function as though it has constant returns by adding producer-specific fixed factors to the model.

[9] In online Appendix E, we extend the model to allow for some downward wage flexibility.

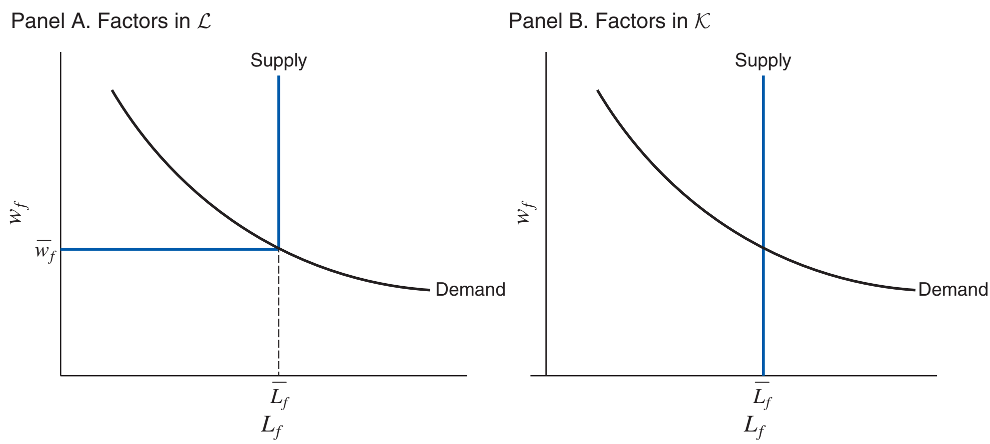

Figure 1. Equilibrium in the Factor Markets

call $\mathcal{L}$ the labor factors and $\mathcal{K}$ the capital factors. Figure 1 illustrates the supply and demand curves in the factor markets.

Of course, these are just names, in practice, one may easily imagine that certain capital markets could also be subject to nominal rigidities. This can be a way to model firm failures: imagine firms take out within-period loans to pay for their variable expenses, secured against their capital income. If the firm's capital income declines in nominal terms, then the firm defaults on the loan, exits the market, and its capital becomes unemployed for the rest of the period. We build on this observation further in online Appendix G, where we formally introduce an extensive margin of firm exit. For the body of the paper, we treat capital markets as being frictionless.

We denote the endogenous set of supply-constrained factor markets by $\mathcal{S} \subseteq \mathcal{G}$. In other words, $f \in \mathcal{S}$ if, and only if, $L_f = \overline{L}_f$. We denote the endogenous set of demand-constrained factor markets by $\mathcal{D} \subseteq \mathcal{G}$. Hence, $f \in \mathcal{D}$ if, and only if, $w_f = \overline{w}_f$ and $L_f < \overline{L}_f$. Of course, capital markets are always supply constrained $\mathcal{K} \subseteq \mathcal{S}$, and demand-constrained sectors are necessarily a subset of labor markets $\mathcal{D} \subseteq \mathcal{L}$.

Equilibrium.—Given a nominal interest rate $(1+i)$, future prices $\bar{p}_*^Y$ and output $\overline{Y}_*$, maximum factor supplies $\overline{L}_f$, productivities A_i, and demand shifters $\omega_{\mathcal{D}}$, an equilibrium is a set of prices p_i, factor wages w_f, intermediate input choices x_{ij}, factor input choices L_{if}, outputs y_i, and final demands c_i, such that each producer maximizes its profits subject to its technological constraint, consumers maximize their utility, and the markets for all goods and factors are in equilibrium. Without loss of generality, we normalize the initial preshock values of output and the price level to be one: $\overline{Y}_* = Y = p^Y = \bar{p}_*^Y = 1$.

B. *Supply and Demand Shocks*

Now we define the shocks we study in this paper. A natural disaster, like the COVID-19 epidemic, can be captured as a combination of negative supply and demand shocks. We define supply shocks to be shocks that change the economy's production possibility set. On the other hand, we define a demand shock to be a shock that changes the households' expenditure shares on the different goods (across sectors and over time) *at given prices and incomes*. We describe each of these shocks in turn.

Supply Shocks.—Changes in the economy's production possibility set could come in the form of either reduced factors or reduced productivity. We call reductions in the available productive endowment of labor $\bar{L}_f$ shocks to *potential labor*. These are reductions that would take place absent any nominal frictions. These reductions could have different drivers. They could be driven directly by government action, like mandated shutdowns and stay-at-home orders. They could also be due to a reduced willingness to work by workers due to fear of infection. Finally, reductions in potential labor could also be the result of a reorganization of production. For example, firms could be forced to operate at lower capacity to reduce legal liability or implement social distancing, such as retailers that can only safely operate at a fraction of their previous capacity. In this case, workers would be involuntarily unemployed due to a reduced physical capacity to employ them and not because there is not enough demand for the good that they produce.[10] Crucially, these "supply"-driven reductions in employment would occur even in the absence of downward nominal wage rigidities. For this reason, we do not include this form of unemployment in our definition of Keynesian unemployment.

In addition to negative shocks to potential labor, the epidemic might also reduce the productivity A_i of the different producers by changing the way firms can operate, for instance by reducing person-to-person interactions.

Demand Shocks.—Whereas supply shocks change household's choices by changing prices and incomes, demand shocks change household choices for fixed prices and income.[11] Accordingly, the pandemic can change the current sectoral composition of final demand, since at given prices and income, households may shift expenditure away from some goods like cruises and air transportation, and toward other goods like groceries and online retail. We model this as a change in the preference shifter $\omega_{\mathcal{D}}$.

Similarly, the pandemic can reduce households' willingness to consume in the present relative to the future: at given prices and income, households may choose

[10] To model capacity constraints formally, imagine that $\bar{L}_f = \min\{1, S_f\}$, where S_f is a "safety" input (capacity) which, in the initial equilibrium, is not scarce. Since it is not scarce, it commands a price of zero initially. However, the pandemic reduces the supply of S_f so that it binds. At this point, the supply of potential labor $\bar{L}_f$ falls one-for-one with S_f. In this case, employers would refuse to hire any additional workers since their marginal product is zero. A formal capacity constraint like this is isomorphic to our formulation where we directly shock $\bar{L}_f$ in terms of real GDP, inflation, and hours worked. The only difference is that the increase in the wage w_f would not take place and would instead be captured as a Ricardian rent by the firm.

[11] Our notion of supply and demand shocks are defined in the context of a general equilibrium, and are not the same as the one used by Brinca, Duarte, and Faria-e Castro (2020). They separate shocks based on whether they shift labor supply or labor demand, but for us, a "supply" shock can shift either labor supply or labor demand. For example, a capacity constraint placed on firms due to social distancing, described in the previous footnote, would manifest as a reduction in labor demand, but be classified as a supply shock under our definition since it reduces the production possibilities of the economy.

to consume less during the pandemic and more afterwards. We model this as an increase in the discount factor $\beta/(1-\beta)$.[12]

II. General Local Comparative Statics

In this section, we describe comparative statics of the model that hold regardless of the details of the production side of the economy. Our results here, which are first-order (local) approximations, clarify which sufficient statistics are needed for understanding the responses of output, inflation, and employment to shocks. In Sections III and IV, we specialize the model further and write these sufficient statistics in terms of microeconomic primitives. We also provide global (as opposed to first-order) comparative statics in Sections III and IV.

Because of downward wage rigidity, variables like aggregate output and inflation are not differentiable everywhere. Therefore, our local comparative statics should be understood as holding almost everywhere. Furthermore, there are potentially multiple equilibria, in which case, local comparative statics should be understood as perturbations of a given locally isolated equilibrium.

We write $d\log X$ for the differential of an endogenous variable X understood as the (infinitesimal) change in an variable X in response to (infinitesimal) shocks. For example, the supply shocks are $d\log A_i$ and $d\log \bar{L}_f$, and the shocks to the sectoral composition of demand are $d\log \omega_D$. For a vector of shocks, like $d\log A$ or $d\log \bar{L}$, we drop the subscripts. For discrete changes in a variable, we write $\Delta \log X$.

Notation.—To analyze the model, we introduce some additional notation. Recall that nominal expenditure is the total sum of all final expenditures

$$E = \sum_{i \in N} p_i c_i = p^Y Y.$$

We define the Domar weight λ_i of producer i to be its sales share as a fraction of GDP

$$\lambda_i \equiv \frac{p_i y_i}{E}.$$

The Domar weight λ_f of factor f is simply its total income share

$$\lambda_f \equiv \frac{w_f L_f}{E}.$$

Unlike the Domar weight for goods, the Domar weights for factors necessarily sum to one $\sum_{f \in \mathcal{G}} \lambda_f = 1$. We denote the Domar weight of f in the future by λ_f^*.

We proceed in two steps. First, we use the first-order conditions of the household to derive an Euler equation summarizing the intertemporal aspects of the equilibrium. Second, we use the first-order conditions of the firms to derive an aggregation equation that summarizes the intratemporal aspects.

[12] In online Appendix C, we provide a simple microfoundation for these demand shocks using a health-related disutility function.

A. *Intertemporal Problem*

The consumption of unconstrained households is governed by their Euler equation

$$y = y_* \left[(1+i) \frac{\beta}{1-\beta} \frac{p^Y}{\bar{p}_*^Y} \right]^{-\rho}.$$

Since HtM households do not consume in the current period, summing the left-hand side over all non-HtM households yields an expression for aggregate output in the current period

$$Y = \bar{Y}_* \left(1 - \sum_{f \in \mathcal{G}} \lambda_f^* (1 - \phi_f)(1 - L_f) \right) \left[(1+i) \frac{\beta}{1-\beta} \frac{p^Y}{\bar{p}_*^Y} \right]^{-\rho}, \tag{2}$$

where we use the fact that the share of future output consumed by HtM households is $\sum_f \lambda_f^* (1-\phi_f)(1-L_f)$. Note that the constrained fraction $(1-L_f)(1-\phi_f)$ rises as employment falls, and it does not depend matter whether the reduction in employment in factor market f is due to binding supply or demand constraints. Log-linearizing the Euler equation results in an aggregate demand curve that relates changes in output $d\log Y$ to changes in the price index $d\log p^Y$.

PROPOSITION 1 (Intertemporal Optimization): *Changes in output are given by*

$$d\log Y = -\rho d\log p^Y + d\log\zeta + d\log\Theta, \tag{3}$$

where $d\log\zeta$ *and* $d\log\Theta$ *are intercepts. The first intercept term is*

$$d\log\zeta = d\log\bar{Y}_* - \rho\left(d\log(1+i) + d\log\frac{\beta}{1-\beta} - d\log\bar{p}_*^Y \right), \tag{4}$$

and the second is

$$d\log\Theta = d\log\left(1 - \mathbb{E}_{\lambda^*}\left((1-\phi_f)(1-L_f) \right) \right),$$

where the expectation uses the factor income shares in the future, λ^**, as the probability distribution.*

We call $d\log\zeta$ an *aggregate demand* shock. A positive aggregate demand shock can come about from an increase in expected future output, reduction in the nominal interest rate or the discount factor, or an increase in future prices (a proxy for forward guidance).[13]

[13] If the crisis lasts for more than one period, and there are no credit constraints, the Euler equation can still be used to write output in each period as a function of the price index in that period and exogenous shocks; that is, $\Delta\log Y_t = -\rho\Delta\log p_t^Y - \rho\left(\sum_{j=1}^T \Delta\log(1+i_{t+j-1}) + \Delta\log\frac{\beta_*}{\beta_t} - \Delta\log\bar{p}_*^Y\right) + \Delta\log\bar{Y}_* + d\log\Theta$, where t indexes time and $*$ is the terminal period when the economy recovers. Since this is the only dynamic relationship, the rest of the analysis can be combined with this Euler equation instead to determine output in each period before recovery. This approach is only tenable if the periods are short-lived however, since we assume that the nominal wage constraint is exogenous.

