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What Comes Next?*

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Abstract

The Covid crisis prompted an unprecedented global economic contraction. Although the worst is likely behind us, the recovery is likely to be uneven, with economic activity in many customer-facing service industries set to remain constrained for some time. I use a quantitative multi-industry model to estimate the economic forces that explain the decline in economic activity in the United States, the Euro Area, Japan and China in the first half of 2020. I then use the model to project the trajectory of the economic recovery. I find that the US, EA and Japan will each face a '98% economy' if half of the constraints faced by customer-facing service industries in the first half of 2020 persist. The economic recovery in China is projected to occur more quickly.

Keywords: Structural change; Macroeconomic outlook; Model projection

JEL codes: C32; E60; E170

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1 Introduction

The Covid crisis has triggered unprecedented decline in global economic activity. In many Advanced Economies (AEs), output contracted by more than 10% in the first half of 2020. Some Emerging Market Economies (EMEs) saw even sharper downturns. In China, whose economy had experienced sustained growth for almost three decades, year-on-year GDP growth turned negative for the first time since the early 1990s.

The economic contraction was felt unevenly across industries. Services that involve personal interactions between customers and workers were hit particularly hard. In the United States (US), consumption of recreation services declined by 49% in 2020Q2, and consumption of transport services by 34%. In contrast, consumption of durable goods, which typically contracts sharply during recessions, fell by only 0.3%. Consumption of recreational goods actually increased. Similar patterns were observed in other economies.

While the trough in economic activity seems to have passed, the recovery looks set to be slow and uneven. Some industries have recovered quickly after the easing of explicit lockdown measures. But many firms, particularly in customer-facing service industries, face ongoing constraints. These include regulatory restrictions on how firms operate as well as voluntary changes in behaviour as customers seek to avoid activities that put them at greater risk of contracting the virus. Some of these constraints are likely to persist until a vaccine or effective treatment is available.

The unevenness of the recovery has led to speculation that many countries could face a '90% economy' in the years ahead.[1] According to this view, depressed conditions in customer-facing service industries will create an ongoing 'hole' in aggregate demand. Firms in these industries will demand fewer inputs from their suppliers, lowering output throughout their supply chains. As firms directly affected by the pandemic cut back on production, the resulting loss of income for workers and shareholders will lower aggregate demand more broadly, deepening the slump further.

At the same time, there are several reasons to think that economies could recover more strongly than the '90% economy' view might suggest. A large part of the decline in economic activity in the first half of the year was due to aggregate forces such as broad-based lockdowns, heightened precautionary saving by consumers and dislocations in financial markets. In part, these responses reflected high levels of uncertainty about the nature of the virus as it spread around the world in the first few months of the year (Baker et al. (2020)). Much of this uncertainty has since been resolved in recent months as the medical community's understanding of the virus and ability to treat its symptoms, has increased. And in most regions, blanket lockdowns have given way to more targeted measures. In the meantime, in many economies monetary and fiscal policymakers have provided considerable stimulus to support aggregate demand and introduced measures to improve the functioning of financial markets. These policies should contribute to an improvement in economic conditions.

At an aggregate level, some of the loss of custom experienced by firms particularly exposed to the virus could also be made up for by increased demand for other goods and services. This could be due to shifts in consumer preferences across industries - eg if less demand for restaurant meals leads to more demand for

[1]See, for example: The Economist (2020a)

food that can be consumed at home - or changes within industries - eg if less foot traffic at retail outlets is replaced by purchases made online. Some of these shifts could merely represent an acceleration of existing trends and some may even be productivity-enhancing. To be sure, the shifts in the composition of demand that the virus has prompted will involve severe disruptions for individual firms and workers. Policy may have an important role to play in helping firms and workers to cope with those disruptions. But it is not clear that these shifts will have large negative effects at an aggregate level.

A number of factors will therefore determine 'what comes next' for global economic activity. Among the most important are the nature of the disturbances affecting individual economies; whether they represent aggregate or industry-specific disturbances and whether they reflect shifts in demand or in supply. The evolution of these disturbances will also matter greatly. And much will depend on how smoothly economies can accommodate the changes in industrial composition that these aggregate and industry-level disturbances will entail.

This paper provides quantitative estimates of these forces. To this end, I build an economic model to capture the key industry-level and aggregate transmission mechanisms that were at work during the Covid crisis and which will shape the recovery. In addition to the usual set of nominal and real rigidities typically used to account for aggregate economic fluctuations, the model features a detailed industry structure on both the demand and production side. This allows it to account for industry-specific shifts in consumer preferences and work practices, and then to project the implications of these shifts for aggregate outcomes. I calibrate the model to match the industrial structure of the US, the Euro Area (EA), Japan and China. I then use the model to estimate the aggregate- and industry-level supply and demand disturbances that explain the contraction in economic activity in the first half of 2020. Conditional on these disturbances, I construct projections for how economic activity could evolve over the coming years.

I find that the US, EA and Japan could each face a '98% economy' over the next few years. That is, even factoring in a fairly rapid economic recovery into the first half of 2021, these economies could see output stagnate persistently 2% below its pre-crisis trend. The recovery is also likely to result in a greater-than-usual degree of industry re-allocation. In particular, the output of customer-facing service industries is projected to remain between 10 and 20% below its pre-crisis trajectory for several years in these three economies.

My results indicate that aggregate economic activity in China will recover more quickly than in the other economies. Under the model's baseline scenario, output in China returns to its pre-crisis trajectory by the end of 2021. However, the recovery in China is also uneven at an industry level. Output in customer-facing service industries is projected to remain more than 5% below its pre-crisis trajectory. The relatively small weight of these industries in aggregate economic activity in China, and a more rapid recovery in other parts of the economy, explain the more positive projections for aggregate output.

The baseline projections rest on two key assumptions: first, that the economy-wide forces constraining economic activity in the first half of 2020 dissipate over the rest of the year; and second, that around half of the disturbances specific to customer-facing service industries persist until mid-2023. Under the more optimistic assumption that the constraints on customer-facing service industries loosen in the first half of 2021, the level of activity in all four economies is estimated to return to its pre-crisis trajectory by early 2022. However, under the more pessimistic assumption that customer-facing service industries face more severe constraints that persist until mid-2025, the US, EA and Japan could face a '95% economy', with activity stagnating 5 per cent below its pre-crisis trajectory.

The rest of the paper is as follows. Section 2 lays out the model the model and describes the differential effects of industry-level supply and demand disturbances. Section 3 explains the economic developments that determined the Covid crisis. Section 4 provides projections under a range of scenarios. Section 5 concludes.

2 Model and calibration

In this section I provide a description of the essential features of the model, and describe its calibration. As many features of the model are standard, I focus on those aspects most relevant for the modelling the Covid crisis and direct readers interested in the full set of model equations to the Online Appendix accompanying the paper.

2.1 The Model

The model consists of a closed economy whose main actors are households, firms, the government and the central bank.

Households come in two types. The first, termed 'Ricardian' households, are able to borrow and save in financial markets. These households make consumption, work, investment and saving decisions in order to maximise their discounted lifetime utility, subject to an intertemporal budget constraint. For example, the utility function of Ricardian household ι is given by:

$$\sum_{t=0}^{\infty} \beta^t \left[e^{\xi_{c,t}} \log(C_t^r(\iota) - hC_{t-1}^r(\iota)) - \frac{A_N}{1+\nu} N_t^r(\iota)^{1+\nu} \right] \tag{1}$$

where $C_t^r(\iota)$ is the total consumption of the household and $N_t^r(\iota)$ is the total labour supply of the household. The term $e^{\xi_{c,t}}$, which is common to all households, is a 'preference shifter'. Movements in this term induce changes in consumption independent of other factors such as income or interest rates.

The budget constraint of a typical Ricardian household is given by:

$$P_{C,t}C_t^r(\iota) + P_{I,t}I_t^r(\iota) + \frac{B_{t+1}^r(\iota)}{R_t} \leq B_t^r(\iota) + \sum_{j=1}^{\mathcal{F}} \left(P_{C,t} \frac{r_{j,t}^K}{\mathcal{M}_t} k_{j,t}^r(\iota) + w_{j,t}(\iota) n_{j,t}^r(\iota) \right) + T_t^r(\iota) \tag{2}$$

where $I_t^r(\iota)$ is the household's total investment in physical capital, $P_{C,t}$ and $P_{I,t}$ are the prices of the investment and consumption goods, $B_{t+1}^r(\iota)$ is a risk free nominal bond that pays one unit of the consumption good in period $t+1$, R_t is the interest rate attached to that bond and $T_t^r(\iota)$ are lump sum transfers from the government to Ricardian households.[2] There are $\mathcal{F}$ industries in the economy (examples of industries include the Agriculture industry or the Manufacturing industry). The variables $k_{j,t}^r(\iota)$ and

[2]These transfers can be either positive or negative.

$n^r_{j,t}(\iota)$ represent total supply of capital and labour from the household to industry j.[3] The variables $r^k_{j,t}$ and $w_{h,t}$ are the return on capital and nominal wages paid by that industry. The variable $\mathcal{M}_t$ introduces a wedge between the return on capital paid by firms and that received by households. It is included as a reduced form device to capture the tendency for spreads between risk free interest rates and returns on risky assets to widen during times of heightened economic uncertainty.[4]

The second type of households, termed 'hand-to-mouth' households have a similar utility function to the Ricardian households. However, these households are financially constrained, meaning that each period their consumption is exactly equal to their income, which consists of wage income and transfers from the government. As such, these households also do no investment and do not own claims to the capital stock of firms. The inclusion of 'hand-to-mouth' households strengthens income effects in the model as the consumption of these individuals is highly sensitive to labour market conditions.

The aggregate consumption and investment goods in Equation 2 consist of bundles of products from individual industries. For example, the aggregate consumption bundle for Ricardian consumers is:

$$C^r_t = \left[\sum_{j=1}^{\mathcal{F}} \omega_{cj}^{\frac{1}{\eta}} (c^r_{j,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{3}$$

where $c^r_{j,t}$ is the consumption of the output of industry j at time t for Ricardian consumers.[5] The parameter $\omega_{c,j}$ controls the weight of industry j in the aggregate consumption bundle. A shift in consumer preferences from, say, eating food at restaurants (a Recreation service) towards purchasing food for consumption at home (a Retail trade service) would appear in the model as a change in $\omega_{c,j}$.[6] The parameter η controls the degree of substitutability between the output of different industries in consumption. If η is large, different industries' output are close substitutes. If η is close to zero, consumers are less willing to substitute between the output of different industries.