Note that with complete financial markets, $\phi_f = 1$ for every f, the second intercept, $d\log\Theta$, is always zero. We call $d\log\Theta$ the *endogenous aggregate demand* shock. This term captures the fact that reductions in employment today reduce spending today, since $1-\phi_f$ of type f workers become constrained. Therefore, as pointed out by Guerrieri et al. (2020), reductions in employment, $d\log L_f < 0$, can feed back into reduced nominal demand because some households are HtM.

Changes in nominal expenditure $d\log E$ are similarly given by

$$d\log E = d\log\left(p^Y Y\right) = \left(1-\rho\right)d\log p^Y + d\log\zeta + d\log\Theta. \tag{5}$$

Recall that ρ is the intertemporal elasticity of substitution (IES). When $\rho > 1$, increases in prices $d\log p^Y > 0$ reduce nominal expenditure as consumers substitute toward the future. Conversely, when $\rho < 1$, increases in prices $d\log p^Y > 0$ increase nominal expenditure as consumers substitute toward the present. When $\rho = 1$, and there are no HtM households, changes in nominal expenditure are exogenously given by the shocks $d\log E = d\log\zeta$. In this paper, we often focus on the case where $\rho = 1$, which is a focal point for the empirical literature on the IES.

B. *Intratemporal Problem*

Whereas Proposition 1 is a consequence of the consumers' first-order conditions, the next proposition is a consequence of the producers' first-order conditions and resource constraints.

PROPOSITION 2 (Intratemporal Optimization): *Changes in output are given by*

$$d\log Y = \sum_{i\in\mathcal{N}}\lambda_i d\log A_i + \sum_{f\in\mathcal{G}}\lambda_f\, d\log L_f, \tag{6}$$

$$= \underbrace{\sum_{i\in\mathcal{N}}\lambda_i d\log A_i + \sum_{f\in\mathcal{G}}\lambda_f d\log\bar{L}_f}_{\Delta\,potential\ output} + \underbrace{\sum_{f\in\mathcal{L}}\lambda_f \min\left\{d\log\lambda_f + d\log E - d\log\bar{L}_f, 0\right\}}_{\Delta\,output\ gap}. \tag{7}$$

Equation (6) for $d\log Y$ shows that a version of Hulten's (1978) theorem holds for this economy. In particular, to a first order, changes in output can only be driven by changes in the productivities $d\log A_i$ weighted by their producer's sales share λ_i, or by changes in the quantities of factors $d\log L_f$ weighted by their income shares λ_f.[14]

To arrive at equation (7), use the fact that changes in capitals $f\in\mathcal{K}$ are exogenous with

$$d\log L_f = d\log\bar{L}_f, \tag{8}$$

and changes in labors $f\in\mathcal{L}$ are endogenous with

$$d\log L_f = \min\left\{d\log\lambda_f + d\log E, d\log\bar{L}_f\right\} \le d\log\bar{L}_f. \tag{9}$$

[14] This expression also shows that changes in the sectoral composition of demand within the period $d\log\omega_{\mathcal{D}}$, or changes in aggregate demand $d\log\zeta$, can only change output through changes in the quantities of factors.

Here we have used the observation that factor f is demand constrained, with $d\log w_f = 0$ and $d\log L_f = d\log\lambda_f + d\log E$ if, and only if, changes in nominal expenditure on this factor $d\log\lambda_f + d\log E$ are below changes in its potential supply $d\log\bar{L}_f$.

The first term in (7) is the change in potential output and corresponds to the change in output that would occur in a neoclassical version of the model with flexible wages. The second term is the negative output gap that can open up in the Keynesian version of the model with downward nominal wage rigidities because of Keynesian unemployment in the different factor markets. These Keynesian spillovers depend on endogenous changes in nominal expenditure $d\log E$, pinned down by the Euler equation (5), and factor income shares $d\log\lambda_f$ (to be determined in later sections).

Crucially, Proposition 2 clarifies how the details of the production network matter in this economy. It is only through the determination of changes in factor shares, $d\log\lambda_f$, that the details of the production network will matter.

Combining the Intra- and Intertemporal Problems.—Without delving into the details of the production network and the disaggregated model, we can already make an observation about the way inflation responds to shocks by combining the intertemporal and intratemporal sides of the model.

COROLLARY 1 (Inflation): *At the full-equilibrium steady state, the change in the price level is given by*

$$d\log p^Y = \frac{1}{\rho}d\log\zeta - \frac{1}{\rho}\sum_{f\in\mathcal{G}}\lambda_f\phi_f d\log L_f - \frac{1}{\rho}\sum_{i\in\mathcal{N}}\lambda_i d\log A_i.$$

Hence, reductions in employment, $d\log L < 0$, and productivity, $d\log A < 0$, are *stagflationary* unless they are also accompanied by exogenous negative aggregate demand shocks $d\log\zeta < 0$. Note that it does not matter whether the reductions in employment $d\log L_f$ are supply driven or demand driven; either way, they are inflationary. Furthermore, Corollary 1 also shows that shocks to the sectoral composition of demand, $d\log\omega_{\mathcal{D}} \neq 0$, generically raise inflation even though they may cause Keynesian unemployment.

Corollary 1 is remarkably general, since it holds regardless of the disaggregated details of the production structure. Furthermore, it also does not rely on the assumption that some factor wages cannot fall. In particular, in online Appendix E, we show that Corollary 1 holds even when wages are fully or semiflexible. Corollary 1 shows that, in order to model a sharp recession without significant inflation, like the COVID-19 crisis, we must allow for negative aggregate demand shocks.

To prove this corollary, combine Propositions 1 and 2 to get

$$(10)\qquad d\log p^Y = \frac{1}{\rho}d\log\zeta + \frac{1}{\rho}d\log\Theta - \frac{1}{\rho}\sum_{i\in\mathcal{N}}\lambda_i d\log A_i - \frac{1}{\rho}\sum_{f\in\mathcal{G}}\lambda_f d\log L_f.$$

This equation shows that reductions in aggregate demand (AD) shifters, $d\log\zeta$ and $d\log\Theta$, lower the price, whereas reductions in supply, $d\log A$ and $d\log L$, tend to raise the price of the consumption good. While $d\log\zeta$ is exogenous, $d\log\Theta$ is endogenous. At the full-equilibrium steady state,

$$d\log\Theta = \sum_{f\in\mathcal{G}} \lambda_f^*\left(1-\phi_f\right) d\log L_f;$$

that is, the endogenous demand shifter depends on the reduction in employment in the current period weighted by the income share of HtM workers in the future. Since at the initial steady state current and future factor income shares are the same, $\lambda_f^* = \lambda_f$, we can substitute this equation for $d\log\Theta$ into (10) to get the desired result.

C. *Input-Output Notation*

Propositions 1 and 2 show that the response of output, inflation, and employment depend on equilibrium changes in factor income shares $d\log\lambda_f$. These are the only endogenous objects left to be determined, and it is through these objects that the production network exerts an influence on the outcome variables of interest.[15] We provide a characterization of changes in factor shares in online Appendix D for general networks. In the body of the paper, we specialize the results in online Appendix D and focus on a Cobb-Douglas and CES special case. To do so, we define some input-output notation used throughout the rest of the paper.

Input-Output and Leontief Matrix.—We slightly abuse notation by treating factors with the same notation as goods. For each factor f, we interchangeably use the notation L_{if} or $x_{i(\mathcal{N}+f)}$ to denote its use by i, the notation L_f or y_f to denote total factor supply, and p_f or w_f to refer to its price or wage. Furthermore, we treat final demand as an additional good produced by producer 0 using the final demand aggregator. We interchangeably use c_i or x_{0i} to denote final consumption of good i. We write $1+\mathcal{N}$ for the union of the sets $\{0\}$ and $\mathcal{N}$, and $1+\mathcal{N}+\mathcal{G}$ for the union of the sets $\{0\}$, $\mathcal{N}$, and $\mathcal{G}$. With this abuse of notation, we can stack every market in the economy into a single input-output matrix that includes the household, the producers, and the factors.

The input-output matrix is the $\left(1+\mathcal{N}+\mathcal{G}\right)\times\left(1+\mathcal{N}+\mathcal{G}\right)$ matrix Ω whose ijth element is equal to i's expenditures on inputs from j as a share of its total income/revenues

$$\Omega_{ij} \equiv \frac{p_j x_{ij}}{p_i y_i} = \frac{p_j x_{ij}}{\sum_{k\in\mathcal{N}+\mathcal{G}} p_k x_{ik}}.$$

The input-output matrix Ω records the *direct* exposures of one producer to another. The first row corresponds to the households' use of inputs, the next $\mathcal{N}$ rows are the producers' uses of inputs, and the last $\mathcal{G}$ rows correspond to the factors' use of inputs (the last $\mathcal{G}$ rows are all equal to zero, since factors do not use any inputs).

[15] See Baqaee and Farhi (2021) for assumptions under which the production network is globally irrelevant for comparative statics.

The Leontief inverse matrix is

$$\Psi \equiv (I - \Omega)^{-1} = I + \Omega + \Omega^2 + \ldots.$$

The Leontief inverse matrix Ψ records instead the *direct and indirect* exposures through the supply chains in the production network.

The accounting identity $p_i y_i = p_i x_{0i} + \sum_{j \in \mathcal{N}} p_i x_{ji} = \Omega_{0i} E + \sum_{j \in \mathcal{N}} \Omega_{ji} \lambda_j E$ links the Domar weights to the Leontief inverse via

$$\lambda_i = \Psi_{0i} = \sum_{j \in \mathcal{N}} \Omega_{0j} \Psi_{ji}, \tag{11}$$

where $\Omega_{0j} = (p_j x_{0j}) / \left(\sum_{k \in \mathcal{N}+\mathcal{G}} p_k x_{0k}\right) = (p_j c_j)/E$ is the share of good j in final expenditure. Equation (11) is a key equation, showing how the input-output matrix pins down the factor income shares, and through this, affects equilibrium employment and output. Online Appendix D provides a general characterization of how factor income shares respond to shocks. In the next two sections, we focus on some intuitive parametric special cases instead.

III. The Cobb-Douglas Economy

In this section, we study the Cobb-Douglas special case, where intertemporal and intersectoral preferences are log and production functions are Cobb-Douglas. In Section IV, we extend the analysis in this section beyond the Cobb-Douglas special case.

A. *Local Comparative Statics*

We analyze the effect of negative supply and demand shocks in turn. Recall that $\mathcal{S}$ and $\mathcal{D}$ are the equilibrium sets of supply- and demand-constrained factors. We give comparative statics for a given $\mathcal{S}$ and $\mathcal{D}$. We then give conditions for these sets of supply- and demand-constrained factors to indeed arise in equilibrium. We start by considering supply shocks. For transparency, we set the share of potentially HtM households in every sector to be the same $\phi_i = \phi$.

Supply Shocks.—Consider negative factor supply shocks on their own. In response to negative supply shocks, aggregate expenditures fall in the present, since some households are HtM. This reduction in spending reduces employment in demand-constrained factor markets and depresses output further.

To see this, define the average negative labor shock to the supply-constrained factors

$$d \log \bar{L}_{\mathcal{S}} = \sum_{f \in \mathcal{S}} \frac{\lambda_f}{\lambda_{\mathcal{S}}} d \log \bar{L}_f,$$

where $\lambda_{\mathcal{S}} = \sum_{f \in \mathcal{S}} \lambda_f$. Similarly, the average employment change in the demand-constrained factors is

$$d \log L_{\mathcal{D}} = \sum_{f \in \mathcal{D}} \frac{\lambda_f}{\lambda_{\mathcal{D}}} d \log L_f < \sum_{f \in \mathcal{D}} \frac{\lambda_f}{\lambda_{\mathcal{D}}} d \log \bar{L}_f = d \log \bar{L}_{\mathcal{D}},$$

where $\lambda_{\mathcal{D}} = \sum_{f \in \mathcal{D}} \lambda_f$. Keynesian unemployment is given by $d\log L_{\mathcal{D}} - d\log \bar{L}_{\mathcal{D}}$.