The aggregate labour supply that appears in the household utility function also consists of a weighted sum of labour supply to individual industries:

$$N^r_t(\iota) = \left[\sum_{j=1}^{\mathcal{F}} \omega_{nj}^{-\frac{1}{\xi}} n_{j,t}(\iota)^{\frac{\xi+1}{\xi}} \right]^{\frac{\xi}{\xi+1}} \tag{4}$$

where the term ω_{nj} captures the relative disutility that the household receives from supply labour to industry j and ξ controls the substitutability of work in different industries. If $\xi = \infty$ workers are indifferent between which industries they work in. For smaller values of ξ workers are less willing to move between industries.

[3] The economy features a single investment good, which can be used to produce capital in any industry. However, once installed, capital is industry-specific. This limits the speed with which the economy's production structure can respond to shifts in demand or supply in an individual industry.

[4] I assume that financial intermediaries return this wedge lump sum to the Ricardian households so that it does not affect their total lifetime income.

[5] The functional form of the consumption bundle for rule-of-thumb consumers is identical to that for Ricardian consumers.

[6] Because the weights in the consumption basket must sum to one, a decrease in $\omega_{c,j}$ for one industry must be offset by an increase in the weight for at least one other industry.

On the production side of the model, each industry consists of a large number of firms that produce differentiated varieties under conditions of monopolistic competition. Individual firms produce output using a multi-stage production process. The first stage of the process combines labour and capital according to the production function:

$$f_{j,t}(i) = \left[\omega_{f,j}^{\frac{1}{\zeta}} n_{j,t}(i)^{\frac{\zeta-1}{\zeta}} + (1-\omega_{f,j})^{\frac{1}{\zeta}} k_{j,t}(i)^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}} \tag{5}$$

where $f_{j,t}(i)$ is the output produced by combining capital and labour firm i in industry j and $n_{j,t}(i)$ and $k_{j,t}(i)$ are the amount of labour and capital used by the firm. The parameter ζ is the elasticity of substitution between capital and labour in the production function.

The resulting output is then combined with intermediate inputs - goods and services sourced from other industries:

$$y_{j,t}(i) = a_{j,t}\left[\omega_{y,j}^{\frac{1}{\varphi}} f_{j,t}(i)^{\frac{\varphi-1}{\varphi}} + (1-\omega_{y,j}) x_{j,t}(i)^{\frac{\varphi-1}{\varphi}}\right]^{\frac{\varphi}{\varphi-1}} \tag{6}$$

where $y_{j,t}(i)$ is the gross output of firm i in in industry j. Because of the use of intermediate inputs, a distinction exists between the gross output of an industry and value added output. The latter is calculated by subtracting the value of intermediate inputs from gross output. The term $a_{j,t}$ is industry-specific total factor productivity in industry j (which is common to all firms in that industry). $x_{j,t}(i)$ is the quantity of intermediate inputs used in industry j. The parameter φ is the elasticity of substitution between intermediate inputs and the aggregate of labour and capital.[7]

Market clearing for the output of industry j requires that the gross output of the industry, $y_{j,t}$ equals the sum of demand for the good as a consumption good ($c_{j,t}$), investment good ($i_{j,t}$) and public demand good ($g_{j,t}$), or as an intermediate input:

$$y_{j,t} = c_{j,t} + i_{j,t} + g_{j,t} + \sum_{k=1}^{\mathcal{F}} x_{k,j,t} \tag{7}$$

where $x_{k,j,t}$ is the quantity of the output of industry j used as an intermediate input in industry k.

The existence of intermediate inputs creates production-side linkages between industries. For example, a decrease in output in the manufacturing industry will also lower demand for the output of industries that provide intermediate inputs to that industry. Similarly, lower productivity in the manufacturing industry will raise costs for firms in industries that use manufacturing as an input into production. The importance of these inter-industry linkages will depend on the weight of intermediate inputs in industry production functions and in the substitutability between intermediate inputs and other factors. Product differentiation means that firms are able to exert a degree of pricing power. Similarly, households are assumed to unionise, giving them a degree of monopoly power in the labour market. Both firms and unions face frictions that limit their ability to reset their prices and wages each period. These generate nominal rigidities in the

[7] The intermediate input is itself a bundle of intermediate goods from the other industries: $x_{j,t} = \left[\sum_{k=1}^{\mathcal{F}} \omega_{k,j}^{\frac{1}{\psi}} x_{k,j,t}(i)^{\frac{\psi-1}{\psi}}\right]^{\frac{\psi}{\psi-1}}$, where ψ is the elasticity of substitution between different varieties of intermediate goods.

Table 1: Common parameter values

Parameter	Description	Value
h	Degree of habits in consumption	0.7
S''	Investment adjustment cost	3
θ_w	Calvo parameter for wages	0.65
θ_p^s	Calvo parameter for sticky prices	0.7
θ_p^f	Calvo parameter for semi-sticky prices	0.5
ψ	Substitutability of labour and capital in production	0.95
ψ	Substitutability of different intermediate products in production	0.5
φ	Substituability of primary factors and intermediates in production	0.6
ν	Aggregate labour supply elasticity	2
δ	Capital discount rate	0.02
η	Substitution elasticity in demand functions	0.9
ξ	Substitution elasticity between industries in labour supply	2
ω_r	Share of Ricardian households	0.75
β	Household discount rate	0.995

model. Real rigidities come from the presence of habits in the household utility function and quadratic adjustment costs in investment.

The government in the model fulfils two function. First, it purchases goods and services directly from firms.[8] I assume that this source of aggregate demand follows an exogenous AR(1) process. Second, it transfers resources between Ricardian and rule-of-thumb consumers.

The model's central bank adjusts the policy interest rate in response to deviations of inflation from target. In practice, several of the central banks in the empirical exercise below have limited ability to stimulate economic activity by lowering their policy interest rates and have adopted unconventional tools such as quantitative easing and forward guidance as their primary policy instruments. The model setup implicitly assumes that these unconventional tools are an effective substitute for interest rate-based monetary policy, meaning that these central banks can be viewed as acting as though they continue to follow a conventional policy rule.[9]

2.2 Calibration

I calibrate the model to match features of four large economies: the US, the EA, China and Japan. For each country, I use the most recent input-output tables to pin down: the weights of capital, labour and industry-specific intermediate inputs in the industry production functions, the weights of consumption, investment and government spending in domestic demand and the weights of each industry in the consumption, investment and government spending bundles.[10]

[8]As the model abstracts from international trade, this role of government could stand in for all exogenous demand, including for exports.

[9]This is consistent with the evidence in Debortoli et al. (2019) that the response of US economic variables to macroeconomic shocks did not change during the period when the Federal Funds rate was pegged at zero between 2009Q1 and 2015Q4.

[10]I model industries at the 1-digit NAISC level.

Most of the parameters controlling the dynamics of the model, such as the habits and investment adjustment cost parameters, or the aggregate labour supply elasticity, have been estimated in similar models many times before. I set the values for these parameters close to the mid-point of estimates from papers such as Smets and Wouters (2007) and Justiniano et al. (2013) for the US and Coenen et al. (2018) and Albonico et al. (2017) for the EA.

The assumption of sticky prices is clearly unrealistic for industries such as Agriculture or Mining, whose goods are largely homogeneous and whose prices can vary enormously from quarter to quarter. For these industries I set the Calvo parameter equal to 0.05, meaning that their prices are almost fully flexible. For the remaining sectors, I rely on information about sectoral differences in the frequency of price adjustment from Bryan and Meyer (2010) and Eusepi et al. (2011). These papers suggest that manufacturing and retail prices are more flexible than those of other sectors, particularly services industries. Consequently, I set the Calvo parameter governing the frequency of price adjustment in the manufacturing and retail industries equal to 0.5, implying an average frequency of price adjustment of two quarters. For all other industries, I set the Calvo parameter equal to 0.7, which is a standard estimate for the value of this parameter in single industry models.

I base the elasticities of substitution in the demand and production functions on available estimates in the literature. For the elasticity of substitution between the output of different industries in final expenditure, I use the value of 0.9 estimated in Herrendorf et al. (2013). For the elasticity of substitution between final goods and intermediate expenditures, I follow Baqaee and Farhi (2020) in choosing a value of 0.6. Estimates of the elasticity of substitution between intermediates suggest that the value of this parameter could be close to zero (Atalay (2017)). However, preliminary investigation revealed that extremely low values of this parameter, in conjunction with the enormous changes in industry output observed in the first half of 2020, led to a large degree of model instability. Therefore, I set this parameter equal to 0.5. This means that intermediate inputs are less substitutable than other components of the demand and production functions while ensuring that it remains possible to solve the model numerically.

For the parameter governing the elasticity of substitution between industries in labour supply, I use the estimate of 2 from Horvath (2000). Finally, I set the share of Ricardian households in each economy to 0.75, which is roughly half way between the estimates of Debortoli and Gali (2017) for the US and Albonico et al. (2017) for the EA.

3 Modelling the Crisis

3.1 Unprecedented Changes in Economic Structure

In working with rational expectations models of the type described above it is common to first linearise the model around its non-stochastic steady state and then examine the effect of small perturbations, or shocks, that drive the economy away from this steady state. This approach will be accurate so long as the perturbations are sufficiently small that the structure of the economy remains unchanged. In the case of standard business cycle fluctuations, this assumption may be justified. But it less plausible in the context of the Covid crisis, which not only led to an unprecedented decline in aggregate economic activity, but also prompted large, and likely persistent, changes in business practices and in the composition of output and demand.

To account for the these changes, I model the Covid crisis as a sequence of structural changes, following the approach described in Kulish and Pagan (2017).[11]

Specifically, I assume that that up to 2019Q4 the structure of the economy could be described by the system of equations:

$$\mathbf{A}x_t = \mathbf{C} + \mathbf{B}x_{t-1} + \mathbf{D}\mathbb{E}_t\{x_{t+1}\} + \mathbf{F}\varepsilon_t \tag{8}$$

where x_t is the vector of model variables and ε_t is a vector of exogenous i.i.d. shocks. The matrices $\mathbf{A}$, $\mathbf{B}$, $\mathbf{C}$, $\mathbf{D}$ and $\mathbf{F}$ are the equation coefficients consistent with the initial structure of the economy. Note that by including $\mathbf{C}$ I am explicitly accounting for the steady state of the model in the solution matrices.

If it exists and is unique, the standard rational expectations solution to Equation (8) is the VAR:

$$x_t = \mathbf{J} + \mathbf{Q}x_{t-1} + \mathbf{G}\varepsilon_t \tag{9}$$

where the reduced form matrices $\mathbf{J}$, $\mathbf{Q}$ and $\mathbf{G}$ are constant, consistent with the stable economic structure.

In solving the model for 2020Q1, I allow the structure of the economy to change, to become:

$$\bar{\mathbf{A}}x_t = \bar{\mathbf{C}} + \bar{\mathbf{B}}x_{t-1} + \bar{\mathbf{D}}\mathbb{E}_t\{x_{t+1}\} + \bar{\mathbf{F}}\varepsilon_t \tag{10}$$

where $\bar{\mathbf{A}}$, $\bar{\mathbf{B}}$, $\bar{\mathbf{C}}$, $\bar{\mathbf{D}}$ and $\bar{\mathbf{F}}$ are the equation coefficients consistent with the structure of the economy that prevailed in 2020Q1. Changes in the structure of the economy could include restrictions on business operations that affect the efficiency with which firms can operate or changes in consumer behaviour, such as the avoidance of crowded retail locations where the probability of contracting the virus is elevated. Once again, the inclusion of a constant in Equation (10) means that I allow the economy's steady state, as well as the dynamic relationship between variables, to change as a result of the Covid crisis.

The solution to Equation (10) depends upon agents' beliefs about the economic structure that will prevail in the future. For 2020Q1 I assume that agents anticipated that the change in the economic structure would be temporary and that from 2020Q2 the economy would revert to its original form.[12] This is consistent with economic forecasts at the time, which until late in the quarter pointed to a rapid recovery in output in the second half of 2020.[13] The reduced form solution for 2020Q1 therefore accounts for both the structural changes that occurred in that quarter, as well as an anticipated reversion to more normal conditions subsequently.[14]

[11] Applications of this approach to model structural changes include Kulish and Rees (2000) in the context of permanent changes in commodity prices and Gomez-Gonzalez and Rees (2018) in the context of entry to a monetary union and Jones (2020) in the context of demographic change.

[12] This does not imply that the economy would recover fully in 2020Q2, as the drop in output in 2020Q1 would take time to unwind. Instead, it assumes that the relationships between variables would have been similar to they had been prior to the Covid crisis.

[13] For example, the mean forecasts for year-on-year GDP growth in 2020 the March Consensus Economics survey were 1.4% for the US, 0.9% for the euro area and 1.0% for Japan.

[14] Specifically, the reduced form solution is: $x_t = \bar{\mathbf{J}} + \bar{\mathbf{Q}}x_{t-1} + \bar{\mathbf{G}}\varepsilon_t$, where $\bar{\mathbf{J}} = (\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q})^{-1}(\bar{\mathbf{C}} + \bar{\mathbf{D}}\mathbf{J})$, $\bar{\mathbf{Q}} = (\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q})^{-1}\bar{\mathbf{B}}$ and $\bar{\mathbf{G}} = (\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q})^{-1}\bar{\mathbf{F}}$.

As it turned out, constraints on economic activity, both regulatory and induced by behavioural shifts, increased in 2020Q2 before receding somewhat in 2020Q3. Moreover, it was clear by the middle of the year that the return to economic normality would take some time. Therefore, in solving the model, I allow for subsequent structural breaks in 2020Q2 and 2020Q3. I also assume that agents in the model take the likely persistence of these changes in economic structure into account in their economic decision-making.

Specifically, assume that the structure of the economy prevailing in 2020Q3 is:

$$\tilde{\mathbf{A}}x_t = \tilde{\mathbf{C}} + \tilde{\mathbf{B}}x_{t-1} + \tilde{\mathbf{D}}\mathbb{E}_t\{x_{t+1}\} + \tilde{\mathbf{F}}\varepsilon_t \tag{11}$$

where $\tilde{\mathbf{A}}$, $\tilde{\mathbf{B}}$, $\tilde{\mathbf{C}}$, $\tilde{\mathbf{D}}$ and $\tilde{\mathbf{F}}$ are the equation coefficients consistent with the structure of the economy that prevailed in 2020Q3. And assume that agents expect that at some future period $\mathbf{T}$ the economy will revert to the economic structure that prevailed prior to the crisis. The solution to the model between 2020Q3 and $\mathbf{T}$ is a time-varying VAR of the form:

$$x_t = \mathbf{J}_t + \mathbf{Q}_t x_{t-1} + \mathbf{G}_t \varepsilon_t \tag{12}$$

where the time-varying reduced form matrices are given by:

$$\mathbf{J}_t = (\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q}_{t+1})^{-1}(\bar{\mathbf{C}} + \bar{\mathbf{D}}\mathbf{J}_{t+1}) \tag{13}$$

$$\mathbf{Q}_t = (\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q}_{t+1})^{-1}\bar{\mathbf{B}} \tag{14}$$

$$\mathbf{G}_t = (\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q}_{t+1})^{-1}\bar{\mathbf{F}} \tag{15}$$

As we know the values of $\mathbf{Q_T}$ and $\mathbf{J_T}$, one can solve this system of equations recursively to derive the sequence of reduced form matrices from the start of the crisis to its resolution.

3.2 Structural changes during the Covid crisis

I model the Covid crisis as a sequence of aggregate and industry-specific disturbances. The aggregate disturbances are:

1. A change in productivity that is common to all sectors, through a proportional shift in the means of $a_{j,t}$;
2. A change in aggregate "desired consumption", through a shift in the mean of $\xi_{c,t}$;
3. A change in the steady-state spread between risk free rates and required returns on capital, through a shift in the mean of $\mathcal{M}_t$; and
4. A change in the exogenous component of demand, which I model as a transitory shock to government spending.

The intuition for the aggregate disturbances is as follows. The change in productivity captures constraints on work practices that affected the efficiency with which firms could operate during the crisis. Examples could include restrictions on restaurant occupancy rates, shifts to remote working or changing workplace arrangements to limit personal interactions between workers. The change in desired consumption captures a general diminished appetite for consumption, which could reflect formal restrictions on mobility, consumer reluctance to expose themselves to the virus or precautionary saving. The change in the capital wedge captures changes in spreads between risk-free and risky borrowing rates, as well as the increased option value of delaying investments at a time of heightened uncertainty. The shift in the exogenous component of expenditure captures changes in government spending on goods and services, as well as net trade and any other components of GDP not explicitly modelled. Because I am working with a general equilibrium model, each of the disturbances will affect all of the other variables in the model. For example, it could turn out that the behaviour of investment is fully explained by the productivity and consumption disturbances, with no role for the return on capital wedge.

In addition to these aggregate disturbances, I allow for idiosyncratic disturbances to industries that have been particularly affected by the pandemic and face ongoing constraints. For this, I focus on industries that rely heavily on face-to-face interaction with customers, where opportunities for remote work are limited. I label these industries as 'customer-facing service industries'. The selection of industries varies slightly between economies depending on how individual statistical agencies classify industries in their input-output tables and national accounts. However, they broadly include the retail trade industry, recreation industry, transport industry, social services industry and other services industry.[15]

The industry-specific disturbances consist of:

1. A change in productivity that is idiosyncratic to each industry, that is a change in $a_{j,t}$ for individual customer-facing service industries;

2. A change in the weight of each industry in the aggregate consumption bundle, that is a change in $\omega_{c,j}$.[16]

The productivity disturbance captures the possibility that constraints on operations may bind particularly tightly on service industries (for example, restrictions on customer numbers in restaurants or retail stores). The industry-specific consumption disturbance captures the idea that the Covid crisis could have led to a substitution of customer preferences away from activities deemed to be more risky. The estimation procedure, however, does not constrain these disturbances to have a negative effect on these industries. For example, it is free to conclude that productivity in the retail sector increased, potentially due to a shift from bricks-and-mortar retailers to online purchases.

The choice of industries to include in the group of those highly affected by the pandemic involves a degree of judgement. Many manufacturing and construction jobs, for example, cannot be performed remotely. And several well-publicised virus outbreaks have occurred at manufacturing plants. One could make the case that these industries have been highly affected by the virus. At the same time, in most economies these industries did not exhibit the large and persistent declines in output seen in industries like transport and recreation. Moreover, these industries supply a relatively small share of their output directly to

[15] The recreation industry includes activities such as accommodation and restaurants, the social services industry includes activities such as education and health care, the other services industries includes activities such as dry cleaning and laundry services and the services of religious organisations.

[16] With an offsetting adjustment to the weights of other industries to ensure that the weights sum to unity.

households. Instead, changes in demand for their output due to shifts in consumption patterns is more likely to show up as changes in the demand for intermediate inputs. This justifies their exclusion from the list of highly affected industries.

The inclusion of retail trade in the list of affected industries may also be controversial. The Covid crisis has clearly had large effects *within* the retail sector. Many bricks-and-morter retailers struggled. But others, particularly those with a large online presence as well as food retailers, saw an increase in demand. The net effects of these changes for demand and productivity in the retail sector is unclear. This, however, makes it important to include this sector in the list of affected industries as its experiences and outlook could conceivably differ materially from that of the aggregate economy.