Using Proposition 2, we can write

$$d\log Y = \lambda_{\mathcal{S}} d\log \bar{L}_{\mathcal{S}} + \lambda_{\mathcal{D}} d\log \lambda_{\mathcal{D}} + \lambda_{\mathcal{D}} d\log E = \lambda_{\mathcal{S}} d\log \bar{L}_{\mathcal{S}} + \lambda_{\mathcal{D}} d\log E.$$

The second equality follows from the fact that factor income shares remain constant due to the Cobb-Douglas assumption. Hence, Keynesian unemployment arises if there are reductions in nominal spending $d\log E$.

Using the Euler equation (5), starting at the full employment allocation, the change in nominal spending today is

$$\begin{aligned} d\log E &= d\log \Theta \\ &= (1-\phi)\lambda_{\mathcal{S}} d\log \bar{L}_{\mathcal{S}} + (1-\phi)\lambda_{\mathcal{D}} d\log E = \frac{(1-\phi)\lambda_{\mathcal{S}} d\log \bar{L}_{\mathcal{S}}}{1-(1-\phi)\lambda_{\mathcal{D}}}. \end{aligned}$$

Hence, negative supply shocks reduce nominal spending by reducing the income of credit-constrained consumers directly and indirectly through a Keynesian-cross type effect. Combining these equations results in the following.

PROPOSITION 3 (Supply Shocks): *Suppose that all within-period production and consumption functions are Cobb-Douglas*, $\rho = 1$, *and* $\phi_j = \phi$ *for all* $j \in \mathcal{N}$. *Then, in response to negative labor supply shocks* $d\log \bar{L}$ *we have*

$$d\log Y = \lambda_{\mathcal{S}} d\log \bar{L}_{\mathcal{S}} + \lambda_{\mathcal{D}} d\log L_{\mathcal{D}} = \frac{\lambda_{\mathcal{S}}}{1-(1-\phi)\lambda_{\mathcal{D}}} d\log \bar{L}_{\mathcal{S}}.$$

The direct impact on output of the negative shock to the supply-constrained factors is given by $\lambda_{\mathcal{S}} d\log \bar{L}_{\mathcal{S}}$, and the amplification of this shock through Keynesian channels is given by the multiplier $1 / \left[1-(1-\phi)(1-\lambda_{\mathcal{S}})\right]$. Naturally, amplification is stronger, the lower is the social insurance parameter $\phi < 1$.

We now go back and check that our conjectured set of supply-constrained factors is indeed the equilibrium set of supply-constrained factors. A factor f is demand-constrained in equilibrium if, and only if, $f \in \mathcal{L}$ and

$$\frac{(1-\phi)}{1-(1-\phi)\lambda_{\mathcal{D}}} \lambda_{\mathcal{S}} d\log \bar{L}_{\mathcal{S}} < d\log \bar{L}_f;$$

that is, as long as the negative shock to factor f is sufficiently small in magnitude compared to the average shock affecting the supply-constrained part of the economy. This condition is harder to satisfy the smaller is the set of supply-constrained factors $\lambda_{\mathcal{S}}$ and the higher is the market completeness parameter ϕ. In particular, if we assume that there are no credit-constrained households $\phi = 1$, then this condition cannot be satisfied and all factors are supply constrained. In this case, Keynesian frictions would not be triggered in response to supply shocks.

Demand Shocks.—When final demand is a Cobb-Douglas aggregator, we can model sectoral demand shocks as a decline in that sector's Cobb-Douglas weight (leaving the other Cobb-Douglas weights unchanged); that is, we assume that within-period utility is given by

$$\log \mathcal{C} = \sum_{i \in \mathcal{N}} \left(\bar{\Omega}_{0i} - \kappa_i\right) \log c_i,$$

where $\bar{\Omega}_{0i}$ is households' initial budget share on good i with $\bar{\kappa}_i = 0$ in the initial equilibrium. A decline in demand for i, $\kappa_i > 0$, maps to shocks to *both* the intersectoral and intertemporal composition of demand. In particular, the shock changes the composition of demand within the period by

$$\Delta \log \Omega_{0i} = \Delta \log \frac{\bar{\Omega}_{0i} - \kappa_i}{\left(1 - \sum_{j \in \mathcal{N}} \kappa_j\right) \bar{\Omega}_{0i}}, \tag{12}$$

and it changes the composition of demand across periods according to

$$\Delta \log \zeta = -\Delta \log(1 + i) - \Delta \log \frac{\beta}{1 - \beta} + \Delta \log \bar{E}_* + \Delta \log \left(1 - \sum_{j \in \mathcal{N}} \kappa_j\right). \tag{13}$$

For future reference, when we refer to an aggregate demand shock, we mean a change in $\Delta \log \zeta$ that keeps the intersectoral composition of final demand constant, that is $\Delta \log \Omega_{0i} = 0$ for every i.

To understand demand shocks, starting at the full employment steady state without supply shocks, we consider an aggregate demand shock first and then sectoral demand shocks.

PROPOSITION 4 (Aggregate Demand Shocks): *Suppose that all within-period production and consumption functions are Cobb-Douglas*, $\rho = 1$, *and* $\phi_j = \phi$ *for all* $j \in \mathcal{N}$. *For an aggregate demand shock*, $d \log \zeta$, *the change in output is*

$$d \log Y = \lambda_{\mathcal{D}} d \log L_{\mathcal{D}} = \lambda_{\mathcal{D}} d \log E = \frac{\lambda_{\mathcal{D}}}{1 - (1 - \phi) \lambda_{\mathcal{D}}} d \log \zeta.$$

Hence, as long as there are some HtM households $\phi \neq 1$, aggregate demand shocks are also amplified by a multiplier $1 / \left(1 - (1 - \phi) \lambda_{\mathcal{D}}\right)$, for similar reasons to supply shocks. So far, the production network has not mattered for either sectoral supply shocks nor aggregate demand shocks, because these shocks do not change factor income shares.

Finally, consider a vector of sectoral demand shocks $d\kappa$, starting at the full employment steady-state without supply shocks. In this case, reduced demand for good i will ripple up the supply chain and differentially affect different factor markets. To see this, note that in demand-constrained sectors, employment falls according to the reduction in nominal spending

$$d \log L_f = d \log \lambda_f + d \log E = d \log \left(\sum_j \Psi_{jf} \left(\bar{\Omega}_{0j} - \kappa_j\right)\right) + d \log \Theta,$$

where the second equality uses the Euler equation for expenditures (5). Intuitively, there are two reasons why nominal spending on factor i can fall. First, as emphasized in Baqaee (2015), a negative demand shock $d\kappa_j > 0$ to consumption good j affects demand for factor f by j's network-adjusted factor intensity $\Psi_{jf} > 0$. Intuitively, Ψ_{jf} is the fraction of j's revenues that are ultimately paid out to factor f, both directly and indirectly. This is the first summand. The second summand captures the fact that demand shocks to any demand-constrained factor depresses the income of credit-constrained consumers, and through this, lowers overall expenditures. The equation above is a linear system in $d\log L$, so solving through gives

$$d\log L_f = \frac{-\sum_j \Psi_{jf} d\kappa_j}{\lambda_f\left(1 - \sum_h \kappa_h\right)} - \left[\frac{1-\phi}{\phi}\sum_{g\in\mathcal{D}} L_g \frac{\sum_j \Psi_{jg} d\kappa_j}{\lambda_i\left(1 - \sum_h \kappa_h\right)}\right];$$

the first summand is the direct effect of the negative demand shock and the second summand is the negative spillovers from HtM households. In the complete markets case, with $\phi = 1$, only the direct effect matters. However, when there are credit-constrained consumers, the indirect effect also matters.

Combining these observations with Proposition 2 allows us to state the following.

PROPOSITION 5 (Sector-Specific Shocks): *Suppose that all within-period production and consumption functions are Cobb-Douglas*, $\rho = 1$, *and* $\phi_j = \phi$ *for all* $j \in \mathcal{N}$. *Starting at steady state, for sector-specific demand shocks*, $d\kappa$, *the change in output is*

$$d\log Y = -\left[\sum_{f\in\mathcal{D}}\sum_{j\in\mathcal{N}} \Psi_{jf} d\kappa_j + \frac{1-\phi}{\phi}\sum_{f\in\mathcal{D}}\sum_{j\in\mathcal{N}} \Psi_{jf} d\kappa_j\right].$$

The first term is the direct effect of the negative demand shock and the second term is the Keynesian spillovers from the presence of HtM households. Unlike aggregate demand shocks, the effects of sectoral demand shocks do depend on the shape of the production network, as these shocks propagate up supply chains.

B. *Global Comparative Statics*

We now show that the intuitions developed using derivatives are globally valid. In general, the equilibrium of this model may not be unique. However, for the Cobb-Douglas economy, there is a simple-to-compute unique "best" equilibrium. We provide global comparative statics for this equilibrium. To formalize this, endow $\mathbb{R}^{\mathcal{G}}$ with the partial ordering $x \leq y$ if and only if $x_f \leq y_f$ for all $f \in \mathcal{G}$. Recall that we use Δ to denote discrete changes in a variable to distinguish them from infinitesimal local changes denoted by d.

LEMMA 1 (Ranking Equilibria): *Suppose that all within-period production and consumption functions are Cobb-Douglas and* $\rho = 1$. *Then there is a unique best equilibrium: for any other equilibrium*, $\Delta\log Y$ *and* $\Delta\log L$ *are lower than at the best equilibrium.*

Lemma 1 provides a straightforward way to compute this best equilibrium using an algorithm along the lines of Vives (1990) or, more recently, Elliott, Golub, and Jackson (2014).[16] For the best equilibrium, we can conduct global comparative statics for both supply and demand shocks.

PROPOSITION 6 (Global Comparative Statics): *Under the assumptions of Lemma 1, in the best equilibrium, the following hold:*

(*i*) *Real GDP* $\Delta \log Y$ *and employment* $\Delta \log L$ *are increasing and the price level* $\Delta \log p^Y$ *is decreasing in supply shocks* $\Delta \log \bar{L}$.

(*ii*) *Real GDP* $\Delta \log Y$, *employment* $\Delta \log L$, *and the price level* $\Delta \log p^Y$ *are increasing in exogenous aggregate demand shocks* $\Delta \log \zeta$.

(*iii*) *Employment* $\Delta \log L$ *is decreasing in individual demand shocks* $\Delta \kappa_i$.

The global comparative static results in Proposition 6 show that the local-comparative static results hold globally. In particular, (i) shows that negative labor shocks in some factor markets raise the overall price level and, if there are HtM households, create Keynesian unemployment in other factor markets. On the other hand, (ii) shows that negative aggregate demand shocks, whether driven by policy, expectations about the future, or health concerns can create Keynesian unemployment whilst lowering the overall price level. Finally, (iii) shows that individual demand shocks lower employment globally.[17]

IV. Beyond Cobb-Douglas

In this section, we extend the analysis in Section III beyond the Cobb-Douglas special case to understand the role of complementarities. We focus on an especially tractable case where elasticities of substitution in production are not equal to one, but are symmetric and uniform for every producer. We show that complementarities have dissimilar effects on supply and demand shocks: complementarities amplify Keynesian spillovers from supply shocks, but mitigate Keynesian spillovers from demand shocks. This implies that in the presence of negative supply shocks and complementarities, aggregate demand stimulus is less potent than in the Cobb-Douglas case.