3.3 Changes in sectoral supply and demand

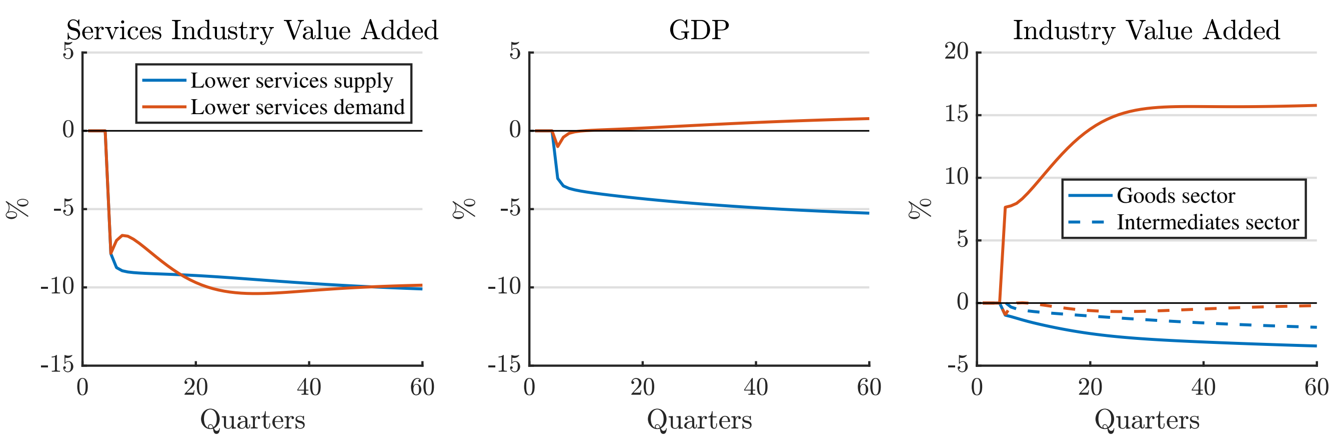
Before turning to the application to the Covid recession, it will be useful to first consider the effects of industry-level supply and demand disturbances in a simpler case.

For this exercise, I work with a stylised version of the model with three sectors: a services sector, a goods sector and an intermediates sector. The services and goods sectors produce final output for consumption and investment. The output of the intermediates sector is used in the production of services and goods.

I then consider two disturbances. The first, a supply disturbance, permanently lowers productivity in the services sector. The second, a demand disturbance, permanently shifts consumer preferences away from services consumption and towards goods consumption. I scale the changes in supply and demand so that value-added in the services sector declines by 10%.

Figure 1 shows the results of these exercises for value-added output in the services sector, aggregate GDP, and value-added output in the goods and intermediates sectors.

Figure 1: Sectoral demand and supply disturbances



Source: Author's calculations.

From the perspective of the services sector, the two scenarios look much the same - output declines by 10%.[17] For aggregate economic activity, however, the scenarios differ greatly. A decline in services sector

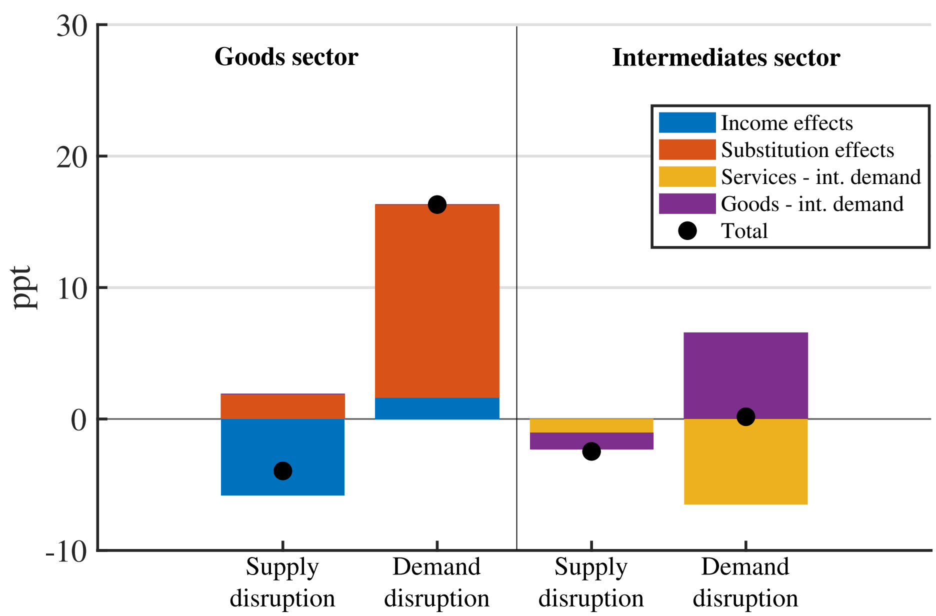
[17] There scenarios have different implications for labour and capital demand, as well as for price changes in the services

productivity leaves the economy permanently poorer. The decline in productivity lowers real incomes, which reduces aggregate demand. At the same time, the relative price of services rises, which leads households to substitute away from services towards goods. Both forces contribute to lower services output. Goods output also declines because the relatively low degree of substitutability between goods and services in the consumption bundle means that the income effect of lower aggregate economic activity overwhelms the substitution effect of lower relative goods prices. The left panel of Figure 2 shows the relative contribution of these *income* and *substitution* effects to the total change in goods output. Output in the intermediates sector also declines because, with lower output in the services and goods sector, there is less demand for intermediate inputs from both the goods and services industries.

In contrast, the preference shift shows up largely as a re-orientation of final demand from the services sector to the goods sector. As productivity is unchanged there is a relatively small income effect in this case. There is, however, a large substitution effect, which ensures that output in the goods sector unambiguously increases. In contrast, total output in the intermediates sector is largely unaffected. However, the direction of intermediates output changes, with a larger share of output being produced for the expanding goods sector and less for the declining services sector. In aggregate, GDP is also largely unaffected as the decline in services output is roughly offset by the increase in goods production.

The example described in this section is highly stylised. Real economies feature a far richer and more complex mix of intersectoral linkages. Nevertheless, the conclusion that the evolution of aggregate economic activity in response to industry-specific disruptions depends on the nature of those disruptions is a general one.

Figure 2: Contributions to changes in industry value-added



Note: "Services - int. demand" refers to demand for intermediate inputs by the services industry; "Goods - int. demand" refers to demand for intermediate inputs by the goods industry.

Source: Author's calculations.

sector, however.

3.4 What disturbances explain the Covid crisis?

I now turn to the application to the Covid crisis.

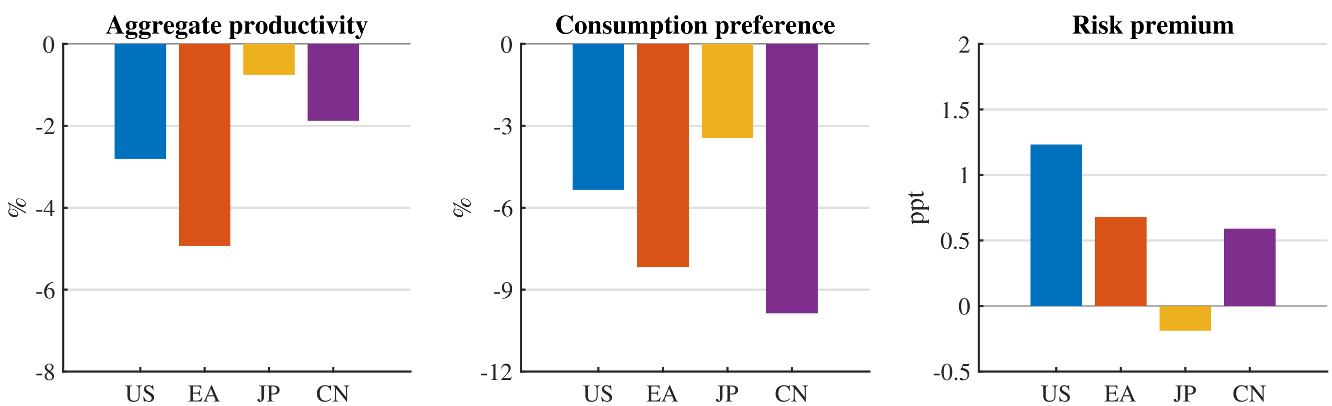
For each economy, I use a numerical procedure to recover the structural changes that the model requires to explain the economic developments that occurred during the first half of 2020.[18] Because I allow for four aggregate disturbances, I target four aggregate series: GDP growth, consumption growth, investment growth and the growth rate of the consumption deflator.[19] For the customer-facing services industries I target industry-level consumption growth and inflation.[20]

For each series, I first estimate a naive autoregressive model using data from 2000Q1 to 2019Q4. I use these models to forecast the growth rate of each series in 2020Q1 and 2020Q2. I treat these forecasts as the counterfactural of how economic variables would have evolved in the absence of the Covid crisis. The estimation algorithm then chooses the sequence of structural changes that allows the structural model to match the deviations between actual outcomes and the autoregressive forecasts. This approach assumes that all of the deviations between actual and forecast outcomes can be attributed to the Covid crisis. While this is unlikely to be strictly accurate, it seems plausible that the Covid crisis accounts for most of the unusual variation in these series in the first half of 2020.

Identification comes from the fact that demand-side and supply-side disturbances have different implications for industry-level production and inflation. So, given price and quantity data for these industries in the first two quarters of 2020, it is possible to identify the disturbances that have driven their changes.

Figure 3 shows the aggregate disturbances that the model requires to match data observed data in the first half of 2020.[21]

Figure 3: Aggregate disturbances during the Covid crisis



Source: Author's calculations.

The left panel shows the implied decline in aggregate productivity (outside of customer-facing services

[18] Because I am working with a closed economy model, I estimate the structural changes for each economy independently of the changes that occurred in other economies.

[19] For China I target fixed asset investment and consumer price inflation as quarterly investment and consumption deflator data are not publicly available.

[20] Appendix A explains how I assign consumption data to each industry.

[21] I show the average of the disturbances in 2020Q1 and 2020Q2.

industries). This was largest, at around 6% in Europe. The decline was around 3% in the US, 2% in China and around 0.5% in Japan.

The middle column shows the implied consumption disturbances. These can roughly be thought of as the declines in steady-state consumption that would have occurred absent any price or income changes. This was around 10% in the EA and China, 5% in the US and a bit under 3% in Japan.

The right column shows the implied increase in required returns on capital. This was largest, at slightly over 1 percentage point in the US, but smaller in the other three economies.

A natural question is how plausible these estimates are? In the case of the EA, US and Japan, the estimates of the supply disturbances are consistent with the relative stringency of lockdown measures, as well as with the relative impact of the virus in terms of number of cases and deaths (allowing for large regional variation within the US and the EA). The estimate of the increase in required capital returns is also consistent with the largest financial disruptions in the first half of 2020 occurring in corporate bond markets, which are a more important source of funding for firms in the US than in the EA or Japan.

The estimates for China are not strictly comparable to those of the other economies as the outbreak of the virus, and associated economic contraction, occurred earlier there. Nevertheless, the relative importance of supply and demand factors is consistent the evidence to hand that the recovery in economic activity since 2020Q2 has been concentrated in investment, trade and public demand. In contrast, consumption has been slower to recover.

Figure 4 shows the estimated industry-specific productivity disturbances during the Covid crisis. These were generally negative for all of the industries. For the US, EA and Japan, the declines in productivity in the recreational industry and social services industry were generally larger than for the economy as a whole. The picture is less clear for the other three industries. For Japan, declines in productivity in the retail, transport and other services industries were larger than the aggregate economy. However, for the US, the declines in productivity were somewhat smaller. In the EA, the declines in productivity in these industries were similar to those elsewhere in the economy.

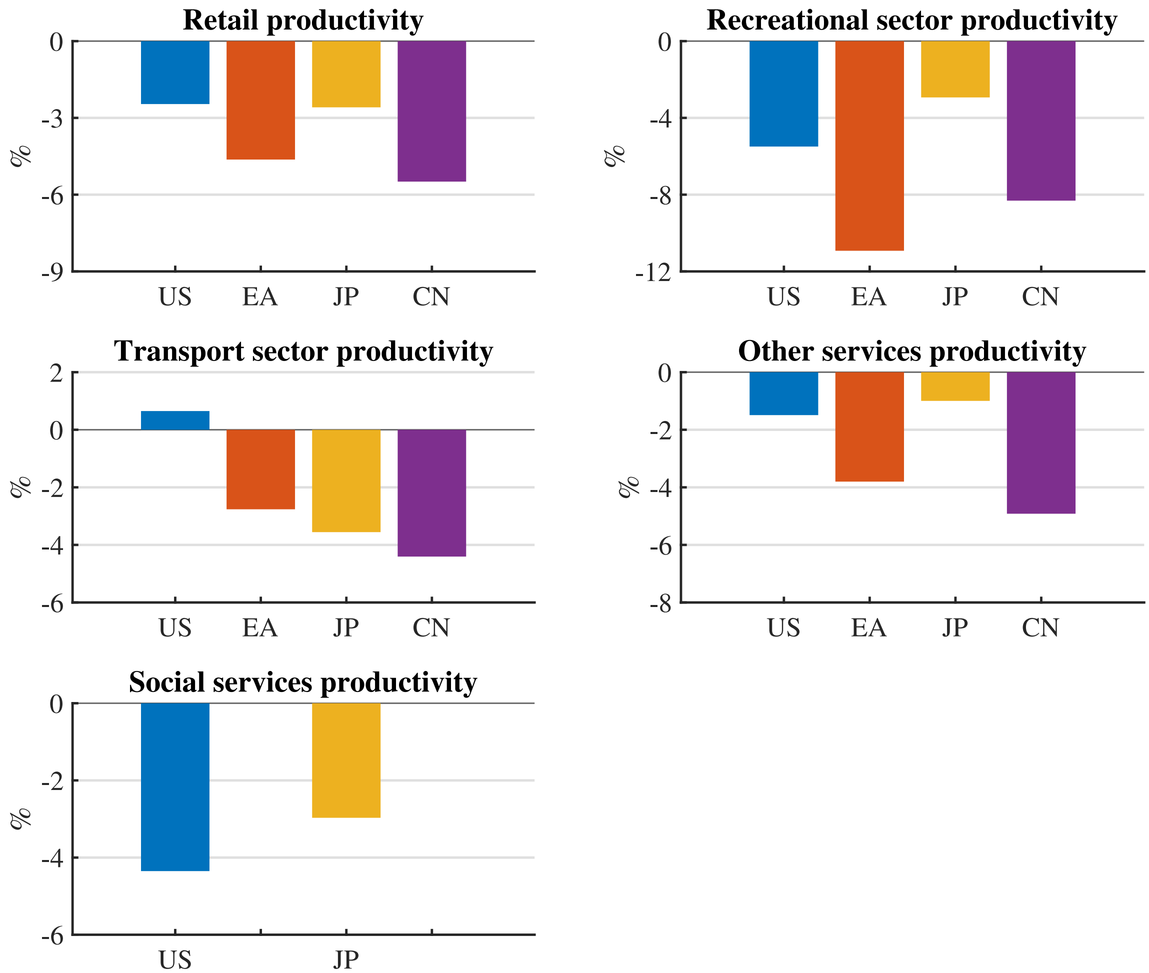
For China, the estimated supply disturbances in customer-affected service industries were considerably larger than for the economy as a whole. This is again consistent with anecdotal evidence that, while manufacturing and construction firms were able to resume activity relatively soon after the peak of the crisis, firms in consumption-focussed industries have faced more persistent constraints.[22]

Figure 5 shows the estimated demand disturbances during the first half of 2020. These can be interpreted as the estimated percentage changes in demand for each sector's output, absent any price changes or aggregate disturbances.

For all economies, demand for recreational services declined 20-40%, while transport and social services also experienced large demand disruptions. In contrast, outside of China the estimated decline in retail trade demand was much smaller, and in fact is estimated to have increased in Japan. This is consistent with the idea that the crisis led to a re-allocation of retail demand towards online purchases, rather than an overall decline in demand for retail products. In China, the decline in retail trade demand was larger.

[22] For example, see The Economist (2020b).

Figure 4: Sectoral productivity disturbances during the Covid crisis



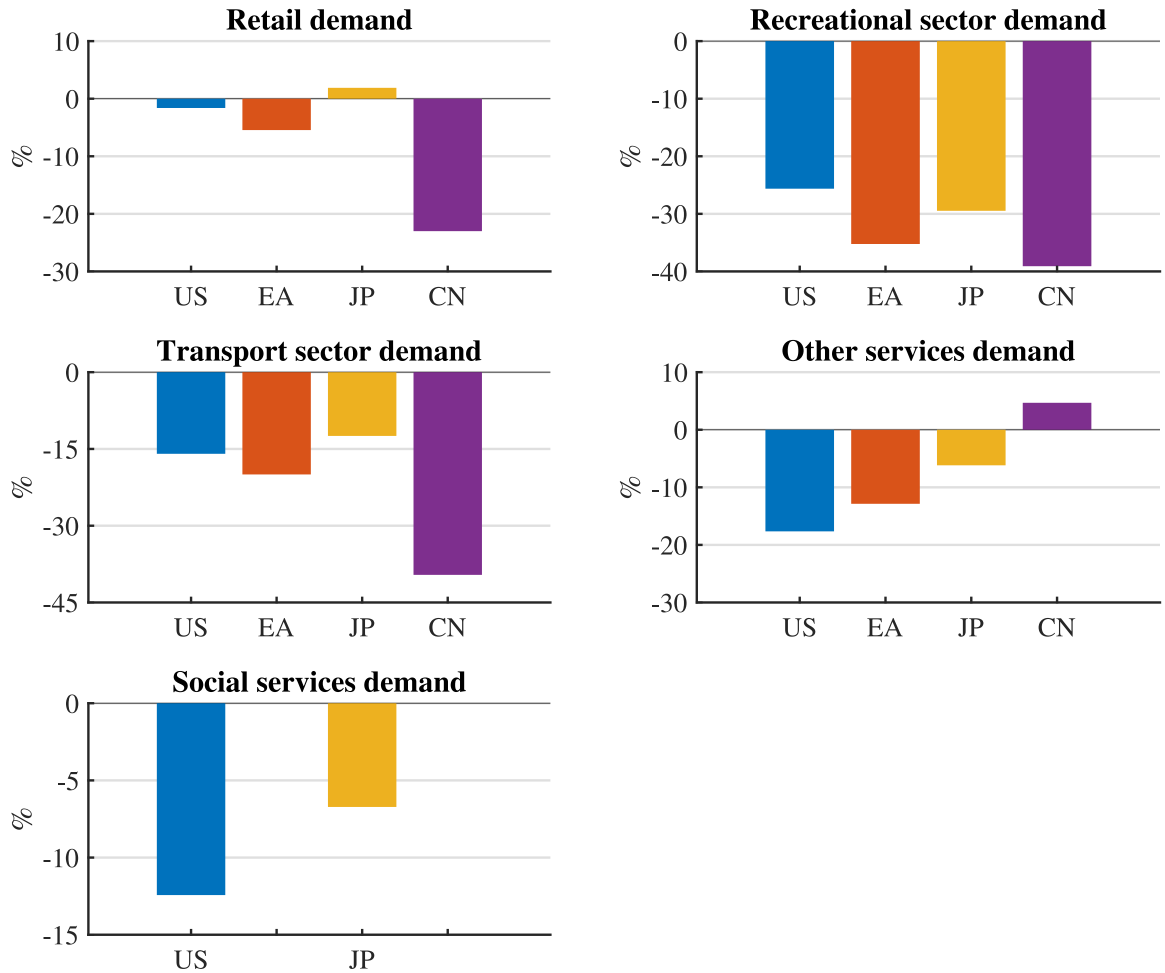
Source: Author's calculations.

In sum, the results in this section suggest that, at an aggregate level the decline in activity due to the Covid crisis reflects a combination of supply-side and demand-side factors. Customer-facing industries experienced particularly large declines in activity. This reflects more stringent constraints on business practices, particularly in recreation and social services industries, and a shift in consumption preferences away from these services. Using these estimates, I now turn to what these disturbances imply for the recovery from from the crisis.

4 Scenarios for the Recovery

I model three scenarios for the recovery. For each, I assume that the aggregate disturbances that occurred in the first half of the year decay by 50% each quarter. This is consistent with the easing of stringent lockdown measures over recent months. This assumption means that the direct effects of the aggregate disturbances on economic activity largely dissipates by early 2021. However, these disturbances continue to exert an indirect effect on economic activity through the inherent amplification and persistence mechanisms in the model.

Figure 5: Sectoral demand disturbances during the Covid crisis



Source: Author's calculations.

I then consider three scenarios for customer-facing service industries:

1. Baseline: 50% of the idiosyncratic disturbances to these industries turn out to be persistent and remain in place until mid-2023.