To do this, suppose each good $i \in \mathcal{N}$ is produced with the production function

$$\frac{y_i}{\overline{y}_i} = \frac{A_i}{\bar{A}_i}\left(\sum_{j\in\mathcal{N}+\mathcal{G}} \bar{\omega}_{ij}\left(\frac{x_{ij}}{\overline{x}_{ij}}\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}}, \tag{14}$$

[16] We can find the best equilibrium as follows. Solve the model assuming all factor markets are supply constrained. If one of the wages is below the minimum, call this market demand constrained and set its wage equal to its lower bound. Recompute the equilibrium assuming that these factor markets are demand constrained. Continue in this manner until the wage in every candidate supply-constrained market is above its lower bound.

[17] For technical reasons, we do not characterize global (nonlocal) changes in output and inflation when the sectoral composition of final demand changes. This is because when the sectoral composition of final demand changes, changes in real GDP can no longer be measured using $\Delta \log Y$ globally (only locally). See the path-dependence problem discussed in Baqaee and Farhi (2020).

where x_{ij} is intermediate inputs from j used by i, $\bar{\omega}_{ij}$ is a demand shifter for i's use of input j, and variables with over-lines are normalizing constants. We assume that the elasticity of substitution in production θ is less than or equal to one. We keep the consumption function Cobb-Douglas, as in Section III. This special case is likely to be an empirically important one since elasticities of substitution across two-digit sectors in production are frequently estimated to be below one, but the ones in consumption are likely close to one (e.g., see Atalay 2017; Herrendorf, Rogerson, and Valentinyi 2013).

A. *Local Comparative Statics*

As discussed in Section II, the key sufficient statistics to be solved for are the changes in factor income shares $d\log\lambda$. To do this, we introduce some additional notation. Denote the fth column of the Leontief inverse by $\Psi_{(f)}$. We denote the covariance of two vectors (of size $1+\mathcal{N}+\mathcal{G}$) weighted using the household budget shares $\Omega^{(0)}$ by $\mathrm{cov}_{\Omega^{(0)}}(\cdot,\cdot)$. Similarly, we denote the expectation of a vector using the household budget shares by $\mathbb{E}_{\Omega^{(0)}}[\cdot]$. Using this notation, we can state the following result.

PROPOSITION 7 (Propagation with Complementarities): *Let household preferences be Cobb-Douglas and production functions be given by* (*14*)*. Then changes in factor income shares solve the following linear system*

$$d\log\lambda_f = \frac{1}{\theta}\mathrm{cov}_{\Omega^{(0)}}\left(d\log\Omega^{(0)},\frac{\Psi_{(f)}}{\lambda_f}\right) - \frac{1-\theta}{\theta}d\log L_f - \frac{1-\theta}{\theta}\sum_{k\in\mathcal{G}}\mathbb{E}_{\Omega^{(0)}}\left(\Psi_{(k)}\frac{\Psi_{(f)}}{\lambda_f}\right)(d\log\lambda_k - d\log L_k) \tag{15}$$

almost everywhere, *where changes in factor employments are given by*

$$d\log L_f = \begin{cases} d\log\bar{L}_f, & \textit{for} \quad f\in\mathcal{K}, \\ \min\{d\log\lambda_f + d\log E, d\log\bar{L}_f\}, & \textit{for} \quad f\in\mathcal{L}. \end{cases}$$

Equation (15) describes the endogenous changes in factor income shares in equilibrium. When $\theta = 1$, we recover the Cobb-Douglas case, where the network structure is irrelevant for supply shocks and aggregate demand shocks. As long as $\theta \neq 1$, the input-output matrix now matters for every shock. We describe the intuition for right-hand side of (15) term-by-term.

The first line is partial equilibrium demand and supply shocks respectively, where by partial equilibrium, we mean holding fixed the wage of factors relative to nominal GDP (i.e, setting $d\log\lambda_k - d\log L_k = d\log w_k - d\log E = 0$ for every $k\in\mathcal{G}$).[18] The second line is the general equilibrium feedback from the fact that wages respond in equilibrium.

[18] This follows from the fact that, by definition, $\lambda_k = w_k L_k/E$.

The first term on the right-hand side captures how changes in the sectoral composition of household demand $d\log\Omega_{(0)}$ affect the share of income accruing to *f*. If demand shifts in favor of goods that use *f* intensively, then $\mathrm{cov}_{\Omega^{(0)}}\left(d\log\Omega_{(0)}, \Psi_{(f)}\right)$ is positive and the income share of *f* increases. The second term captures the fact that an increase in the supply $d\log L_f > 0$ depresses spending on *f* if there are complementarities in the production network $(\theta < 1)$.

The terms on the second line are the general equilibrium effects and capture how changes in the wages of factors affect spending on *f*. In particular, note that $d\log\lambda_k - d\log L_k > 0$ implies that the wage of factor *k* is rising faster than nominal GDP $d\log w_k - d\log E > 0$. In this case, due to complementarities, the increase in the relative price of *k* redirects spending away from *f* and toward *k*. The strength of this general equilibrium effect depends on the similarity of *k* and *f*'s demand chain as measured by $\mathbb{E}_{\Omega^{(0)}}\left(\Psi_{(k)}\Psi_{(f)}\right) \geq 0$.

To understand why $\mathbb{E}_{\Omega^{(0)}}\left(\Psi_{(k)}\Psi_{(f)}\right)$ measures similarity of demand, note that it is the dot product of two nonnegative vectors $\Psi_{(k)}$ and $\Psi_{(f)}$. These two vectors capture the network-adjusted reliance of each good in the economy on factor *k* and *f* respectively. The inner product of these two vectors is proportional to the cosine of the angle between them. Intuitively, when $\mathbb{E}_{\Omega^{(0)}}\left(\Psi_{(k)}\Psi_{(f)}\right)$ is large and positive, this means that producers who are heavily reliant on *k* are also heavily reliant on *f*, and hence, an increase in the price of *k* will, in the presence of complementarities, reduce *f*'s share of income. On the other hand, when $\Psi_{(f)}$ and $\Psi_{(k)}$ orthogonal, which happens when *f* and *k* have disjoint demand chains, the shock to the price of *k* has no direct effect on the income share of *f*.

Proposition 7 together with Propositions 1 and 2 pin down all the endogenous variables in the model in terms of primitives. In online Appendix D, we generalize Proposition 7 for production networks with arbitrary elasticities of substitution and nesting structures but the intuition remains similar.

Amplification of Supply and Mitigation of Demand Shocks.—To better understand the intuition for why complementarities amplify supply shocks and mitigate demand shocks, consider the following worked-out example.

PROPOSITION 8 (Supply and Demand Shocks with Complementarities): *Let household preferences be Cobb-Douglas and production functions be given by* (*14*). *Consider labor supply shocks* $d\log\bar{L}$, *aggregate demand shocks* $d\log\zeta$, *and shocks to the sectoral composition of demand* $d\log\Omega^{(0)}$. *Suppose only one factor is supply constrained. Then we have*

$$d\log Y = \left[\lambda_{\mathcal{S}} + \frac{(1-\theta)\,\mathbb{E}_{\Omega^{(0)}}\left(\Psi_{(\mathcal{D})}\Psi_{(\mathcal{S})}\right)\lambda_{\mathcal{S}}}{\lambda_{\mathcal{S}} - (1-\theta)\,\mathbb{E}_{\Omega^{(0)}}\left(\Psi_{(\mathcal{D})}\Psi_{(\mathcal{S})}\right)}\right] d\log\bar{L}_{\mathcal{S}} \tag{16}$$
$$+ \left[\lambda_{\mathcal{D}} - \frac{(1-\theta)\,\mathbb{E}_{\Omega^{(0)}}\left(\Psi_{(\mathcal{D})}\Psi_{(\mathcal{S})}\right)\lambda_{\mathcal{S}}}{\lambda_{\mathcal{S}} - (1-\theta)\,\mathbb{E}_{\Omega^{(0)}}\left(\Psi_{(\mathcal{D})}\Psi_{(\mathcal{S})}\right)}\right] d\log E$$
$$+ \frac{\lambda_{\mathcal{S}}\mathrm{cov}_{\Omega^{(0)}}\left(d\log\Omega^{(0)}, \Psi_{(\mathcal{D})}\right)}{\lambda_{\mathcal{S}} - (1-\theta)\,\mathbb{E}_{\Omega^{(0)}}\left(\Psi_{(\mathcal{D})}\Psi_{(\mathcal{S})}\right)},$$

where $\lambda_{\mathrm{D}} = \sum_{f\in\mathcal{D}}\lambda_f = 1 - \lambda_{\mathrm{S}}$, *and* $\Psi_{\mathrm{D}} = \sum_{f\in\mathcal{D}}\Psi_{(f)}$. *When there is full social insurance* ($\phi_f = 1$ *for every* $f \in \mathcal{G}$), *changes in nominal GDP are equal to aggregate demand shocks* $d\log E = d\log\zeta$.

The first line is the effect of supply shocks ($d\log\bar{L}_{\mathcal{S}}$), the second line is the effect of aggregate demand shocks ($d\log E$) and the third line is the effect of sector-specific demand shocks ($d\log\Omega_{(0)}$). We consider the intuition for supply shocks first and then consider the intuition for demand shocks. For this discussion, note that $0 < \lambda_{\mathcal{S}} - (1-\theta)\,\mathbb{E}_{\Omega^{(0)}}\big(\Psi_{(\mathcal{D})}\,\Psi_{(\mathcal{S})}\big) < 1$.[19]

The first line shows that a negative supply shock to the supply-constrained factor, $d\log\bar{L}_{\mathcal{S}}$, reduces output directly by the income share of the factor $\lambda_{\mathcal{S}}d\log\bar{L}_{\mathcal{S}}$ and indirectly due to complementarities. When supply chains between the supply-constrained factor $\mathcal{S}$ and the demand constrained factors $\mathcal{D}$ are similar, the supply shock causes expenditures to switch away from $\mathcal{D}$ and toward $\mathcal{S}$, causing Keynesian unemployment and further reducing output. Therefore, unlike the Cobb-Douglas model, complementarities amplify the effects of the negative supply shock, even in the absence of credit-constraints.

Now consider the effect of shocks to aggregate demand $d\log E = d\log\zeta + d\log\Theta$. As explained, these negative demand shocks may be exogenous $d\log\zeta$ or endogenous $d\log\Theta$. Either way, reduced nominal spending reduces output directly by $\lambda_{\mathcal{D}}d\log E < 0$ since it reduces employment in demand-constrained sectors one-for-one. However, this effect is mitigated by complementarities. When nominal spending falls $d\log E < 0$ this reduces the price of the supply-constrained factor relative to the demand-constrained factors, redirecting spending away from the supply-constrained factor and stabilizing employment in the demand-constrained factor markets. This means that complementarities mitigate aggregate demand shocks because shocks that change nominal spending $d\log E$ are dissipated by complementarities.

The final summand on the second line of equation (16) captures the effect of shocks to the sectoral composition of demand. Unlike aggregate demand shocks, shocks to the sectoral composition of demand are magnified by complementarities. Intuitively, a sectoral demand shock that moves final demand away from demand-constrained sectors, captured by $\mathrm{cov}_{\Omega^{(0)}}\big(d\log\Omega_{(0)},\Psi_{(\mathcal{D})}\big) < 0$, causes the price of supply-constrained sectors to rise because it redirects that demand toward supply-constrained factors $\mathrm{cov}_{\Omega^{(0)}}\big(d\log\Omega_{(0)},\Psi_{(\mathcal{S})}\big) = -\mathrm{cov}_{\Omega^{(0)}}\big(d\log\Omega_{(0)},\Psi_{(\mathcal{D})}\big) > 0$. In the presence of complementarities, this increase in price reinforces the substitution away from demand-constrained sectors.[20]

[19] This follows from the fact that $\lambda_{\mathcal{S}} = \mathbb{E}_{\Omega^{(0)}}\big(\Psi_{(\mathcal{S})}\big)$, $0 \leq \theta < 1$, and the fact that $\Psi_{(\mathcal{D})} = 1 - \Psi_{(\mathcal{S})}$.

[20] For completeness, shocks to the households' Cobb-Douglas shares $d\kappa$, which are a mixture of intertemporal and intratemporal demand shocks, affect output by $d\log Y = -\sum_i\left(\Psi_{i\mathcal{D}} - \frac{(1-\theta)(1-\Psi_{i\mathcal{D}})\,\mathbb{E}_{\Omega^{(0)}}\big(\Psi_{(\mathcal{S})}\,\Psi_{(\mathcal{D})}\big)}{\lambda_{\mathcal{S}} - (1-\theta)\,\mathbb{E}_{\Omega^{(0)}}\big(\Psi_{(\mathcal{S})}\,\Psi_{(\mathcal{D})}\big)}\right)d\kappa_i$. The intuition for these is very similar to that of aggregate demand shocks.

B. *Global Comparative Statics*

Proposition 8 takes the set of demand- and supply-constrained factor markets as given. We now generalize the global comparative static results to account for the fact that these sets are determined endogenously. As in Section III, we begin by proving that the set of equilibria can still be ranked.

LEMMA 2 (Ranking Equilibria with Complementarities): *Suppose that household preferences are Cobb-Douglas across sectors*, $\rho = 1$, *and the elasticity of substitution in production is* $\theta < 1$. *Then there is a unique best equilibrium: for any other equilibrium*, $\Delta \log Y$ *and* $\Delta \log L$ *are lower than at the best equilibrium.*

The following proposition shows that the qualitative insights from the Cobb-Douglas economy continue to hold.

PROPOSITION 9 (Global Comparative Statics with Complementarities): *Under the assumptions of Lemma 2, in the best equilibrium, the comparative statics in Proposition 6 still hold.*

Therefore, although complementarities change the quantitative behavior of the model, the qualitative predictions are unchanged relative to the Cobb-Douglas model.

V. Quantitative Illustration

We now turn to a quantitative illustration. We use a parsimonious and highly stylized quantitative model to disentangle supply and demand shocks and conduct counterfactuals. We calibrate our model to match the peak to trough reductions in employment from February 2020 to May 2020. We show that complementarities amplify supply shocks and mitigate demand shocks to roughly offsetting effects. We also show that social insurance is crucial for ameliorating the effects of the crisis, significantly raising output, prices, and employment. Finally, we show that the sectorally disparate nature of the COVID-19 crisis, coupled with complementarities, has significantly sapped the potency of aggregate demand stimulus compared to a traditional demand-driven recession.

A. *Calibration*

We start by describing how we calibrate the model's parameters and then describe how we calibrate the demand and supply shocks.

Calibrating Model Parameters.—Our quantitative model has 66 industries and industrial production functions are nested-CES aggregators of labor, capital, and intermediates. We set the elasticity of substitution between labor and capital to 0.6, between value-added and intermediate inputs to 0.6, across intermediates to 0.2. We assume that household demand is Cobb-Douglas across goods within each period, and we set the intertemporal elasticity of substitution $\rho = 1.0$. These elasticities are broadly in line with estimates from Atalay (2017); Herrendorf, Rogerson, and Valentinyi (2013); Oberfield (2013); and Boehm, Flaaen, and Pandalai-Nayar (2019), and close to our theoretical benchmark in Section IV.

The share parameters of utility functions and production functions are calibrated so that at the initial preshock allocation, expenditure shares match those in the 2015 annual US input-output tables the BEA once we drop the government, noncomparable imports, and secondhand scrap industries. We focus on the short run and assume, following Baqaee and Farhi (2019), that labor and capital cannot be reallocated across sectors.

We assume that sectoral labor markets feature perfectly rigid downward nominal wages, but suppose that sectoral capital markets have perfectly flexible rental rates. Goods prices are also set competitively and flexibly. Finally, since personal incomes did not decline during our sample, due to large government transfer programs, we assume full social insurance and set the fraction of households that become HtM to zero for the initial calibration. We consider counterfactuals with imperfect social insurance at the end of the section.

We now describe how we calibrate the primitive demand and supply shocks.

Calibrating Demand Shocks.—Since both the intertemporal and intersectoral elasticities of substitution are equal to one for the household, realized changes in household spending patterns can be directly fed into the model as demand shocks (because household expenditure shares do not depend on relative prices). Our data for realized changes in spending come from the Bureau of Economic Analysis (BEA). Using equation (5), we calibrate the discount factor shock to deliver a -9.5 percent reduction in nominal GDP to match the reduction in nominal GDP between the first and second quarter of 2020. We calibrate shocks to the sectoral composition of demand to match the sectoral composition of personal consumption expenditures in May 2020. Since personal consumption is about two-thirds of final demand, we downweight shocks to the sectoral composition of demand by two-thirds. This is equivalent to assuming that sectoral composition of other components of final demand has not changed (principally, this is private investment and government spending). The left panel of Figure A1 in Appendix A shows the demand shocks by sector.

Calibrating Supply Shocks.—We assume that supply shocks only affect the quantity of potential labor used by each industry. Given the demand shocks, and taking the structure of the model literally and assuming there is no labor mobility across sectors, we can use the vector of changes in hours by sector as the primitive supply shocks. This is because if a labor market is supply constrained, then the only way to match hours in that market is via a reduction in potential employment. On the other hand, if a labor market is demand constrained and has Keynesian unemployment, then any reduction in potential labor supplied up to the realized reduction in hours will have no effect on any observed outcome.[21] This also means that supply shocks

[21] This results in good fit to employment data. The (size-weighted) average industry-level error in hours in nonhealth-care sectors is 2.66 percent. Our simulations predict counterfactually large reductions in employment by hospitals and ambulatory health care services. However, despite large reductions in expenditures on these sectors

in demand-constrained sectors are not identified, since the resource constraint is not binding in those markets.

In reporting our results, we resolve this ambiguity by setting supply shocks in demand-constrained sectors to zero. This choice does not matter for our baseline results in terms of aggregate and sectoral output, inflation, and employment but it does maximize the amount of Keynesian unemployment we measure. We do this because the other extreme, where we minimize the amount of Keynesian unemployment is uninteresting and results in zero Keynesian unemployment. This is because we can always imagine that there were negative supply shocks in demand-constrained sectors that were exactly equal to the observed reduction in hours in that sector.

We calibrate the primitive supply shocks to match changes in hours worked by sector from the May 2020 Bureau of Labor Statistics Economic News release following the procedure described in Baqaee et al. (2020). The right panel of Figure A1 in Appendix A shows the sectoral supply.

B. *Out-of-Sample Fit*

Having calibrated the model and the shocks, we now discuss the model's predictions about variables that we did not use for calibration. We judge the model's performance in terms of aggregate output, prices, and wages. At the aggregate level, the model predicts a reduction of real GDP of around -8.1 percent and a reduction in inflation of around -1.5 percent, which are both in line with the decline in real GDP and deflation measured by the BEA for our sample period.[22] Since we did not target changes in aggregate inflation or real GDP in our calibration, the model does well in terms of matching the aggregates.

At a more disaggregated level, we compare the change in industry-level prices in the model to realized changes in producer prices over the sample period. In the model, demand-constrained sectors experience -5.2 percent inflation and supply-constrained sectors experience inflation of 1.3 percent. In the data, those sectors that are demand constrained (according to the model) experienced inflation of -1.9 percent whereas those identified by the model as being supply constrained had inflation of 0.8 percent. Figure A2 in Appendix A shows a scatterplot of prices in the model against the data at the sectoral level, and Tables A1 and A2 in Appendix A report the list of demand- and supply-constrained industries along with the observed and model-implied price changes.

Overall, the model performs a reasonable job of predicting price changes, despite being highly stylized. The model does somewhat overpredict the magnitude of disaggregated price changes. This may be due to the fact that some capital markets also have nominal rigidities,[23] goods prices are also likely to be sticky, and producers

(from reduced elective procedures, etc.), in the data, health-care industries do not show large reductions in employment. Presumably, this reflects the fact that the excess capacity in the health-care industry is not wasted. Health-care workers are instead engaged in nonmarket activities related to the pandemic. Due to the unique role these sectors play in the pandemic, we exclude them here.

[22] We measure real GDP and the change in inflation using chained Tornqvist approximations to the Divisia index along a linear path.

[23] As explained in Section I, downward price rigidity in capital markets can be justified by appealing to nominal rigidities in credit markets, where firms whose nominal capital income falls violate financial covenants, default on their loans, and their capital becomes unemployed for the rest of the period.

may be unwilling to raise prices during a crisis, which are issues we have abstracted away from.

We also consider the model's performance in terms of matching changes in wages. We construct a measure for hourly industry-level wages by combining information from the Quarterly Census on Employment and Wages (QCEW) with the Current Population Survey (CPS).[24] The QCEW reports industry-level average weekly wages, defined as the total weekly wage bill for an industry divided by the number of employees. The CPS reports weekly hours per worker for workers in different industries. We compute changes in hourly wages by subtracting the change in average weekly hours from the CPS (between February and May of 2020) from changes in weekly wages (between the second and first quarter of 2020) from the QCEW.

The (wage-bill weighted) average wage inflation in supply-constrained sectors in the data is 2.0 percent and in demand-constrained industries is -8.1 percent. In other words, the sectors that the model identifies as being supply constrained experienced wage inflation whereas those the model identifies as demand constrained experienced significant wage deflation. This is especially interesting since hours fell by more in supply-constrained sectors (-18 percent) than in demand-constrained sectors (-11 percent). Therefore, supply-constrained sectors reduced hours by more than demand-constrained sectors, and yet experienced wage inflation, which is highly suggestive that these industries were affected by supply constraints. As with prices, since no wage data are used to calibrate the model, the large difference in wage inflation in the two sets of industries indicates that the model is able to separate supply and demand constraints.

Despite this success, comparing wages in the data and the model is problematic for two reasons. First, if the within-industry composition of workers changes toward lower-paid workers, then measured industry-level wages fall by more than true wages. Changing job composition is a major barrier to detecting downward wage rigidity in aggregated data like ours (see, for example, Hazell and Taska 2020).[25]

Second, the change in wages in supply-constrained sectors is not uniquely pinned down in our model (see footnote 10 for formal details). This is because reductions in potential labor are isomorphic to reductions in production capacity. For output, employment, and price inflation, reductions in capacity and potential labor are equivalent, but the implications for wages are different. If the supply shocks are entirely due to capacity constraints, then the increases in wages in supply-constrained sectors do not take place and are instead captured as Ricardian rents by the producers. In other words, the change in wages in supply-constrained sectors depends on what fraction of the increase in rent windfalls is captured by workers relative to firms. Thus, we can only provide a range of possible wage changes in supply-constrained industries, and any number between 0 percent and 19 percent is consistent with the model. In the demand-constrained sectors, wage inflation is of course necessarily 0 percent because of the binding downward wage rigidity.

[24] See Bureau of Labor Statistics (2020c) and Flood et al. (2021).

[25] In practice, wages are also not perfectly rigid downwards. Allowing for this is not conceptually difficult; see online Appendix E for a description of how the model can be extended to cover semiflexible wages.