2. Optimistic: 25% of the idiosyncratic disturbances to these industries are persistent and remain in place until mid-2021.

3. Pessimistic: 75% of the idiosyncratic disturbances to these industries are persistent and remain in place until mid-2025.

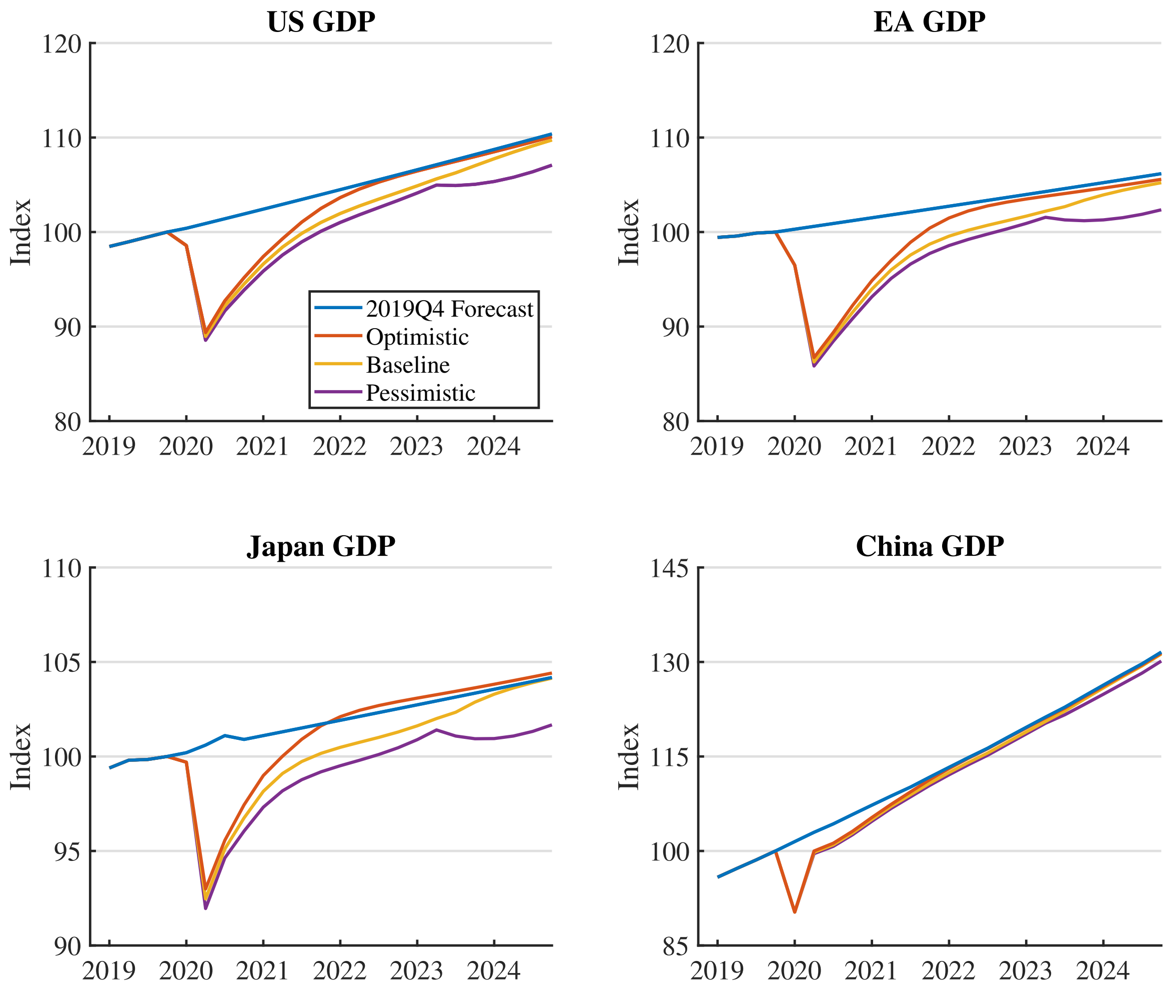
I present first the aggregate model projections and then turn to the industry-level implications, including the role of cross-industry spillovers.

4.1 Key results

Figure 6 shows projections for the level of real GDP for the four economies. In each panel, the blue line shows the GDP projections implied by the median Consensus Economics growth forecast in 2019Q4. I take this to be the counterfactual path for GDP in the absence of the pandemic. The yellow line shows the path of GDP under the baseline scenario. The red and purple lines show the projections under the optimistic and pessimistic scenarios.

Figure 6: GDP projections

2019Q4 = 100



Source: Author's calculations; Consensus Economics.

In the baseline scenario the US, GDP and Japan experience a persistent shortfall in economic activity. Output grows quickly in the second half of 2020. But the pace of recovery then slows and GDP does not return to its 2019Q4 level until early 2022. Even then, all three economies face a '98% economy' as output stagnates persistently 2% below its pre-crisis trend for several years.

In the near-term, the path of output under the optimistic scenario is similar to the baseline scenario. However, in the optimistic case the robust economic recovery continues into 2021, alongside the easing in constraints on customer-facing service industries in the second half of that year. By early 2022 GDP has returned to its pre-crisis trend.

In contrast, in the pessimistic scenario, the US, EA and Japan face a persistent slump. In this scenario, these economies face a 95% economy, with output persistently 5% below its pre-crisis trend.

The recovery in China proceeds faster. Although the model anticipates that growth will slow somewhat in the second half of 2020, GDP returns near its pre-crisis trend by mid 2021. There is also relatively little difference between the three scenarios for China. This reflects two factors. First, the rapid growth that occurred in 2020Q2 means that there is less ground to make up. Second, the calibration attributes more of the decline in customer-facing service industries to aggregate disturbances and industry-specific demand disturbances, than for the other three economies.

Figure 7 shows the implications of the forecasts for year-on-year GDP growth in the calendar years 2020, 2021 and 2022. It also compares these figures to the the median Consensus Forecast from September 2020. Relative to Consensus, the model based forecasts for the US, EA and China point to weaker GDP growth in 2020, but a faster recovery in 2021.[23] For Japan, the year-on-year growth profiles in the baseline scenario are close to the Consensus Forecasts. For all economies, the level of GDP at the end of 2021 in the model-based scenarios is similar to that implied by the Consensus Forecast profile. This largely reflects the easing of aggregate constraints on activity. The lingering constraints on customer service industries are most keenly felt in 2022, when *growth* in the AEs is projected to revert to something close to its long-term trend. This leaves a persistent gap between the projected *level* of GDP and its pre-Covid trend in these economies.

4.2 Supply- and demand-side determinants and potential output

The calibration attributes the contractions in GDP in the first half of 2020 to a combination of demand- and supply-side factors. To illustrate the implications of these two sets of forces for the recovery, Figure 8 shows GDP projections that isolate the effects of supply- and demand-side disruptions separately. The lines labelled 'Only supply disturbances' show GDP projections constructed by feeding only the estimated changes in aggregate- and industry-specific productivity into the model. The lines labelled 'Only demand disturbances' show GDP projections constructed by feeding only the changes in aggregate and industry-specific consumption preferences into the model.[24]

Both sets of disturbances contributed to the decline in activity in the first half of 2020. However, the contraction in GDP induced by supply disturbances is quantitatively larger and more persistent for each economy. Absent supply disturbances, these economies would face sizeable, but by no means unprecedented, recessions. The ongoing constraints on supply in consumer-facing service industries make the downturns unusually deep and persistent.

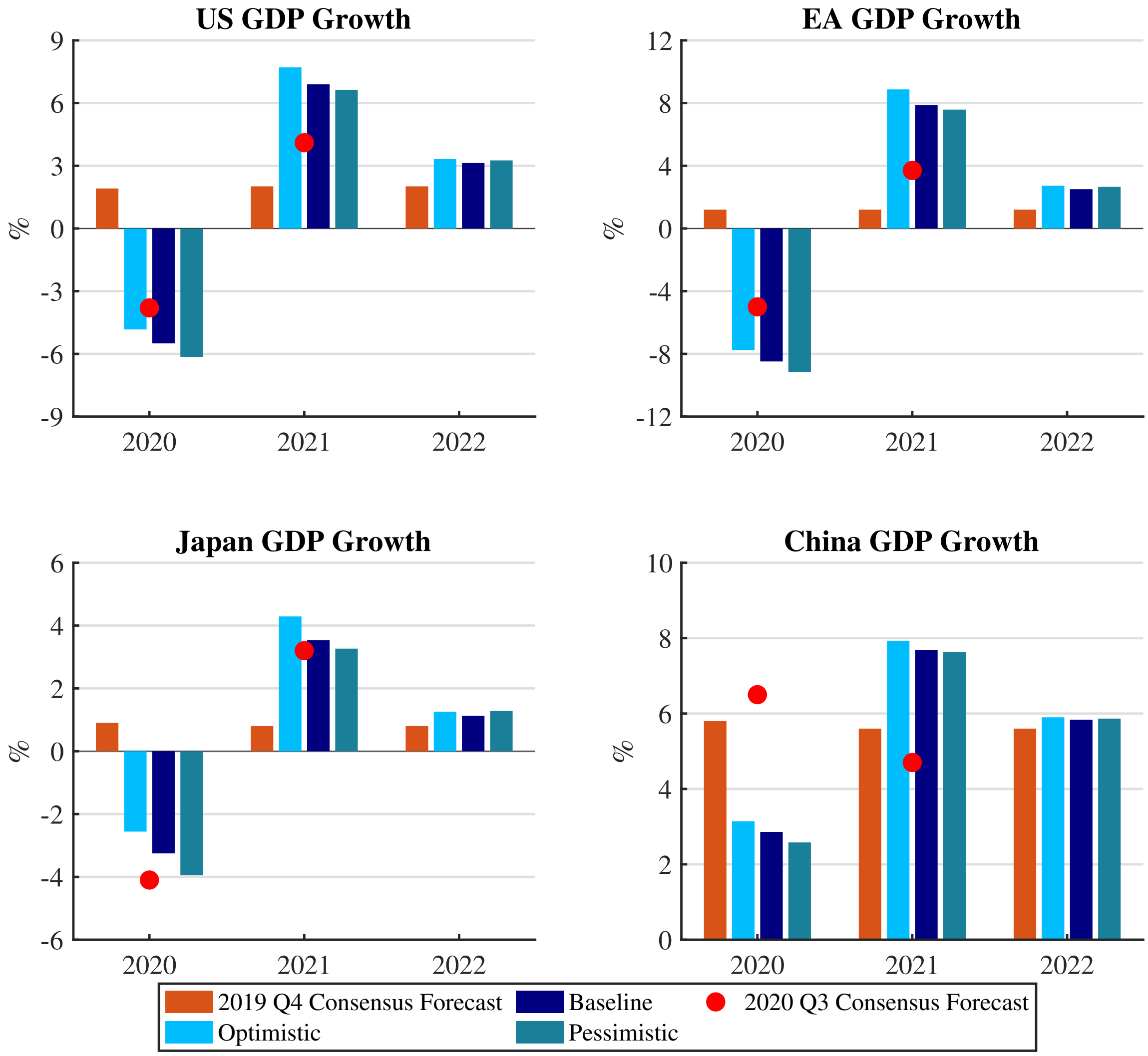
Another way to view the economic forces driving the recovery is to compare the model's output projections to its estimates of potential GDP. Of course, the concept of 'potential output' is far from clear in an environment where government restrictions, and individual behavioural responses, are directly constraining economic activity. For this exercise, I use the standard approach in the DSGE literature and define

[23] Because these forecasts include the same information about GDP growth in the 2020Q1 and Q2, this implies that the model-based forecasts project slower GDP growth in the second half of 2020.