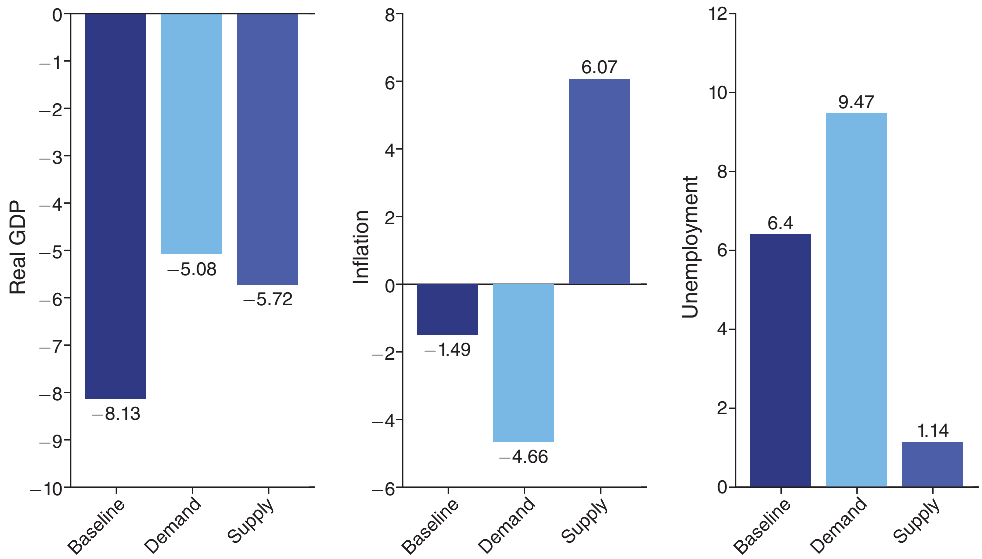

Figure 2. Real GDP, Inflation, and Keynesian Unemployment as a Function of Shocks for the Model with Complementarities

Notes: The "baseline" bar includes negative demand and supply shocks. The "supply" bar only includes the sectoral supply shocks. The "demand" bar only includes the demand shocks.

Source: Authors' calculations

C. *Importance of Supply and Demand Shocks*

Having discussed the model's out-of-sample fit to the data, we now use the model to decompose the importance of supply and demand shocks. Figure 2 displays the baseline calibration and decomposes the effect into only supply or only demand shocks. The "baseline" is the model which includes both the negative demand and negative sectoral supply shocks. The "supply" bar features only the negative sectoral supply shocks whereas the "demand" bar features only the demand shocks.

As mentioned before, supply shocks in demand-constrained sectors are not point identified, since the resource constraint is not binding in those markets. In other words, there could be negative supply shocks in demand-constrained sectors that are unobservable since these sectors are not operating at capacity. In reporting our results, we resolve this ambiguity by setting supply shocks in demand-constrained sectors to zero, which means that we pick the minimum-sized supply shocks that are consistent with the model. Of course, in practice, demand-constrained sectors also likely experienced negative supply shocks; however, since these shocks are unobservable in our model, we choose the calibration that allows us to best illustrate the economic forces our theoretical analysis highlights. Given this choice, we discuss the decomposition for real GDP, prices, and unemployment in turn.

Real GDP.—Figure 2 shows that negative demand shocks lead to a 5.1 percent reduction of real GDP and negative supply shocks reduce real GDP by 5.7 percent. Because of nonlinearities, the effect of the shocks together (-8.1 percent) is not the same as the sum of the two shocks. Intuitively, reductions in demand in sectors already experiencing large negative supply shocks do not reduce output by as much.

Prices.—Although the supply shocks on their own generate large reductions in output, Figure 2 shows that they also generate very substantial amounts of inflation around 6 percent. Meanwhile, the demand shocks, on their own, generate substantial deflation of around 5 percent. The baseline model, on the other hand, predicts an inflation rate of around -1.5 percent. The baseline model performs relatively well, since most price indices show either moderate inflation or moderate deflation. For instance, consumer price index (CPI) inflation for this period was -0.9 percent while personal consumption expenditures (PCE) inflation was -0.7 percent.[26] Both supply and demand shocks are needed to make sense of the large output reduction and moderate deflation observed in the data.

Unemployment.—We measure Keynesian unemployment by the reduction in hours in labor markets that are demand constrained.[27] As mentioned above, this means that we assume that demand-constrained sectors received no negative supply shocks and hence, Figure 2 is the maximum amount of Keynesian unemployment consistent with the model.

Figure 2 shows that the negative demand shocks, on their own, generate about 9.5 percent Keynesian unemployment. The "supply" bar in the figure shows that sectoral supply shocks, on their own, generate 1.1 percent Keynesian unemployment. Since this calibration has complete markets, this amplification effect is entirely due to complementarities, as discussed in Section IVA. Together, the supply and demand shocks generate around 6 percent Keynesian unemployment, which is less than demand shocks on their own, since some of the sectors hit with negative demand shocks are supply constrained once we account for the negative supply shocks.

D. *Tightness and Slackness across Sectors*

Although almost all sectors experienced reductions in hours, in some sectors, these reductions are due to supply constraints whilst in others they are due to demand shortfalls (see Figure A3 in Appendix A for a complete description). In the baseline, 28 factor markets are demand constrained and 38 factor markets are supply constrained.

Supply-constrained sectors include food and beverage and tobacco products (-8 percent), food services and drinking places (-37 percent), construction (-9 percent), and motion pictures (-54 percent). We interpret the reduction in hours in these sectors to be driven by state-mandated lockdowns, social distancing orders that limited capacity, and employers' fears of being held legally liable should

[26] The PCE is computed as a Fisher index and it therefore has changing weights reflecting the changing sectoral composition of final demand (unlike the CPI) and is therefore consistent with our model. On the other hand, the PCE does not capture changes in product variety, which could be of concern during lockdowns. Jaravel and O'Connell (2020) show that disappearing goods increased the effective inflation rate in the UK by around 80 basis points. This bias is not large enough to significantly affect our conclusions. We refer the reader to online Appendix G for an extension of the model which allows for disappearing varieties.

[27] Keynesian unemployment is defined as $\sum_{f\in\mathcal{L}}\left(\bar{\lambda}_f/\bar{\lambda}_{\mathcal{L}}\right)\left(\Delta\log\bar{L}_f - \Delta\log L_f\right) \geq 0$, where $\bar{\lambda}_{\mathcal{L}} = \sum_{f\in\mathcal{L}}\bar{\lambda}_f$. This captures the percentage underutilization of efficiency units of labor across labor markets.

their employees get sick. These restrictions and fears were severe during March and early April. Recall that supply constrained does not necessarily imply that the reductions are driven by reductions in labor supply or workers' willingness to work. Rather, a supply-constrained sector is one where an increase in nominal demand for the good the sector produces would not translate into increased employment.

Demand-constrained sectors include transportation industries, like air transportation (-40 percent), water transportation (-43 percent), rail transportation (-20 percent), and petroleum and coal (-21 percent) and oil and gas extraction (-20 percent).[28] These are industries that experienced sharp reductions in nominal spending, either directly by the household, or indirectly through the supply chain.

E. *Role of Complementarities*

Figure 3 displays aggregate outcomes in a version of the model where we set all elasticities of substitution equal to one—that is, the Cobb-Douglas model in Section III.

Real GDP, Inflation, and Unemployment.—In the Cobb-Douglas model, real GDP declines by around 8 percent in response to the shocks, which is similar to the response of the benchmark model. However, the breakdown between supply and demand is quite different. The supply shocks, on their own, reduce real GDP by only 4.8 percent (compared to 5.7 percent in the benchmark) while the demand shocks reduce real GDP by 6.0 percent (compared to 5.1 percent in the benchmark). Hence, as explained in Section IVA, complementarities amplify the importance of supply shocks and mitigate the effect of demand shocks, and these effects seem to be roughly off-setting one another.

With only sectoral supply shocks, Keynesian unemployment is now 0 percent (instead of 1.1 percent in the benchmark). This follows from the discussion in Section III: this version of the model has complete markets and no complementarities, so supply shocks in one sector do not change nominal spending on other sectors, and hence do not have Keynesian spillovers.

F. *Policy Implications*

We end this section by considering some policy counterfactuals. Two important policy tools used to combat adverse effects of the COVID-19 pandemic have been stimulative monetary policy and increased social insurance, in the form of transfers like unemployment benefits. We discuss both of these in turn.

Implications for Aggregate Demand Management.—Sectorally disparate supply and demand shocks blunt the power of aggregate demand stimulus. Conventional monetary policy, forward guidance, and untargeted fiscal policy boost aggregate

[28] Our simulations also show that health-care related industries, like hospitals and ambulatory health care services also experienced reductions in employment of (-13 percent) and (-15 percent). However, presumably, this excess capacity in the health-care industry is not wasted but engaged in nonmarket activities related to the pandemic.

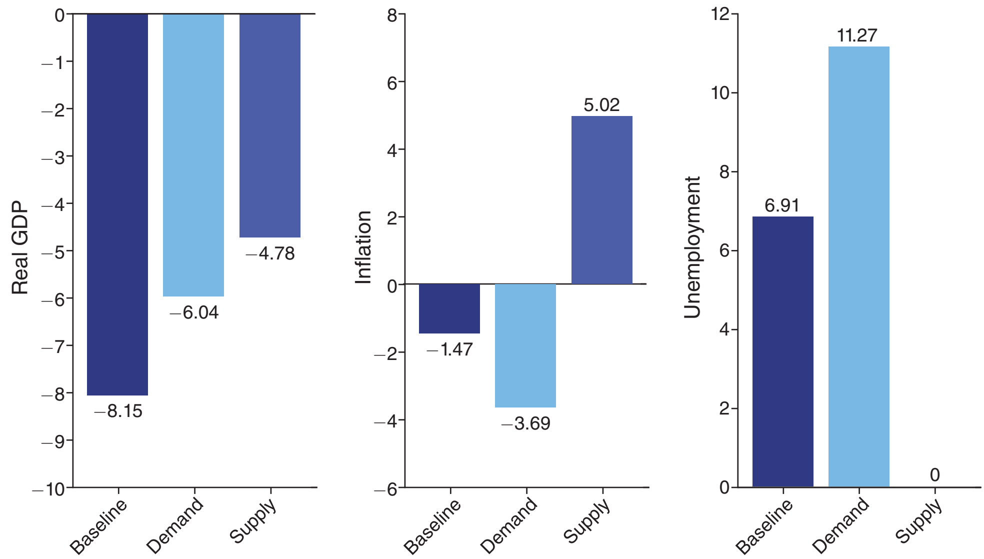

Figure 3. Real GDP, Inflation, and Keynesian Unemployment as a Function of Shocks without Complementarities

Notes: The "baseline" line includes negative demand and supply shocks. The "supply" bar only includes the sectoral supply shocks. The "demand" bar only includes the demand shocks.

Source: Authors' calculations

demand. However, with heterogeneous supply and demand shocks, reversing the decline in aggregate demand is not enough to offset the negative effect of the shocks.

To see this, we consider the reduction in real GDP in response to a pure negative demand shock, holding fixed the sectoral composition of final demand and setting supply shocks to zero. In the Cobb-Douglas model, the negative aggregate demand shock associated with COVID-19, on its own, reduced real GDP by around 5 percent. Therefore, a large enough aggregate demand stimulus can raise real GDP by around 5 percent fully offsetting the negative aggregate demand shock. However, with the full set of supply and demand shocks, the same sized aggregate demand stimulus raises real GDP from -8.2 percent to -6.4 percent. In other words, the same aggregate demand stimulus only raises real GDP by around 1.8 percent. Hence, the presence of sectoral shocks cuts the potency of aggregate demand stimulus by around *one-half* in the Cobb-Douglas model.

In the model with complementarities, this effect is even more extreme. Whereas the aggregate demand shock on its own reduces output by 4.3 percent, with the full set of sectoral supply and demand shocks, reversing the reduction in aggregate demand through stimulus only boosts output by around 1.3 percent. Hence, the potency of the aggregate demand stimulus is cut almost by a factor of four in the model with complementarities. Intuitively, this is because the increase in aggregate demand raises the price of supply-constrained factors, and complementarities then cause expenditures to switch toward these factors and away from demand-constrained ones. This reduces the stimulative effect of aggregate demand stimulus.

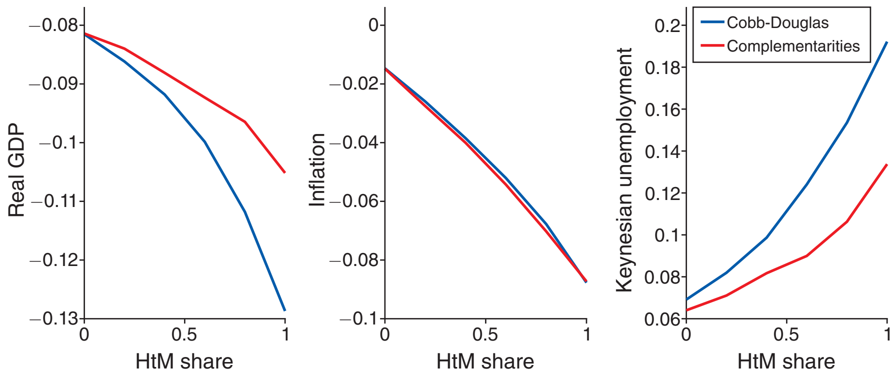

Figure 4. Real GDP, Inflation, and Keynesian Unemployment in the Cobb-Douglas Model and the Model with Complementarities as a Function of the Share of Potentially HtM Workers

Source: Authors' calculations

If we think of the model without sectoral shocks as a typical recession, this means that aggregate demand stimulus is significantly less effective in the COVID-19 recession than in a typical recession. The reason is that without sectoral shocks, the reduction in aggregate demand renders all labor markets demand constrained, and starting from there, an increase in aggregate demand increases employment in all labor markets. By contrast, with sectoral shocks, some labor markets are supply constrained, and starting from there, an increase in aggregate demand is partly dissipated in wage increases in supply-constrained labor markets (the more so, the stronger the complementarities across sectors).

Reduced Social Insurance.—Figure 4 shows how aggregate outcomes change in the model with complementarities and in the Cobb-Douglas model as we vary the share of households that are potentially HtM. As expected, the presence of HtM households amplifies the reduction in real GDP, reduces inflation, and causes Keynesian unemployment. For example, in the Cobb-Douglas model, when all unemployed workers are HtM, real GDP falls by 13 percent rather than 8 percent, with very significant deflation of −9 percent rather than −1 percent, and Keynesian unemployment of 19 percent rather than 7 percent. This underscores the important role that transfers have played in mitigating the negative demand effects associated with the COVID-19 crisis. In the absence of these policies, employment and output would be significantly lower.

These numbers are smaller with complementarities, since the endogenous negative aggregate demand shock associated with HtM households is partially absorbed by supply-constrained factor markets. Specifically, in response to the negative endogenous aggregate demand shock, the price of capital and supply-constrained labor declines, which triggers substitution away from supply-constrained markets toward demand-constrained markets due to complementarities. This is a quantitatively significant stabilizing force in the model. Nevertheless, even in the model with complementarities, social insurance is still very important.

Inflation, the middle panel of Figure 4, is relatively insensitive to complementarities. This is to be expected when there are complete markets, because in this case, the complementarities amplify the supply shocks by roughly the same amount that they mitigate the demand shocks, leaving the overall change in real GDP (and hence the price level) roughly unchanged. This is also to be expected at the opposite extreme when all unemployed workers are credit constrained. According to Corollary 1, when all unemployed workers are HtM, $\phi_f = 0$, the change in the price level is just the negative aggregate demand shock $d\log p^Y = d\log\zeta \approx -9\%$ regardless of complementarities.

Intuitively, when markets are incomplete, reductions in employment in the Cobb-Douglas model are greater (and so inflation is higher), but these reductions are less and less inflationary as we lower ϕ because, for lower ϕ, reductions in employment also reduce total nominal expenditures and hence raise inflation by less. At the extreme point where $\phi = 0$, reductions in employment cease to be inflationary.

VI. Extensions

In this section, we briefly summarize extensions of the basic framework that appear in the online Appendices. Online Appendix D provides local comparative statics for production networks with arbitrary elasticities of substitution. Online Appendix E extends our results to the case where wages are semiflexible. Online Appendix G extends the framework to cover capital market imperfections and bankruptcies. In this appendix, we show that firm exits act like endogenous negative productivity shocks. Accordingly, they are amplified by input-output linkages (just as exogenous productivity shocks are amplified by input-output linkages). Furthermore, exits change relative prices, and these relative price changes can redirect the flow of spending and cause Keynesian spillovers, much as negative supply shocks. Finally, we also show how exits can result in scarring effects since firms that exit today may not be replaced in the future, this lowers output in the future, which reduces aggregate demand today via the Euler equation (a mechanism emphasized by Fornaro and Wolf 2020). Online Appendix F generalizes the results in Section II to environments with investment and establishes global comparative statics.

VII. Conclusion

This paper analytically characterizes the impact of supply and demand shocks in disaggregated economies with multiple sectors, factors, and input-output linkages, as well as occasionally binding downward nominal wage rigidity, credit constraints, and a zero lower bound. Using a stylized model, we numerically quantify the impact of supply and demand shocks associated with the COVID-19 crisis, zooming in on the role of complementarities and the implications for aggregate demand management.

Separating the supply and demand sources for the crisis are important since supply- and demand-constrained industries respond differently to policy interventions. Nevertheless, the analysis in this paper is purely positive. For a normative analysis, we would have to take a stance on the health-related externalities of production and consumption. In particular, it may be that implementing the flexible price allocation is not necessarily optimal once we account for these externalities. Nevertheless, the results of any normative analysis would rely on understanding the positive forces analyzed in this paper.

Appendix A. Additional Graphs and Tables

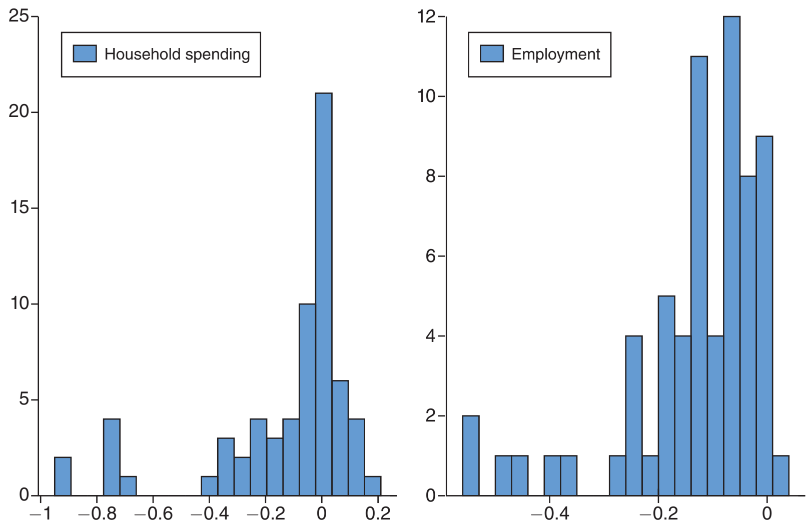

Figure A1

Note: Reduction in nominal household spending (left panel) and hours worked (right panel) as fractions by sector in May 2020 compared to February 2020.

Sources: Bureau of Labor Statistics (2020a) and Bureau of Economic Analysis (2020)

Table A1—Demand-Constrained Sectors with Model-Implied and Observed Growth Rate in Prices from February to May 2020

Demand-constrained sectors	Inflation (model)	Inflation (data)
Farms	−0.22	−0.39
Oil and gas extraction	−0.22	−0.36
Utilities	−0.18	−0.09
Petroleum and coal products	−0.18	−0.05
Chemical products	−0.12	−0.01
Food and beverage stores	−0.1	0.01
General merchandise stores	−0.08	0
Air transportation	−0.06	0.01
Rail transportation	−0.06	−0.01
Water transportation	−0.06	−0.01
Pipeline transportation	−0.06	0.01
Other transportation and support activities	−0.06	−0.02
Broadcasting and telecommunications	−0.06	−0.01
Data processing, internet publishing, and other information services	−0.05	0
Federal Reserve banks, credit intermediation, and related activities	−0.05	0
Securities, commodity contracts, and investments	−0.05	0.01
Insurance carriers and related activities	−0.05	0.01
Funds, trusts, and other financial vehicles	−0.04	−0.09
Other real estate	−0.04	−0.01
Legal services	−0.03	0
Computer systems design and related services	−0.03	0.01
Miscellaneous professional, scientific, and technical services	−0.02	−0.01
Management of companies and enterprises	−0.02	0.01
Waste management and remediation services	−0.02	−0.1
Ambulatory health care services	−0.02	0.01
Hospitals	−0.02	−0.01
Nursing and residential care facilities	−0.01	0.02
Other services, except government	−0.01	−0.07

Note: Sectors with missing prices are excluded.

Sources: Authors' calculations and Bureau of Labor Statistics (2020b) and Census Bureau (2020)

Table A2—Supply-Constrained Sectors with Model-Implied and Observed Growth Rate in Prices from February to May 2020

Supply-constrained sectors	Inflation (model)	Inflation (data)
Forestry, fishing, and related activities	−0.14	−0.03
Mining, except oil and gas	−0.1	−0.11
Support activities for mining	−0.1	0.01
Construction	−0.08	0.01
Wood products	−0.07	−0.06
Nonmetallic mineral products	−0.06	−0.04
Primary metals	−0.03	0
Fabricated metal products	−0.03	0
Machinery	−0.02	0
Computer and electronic products	−0.02	0
Electrical equipment, appliances, and components	−0.02	0
Motor vehicles, bodies and trailers, and parts	−0.01	−0.01
Other transportation equipment	−0.01	−0.06
Furniture and related products	−0.01	0.01
Miscellaneous manufacturing	0	0.06
Food and beverage and tobacco products	0.01	0.01
Textile mills and textile product mills	0.01	0.02
Apparel and leather and allied products	0.01	0.01
Paper products	0.02	0
Printing and related support activities	0.02	0
Plastics and rubber products	0.02	0
Wholesale trade	0.02	0
Motor vehicle and parts dealers	0.02	0
Other retail	0.03	0
Truck transportation	0.03	0.07
Transit and ground passenger transportation	0.04	−0.02
Warehousing and storage	0.04	0
Publishing industries, except internet (includes software)	0.04	0
Motion picture and sound recording industries	0.05	0
Housing services	0.05	0
Rental and leasing services and lessors of intangible assets	0.05	0
Administrative and support services	0.06	0.01
Educational services	0.07	−0.01
Social assistance	0.09	0.01
Performing arts, spectator sports, museums, and related activities	0.1	0
Amusements, gambling, and recreation industries	0.12	0.02
Accommodation	0.15	−0.05
Food services and drinking places	0.19	0

Note: Sectors with missing prices are excluded.

Sources: Authors' calculations and Bureau of Labor Statistics (2020b) and Census Bureau (2020)

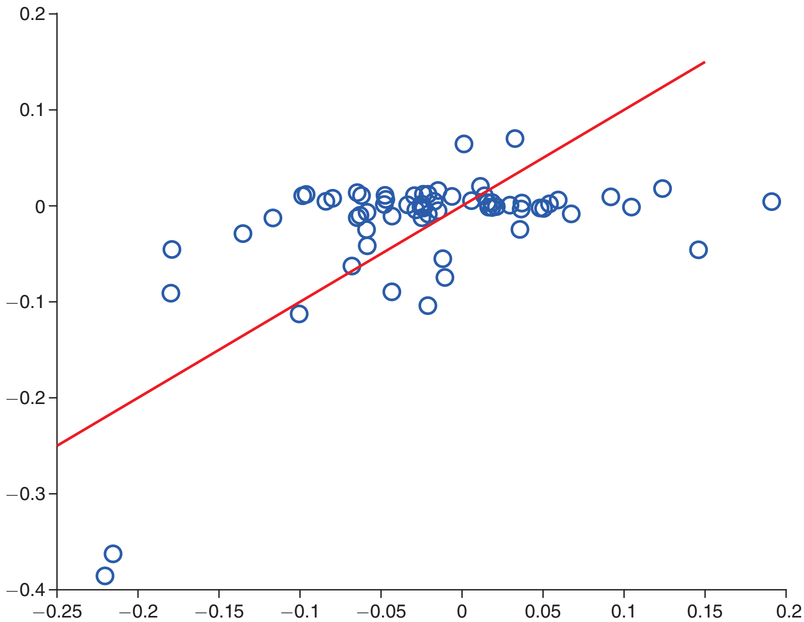

FIGURE A2

Notes: Changes in model implied prices are on the *x*-axis and changes in producer prices are on the *y*-axis. The red line is the 45-degree line.