[24] In both sets of projections, I omit the aggregate disturbances to the return on capital and government demand. The aggregate effects of these disturbances are generally small relative to the other disturbances.

Figure 7: GDP growth projections

Year-on-year, December Quarter



Source: Author's calculations; Consensus Economics.

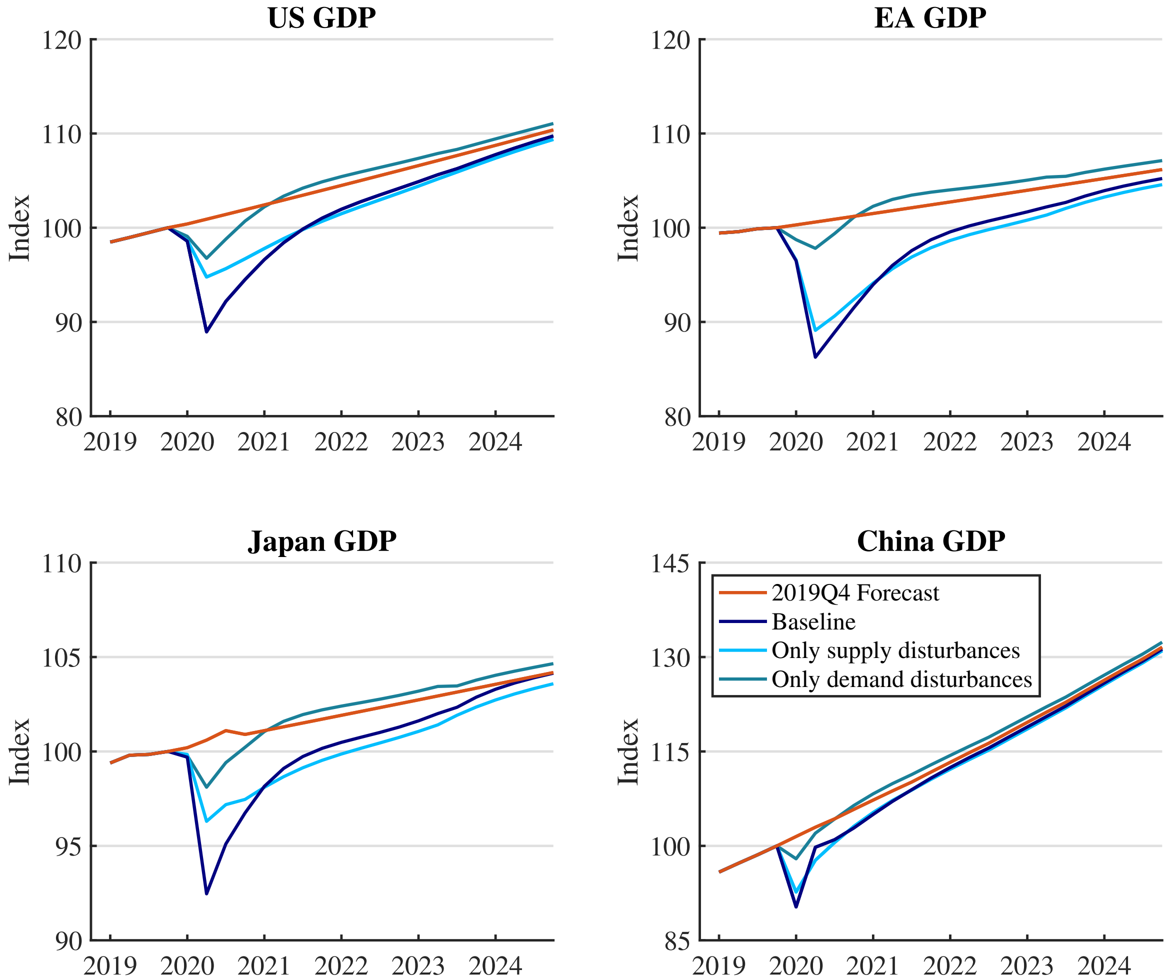
potential output as the level of GDP that would occur if an economy experienced the same sequence of economic shocks and structural changes but all prices and wages were flexible. This represents a measure of potential output conditional on the administrative restrictions and behavioural changes induced by the pandemic. The model is silent on whether these constraints are appropriate.

Figure 9 compares the model's baseline GDP projections to its estimates of potential output. All variables are expressed in percent deviations from their pre-Covid trends.[25] For all four economies, the model attributes most of the decline in economic activity in the first half of the 2020, and almost all of the ongoing shortfall of GDP below its pre-crisis trend, to a lower level of potential output. This accords with the common-sense view that the Covid crisis reflects policy and behavioural responses to a health crisis, with little role for price and wage ridity in shaping economic outcomes. Nonetheless, the model expects output to be somewhat below potential in the coming years in the US and Japan, suggesting an ongoing role for demand management policy in shaping economic outcomes in the near-term. In contrast, the

[25]The model does not tell us what the output gaps in these economies would have been in the absence of the Covid crisis.

Figure 8: GDP projections: demand and supply-side disruptions

2019Q4 = 100



Source: Author's calculations; Consenus Economics.

model estimates indicate that output is likely to be close to potential in the EA and China.

4.3 Industry-level implications

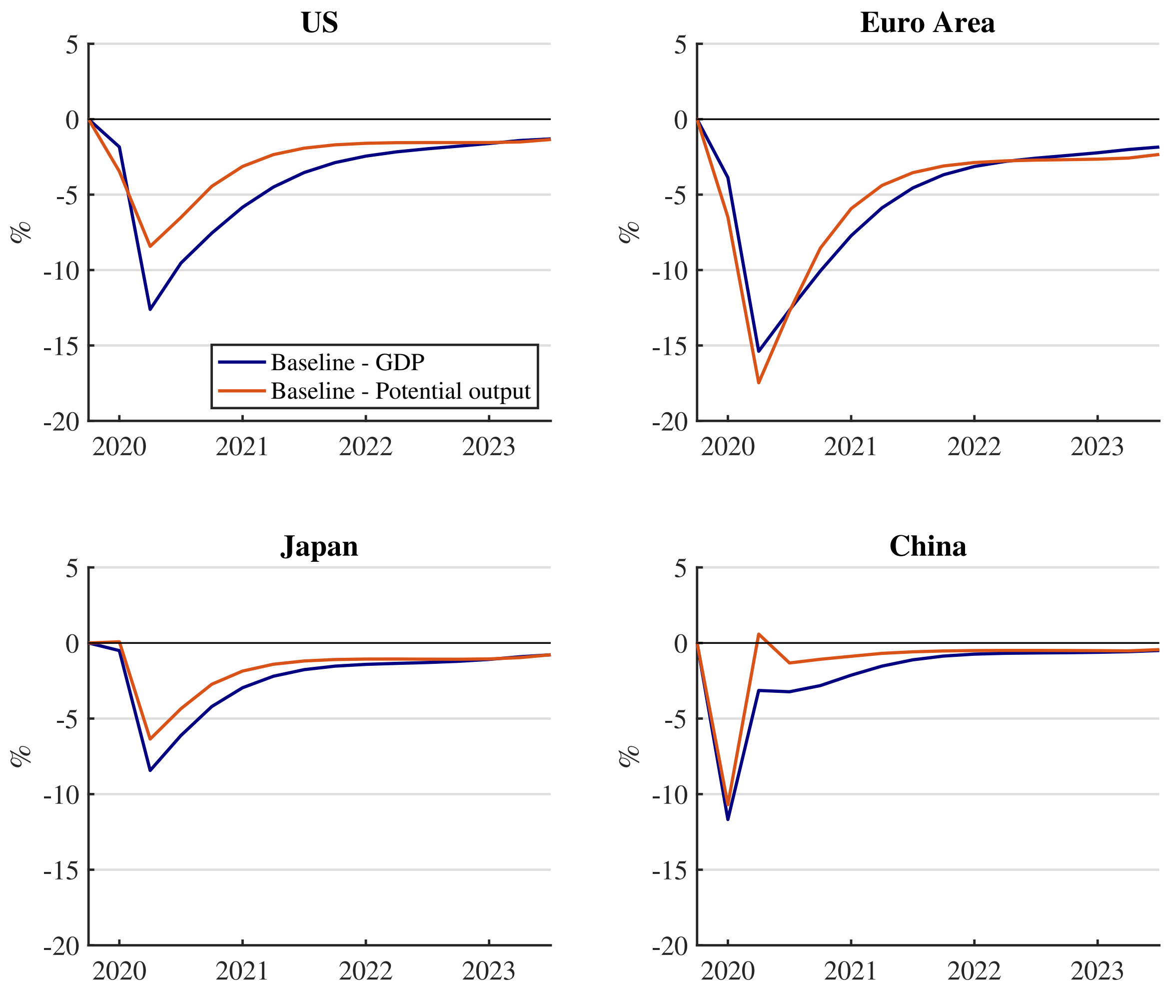
The ongoing slump in aggregate economic activity is likely to be profoundly uneven in its industry composition. To illustrate this, Figure 10 shows industry-level value-added projections for the baseline scenario in the EA and China. The results for Japan and the US are similar to those for the EA. In the graph, I group the industries into four broad categories: customer-facing industries, primary industries, goods industries and other services industries.[26] The lines are scaled to show the output of each industries in percent deviations from their pre-crisis trend.