Sources: Authors' calculations and Bureau of Labor Statistics (2020b) and Census Bureau (2020)

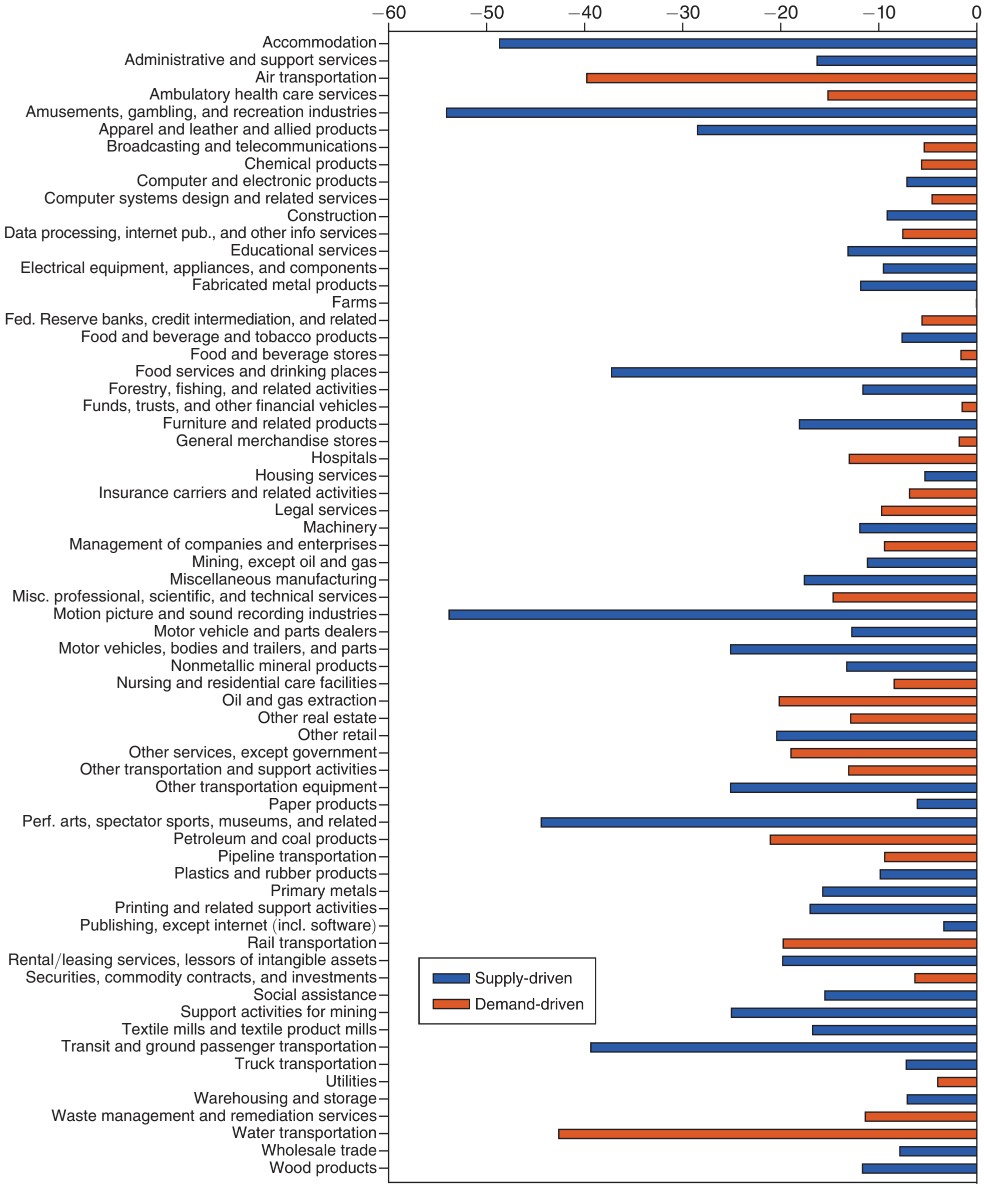

FIGURE A3

Notes: Model implied percentage reduction in hours by sector from February to May 2020. Sectors below capacity are "demand-driven."

Source: Authors' calculations

REFERENCES

Atalay, Enghin. 2017. "How Important Are Sectoral Shocks?" *American Economic Journal: Macroeconomics* 9 (4): 254–80.

Baqaee, David Rezza. 2015. "Targeted Fiscal Policy." Unpublished.

Baqaee, David, and Emmanuel Farhi. 2019. "The Macroeconomic Impact of Microeconomic Shocks: Beyond Hulten's Theorem." *Econometrica* 87 (4): 1155–1203.

Baqaee, David, and Emmanuel Farhi. 2020. "Nonlinear Production Networks with an Application to the Covid-19 Crisis." Unpublished.

Baqaee, David, and Emmanuel Farhi. 2021. "Keynesian Production Networks and the COVID-19 Crisis: A Simple Benchmark." *AEA Papers and Proceedings* 111: 272–76.

Baqaee, David, and Emmanuel Farhi. 2022. "Replication Data for: Supply and Demand in Disaggregated Keynesian Economies with an Application to the COVID-19 Crisis." American Economic Association [publisher], Inter-university Consortium for Political and Social Research [distributor]. https://doi.org/10.3886/E152801V1.

Baqaee, David, Emmanuel Farhi, Michael J. Mina, and James H. Stock. 2020. "Reopening Scenarios." NBER Working Paper 27244.

Barrot, Jean-Noel, Basile Grassi, and Julien Sauvagnat. 2020. "Sectoral Effects of Social Distancing." SSRN Working Paper 3569446.

Benigno, Gianluca, and Luca Fornaro. 2018. "Stagnation Traps." *Review of Economic Studies* 85 (3): 1425–70.

Bigio, Saki, Mengbo Zhang, and Eduardo Zilberman. 2020. "Transfers vs Credit Policy: Macroeconomic Policy Trade-offs during Covid-19." Unpublished.

Bodenstein, Martin, Giancarlo Corsetti, and Luca Guerrieri. 2020. "Social Distancing and Supply Disruptions in a Pandemic." Unpublished.

Boehm, Christoph E., Aaron Flaaen, and Nitya Pandalai-Nayar. 2019. "Input Linkages and the Transmission of Shocks: Firm-Level Evidence from the 2011 Tōhoku Earthquake." *Review of Economics and Statistics* 101 (1): 60–75.

Bonadio, Barthélémy, Zhen Huo, Andrei Levchenko, and Nitya Pandalai-Nayar. 2020. "Global Supply Chains in the Pandemic." Unpublished.

Brinca, Pedro, Joao Duarte, and Miguel Faria-e Castro. 2020. "Measuring Sectoral Supply and Demand Shocks during COVID-19." Unpublished.

Bureau of Economic Analysis. 2020. "National Income and Product Accounts Table 2.4.5U." Bureau of Economic Analysis. https://apps.bea.gov/iTable/iTable.cfm?reqid=19&step=2#reqid=19&step=2&isuri=1&1921=underlying.

Bureau of Labor Statistics. 2020a. "Establishment Survey Table B-1 and B-2." Bureau of Labor Statistics. https://www.bls.gov/news.release/empsit.nr0.htm.

Bureau of Labor Statistics. 2020b. "Industry and Commodity-level Producer Price Index." Bureau of Labor Statistics. https://data.bls.gov/cgi-bin/srgate.

Bureau of Labor Statistics. 2020c. "Quarterly Census of Employment and Wages." Bureau of Labor Statistics. https://data.bls.gov/cew/apps/data_views/data_views.htm#tab=Tables.

Caballero, Ricardo J., and Alp Simsek. 2020. "A Model of Asset Price Spirals and Aggregate Demand Amplification of a 'COVID-19' Shock." SSRN Working Paper 3576979.

Census Bureau. 2020. "Industry Sales." Census Bureau. https://data.census.gov/cedsci/table?q=industry\%20sales&n=N0200.00\%3AN0300.00\%3AN0400.00&tid=ECNBASIC2017.EC1700BASIC&hidePreview=true.

Eggertsson, Gauti B., and Paul Krugman. 2012. "Debt, Deleveraging, and the Liquidity Trap: A Fisher-Minsky-Koo Approach." *Quarterly Journal of Economics* 127 (3): 1469–1513.

Elliott, Matthew, Benjamin Golub, and Matthew O. Jackson. 2014. "Financial Networks and Contagion." *American Economic Review* 104 (10): 3115–53.

Flood, Sarah, Miriam King, Renae Rodgers, Steven Ruggles, and J. Robert Warren. 2021. "Integrated Public Use Microdata Series, Current Population Survey: Version 9.0 [dataset]. Minneapolis: IPUMS." IPUMS. https://www.ipums.org/projects/ipums-usa/d010.v9.0.

Fornaro, Luca, and Martin Wolf. 2020. "Covid-19 Coronavirus and Macroeconomic Policy." Unpublished.

Guerrieri, Veronica, Guido Lorenzoni, Ludwig Straub, and Iván Werning. 2020. "Macroeconomic Implications of COVID-19: Can Negative Supply Shocks Cause Demand Shortages?" NBER Working Paper 26918.

Hazell, Jonathon, and Bledi Taska. 2020. "Downward Rigidity in the Wage for New Hires." Unpublished.

Herrendorf, Berthold, Richard Rogerson, and Akos Valentinyi. 2013. "Two Perspectives on Preferences and Structural Transformation." *American Economic Review* 103 (7): 2752–89.

Hulten, Charles R. 1978. "Growth Accounting with Intermediate Inputs." *Review of Economic Studies* 45 (3): 511–18.

Jaravel, Xavier, and Martin O'Connell. 2020. "Inflation Spike and Falling Product Variety during the Great Lockdown." *Journal of Public Economics* 191: 104270.

Kaplan, Greg, Benjamin Moll, and Gianluca Violante. 2020. "Pandemics According to HANK." Unpublished.

Krugman, Paul R. 1998. "It's baaack: Japan's slump and the return of the liquidity trap." *Brookings Papers on Economic Activity* 2: 137–87.

La'O, Jennifer, and Alireza Tahbaz-Salehi. 2020. "Optimal Monetary Policy in Production Networks." Unpublished.

McKenzie, Lionel W. 1959. "On the Existence of General Equilibrium for a Competitive Market." *Econometrica* 27: 54–71.

Oberfield, Ezra. 2013. "Productivity and Misallocation during a Crisis: Evidence from the Chilean Crisis of 1982." *Review of Economic Dynamics* 16 (1): 100–119.

Ozdagli, Ali, and Michael Weber. 2017. "Monetary Policy through Production Networks: Evidence from the Stock Market." NBER Working Paper 23424.

Pasten, Ernesto, Raphael Schoenle, and Michael Weber. 2017. "Price Rigidity and the Granular Origin of Aggregate Fluctuations." Unpublished.

Pasten, Ernesto, Raphael Schoenle, and Michael Weber. 2019. "The Propagation of Monetary Policy Shocks in a Heterogeneous Production Economy." *Journal of Monetary Economics* 116: 1–22.

Rubbo, Elisa. 2020. "Networks, Phillips Curves and Monetary Policy." Unpublished.

Vives, Xavier. 1990. "Nash Equilibrium with Strategic Complementarities." *Journal of Mathematical Economics* 19 (3): 305–21.