Customer-facing service industries experience a large and persistent depression. In the EA, output in these industries contracted by 25% in the first half of 2020. Moreover, under the assumptions of the scenario,

[26] Customer facing industries include recreation services, retail trade, transport, social services and other services. Primary industries include agriculture and mining. Goods industries include construction, utilities, manufacturing and wholesale trade. Other services industries include transportation, information services, business services and government services.

Figure 9: GDP projections and potential output

Percent deviation from pre-Covid trend



Source: Author's calculations.

their output is projected to remain more than 10% below their pre-crisis trends until the end of 2022. Other sectors of the economy also experienced a sharp contraction in activity in the first half of 2020. However, conditions in these industries are expected to recover more quickly and, by the end of 2022, be close to their pre-crisis trend. In China, output in customer-facing service industries remains more than 5% below its pre-crisis trajectory for several years after output in other industries fully recovers.

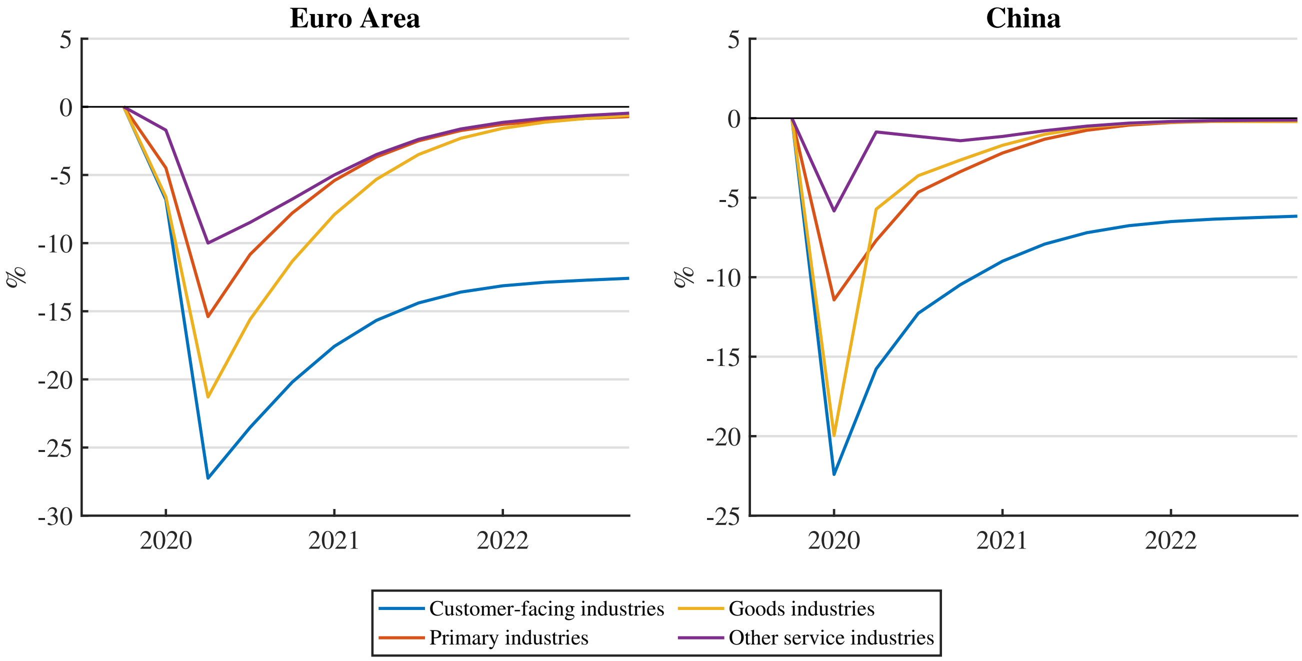
The declines in industry output reflect a number of forces. These include changes in aggregate demand, shifts in relative prices and preferences, and changes in the demand for goods as an intermediate input into production. Figure 11 shows the relative importance of these forces for the four industry groups used in Figure 10 for the EA.[27] In the Figure, I decompose changes in industry value added into three factors: income effects due to changes in the aggregate level consumption, investment and public demand, substitution effects due to shifts in preferences and relative prices and changes in demand for goods as intermediate inputs.[28]

[27] Results for the other economies are qualitatively similar.

[28] Industry value added is also affected by changes in the volume of intermediate inputs used as a production *input*. Because the industry production functions are independent of the final destination of the output, I allocate the intermediate inputs proportionally to the income, substitution and intermediate components of industry gross output. Appendix B describes the

Figure 10: Industry value-added

Percent deviation from pre-Covid trend



Source: Author's calculations.

The decline in output in customer facing services industries reflects all three of these forces listed above. Lower demand for final goods and services exerts a negative income effect. Adverse shifts in customer preferences and higher relative prices for these services represents a negative substitution effect. And the lower level of aggregate demand lowers demand for these services as an input into production. Income effects also lower the output of other industries, although by somewhat less given the smaller share of output of these industries devoted to servicing final demand. In contrast, substitution effects contribute to higher output, as other industries benefit from preference shifts away from customer-facing services. Reduced demand for intermediate inputs contributes particularly to lower output in goods and primary industries. This illustrates the importance of account for input-output linkages to fully understand the effects of the Covid crisis at the industry level.

Recessions commonly involve large contractions in a small number of cyclically sensitive industries. However, the extent of the dispersion in the Covid crisis is unusually large. To illustrate this, I calculate an industry dispersion growth index as in Lilien (1982). Let $s_{i,t-j}$ be industry i's share of gross value added at time $t-j$, $g_{i,t-j,t}$ be the growth rate of value-added in industry i between $t-j$ and t and $g_{t-j,t}$ be the growth rate of GDP between $t-j$ and t. The industry output dispersion index is:

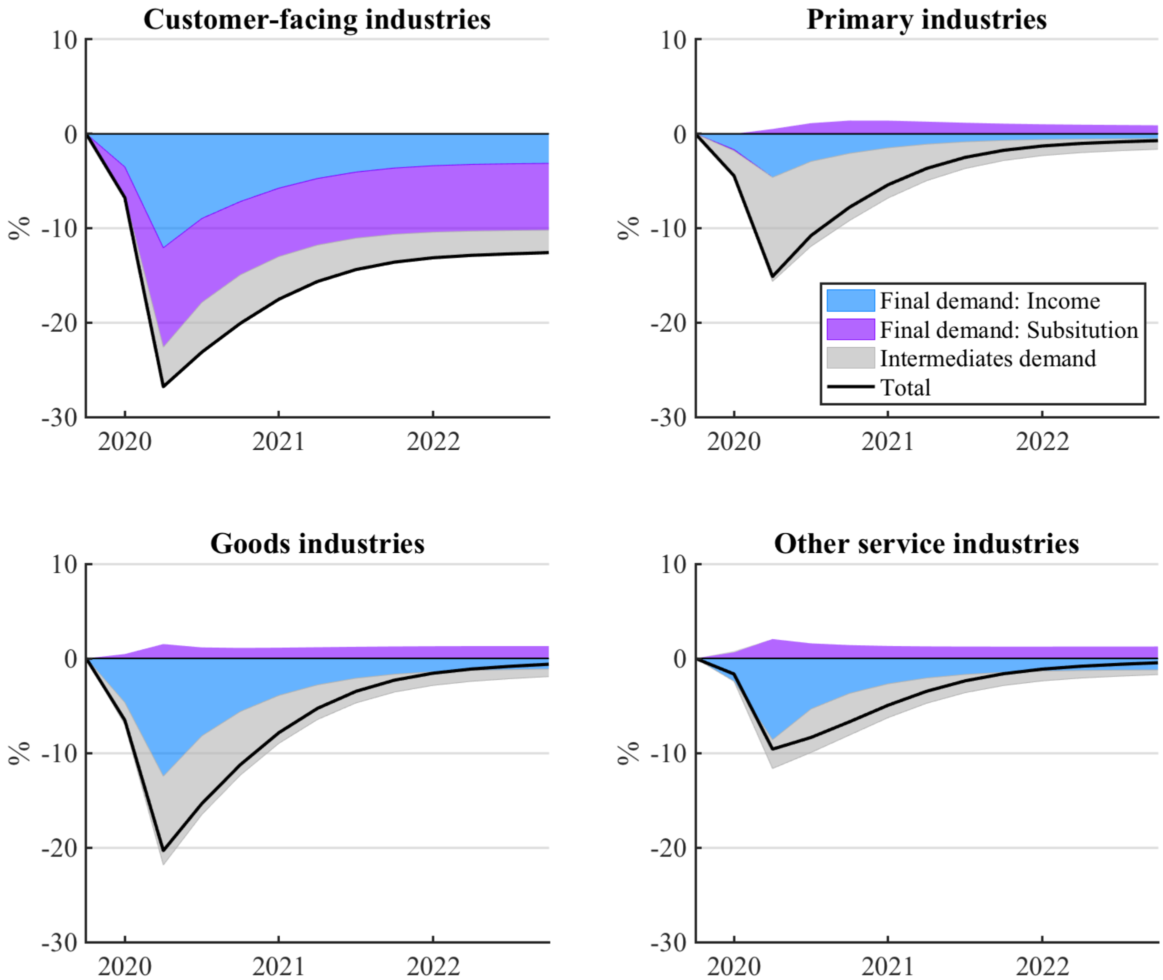
$$R_t = \sqrt{\sum_{i=1}^{\mathcal{F}} s_{i,t-j} \left(\frac{g_{i,t-j,t}}{g_{t-j,t}} - 1 \right)^2} \tag{16}$$

The measure R_t will take a value between 0 and 1, with a larger value indicating more growth dispersion.

decomposition in more detail.

Figure 11: Industry value-added: Euro Area

Percent deviation from pre-Covid trend



Source: Author's calculations.

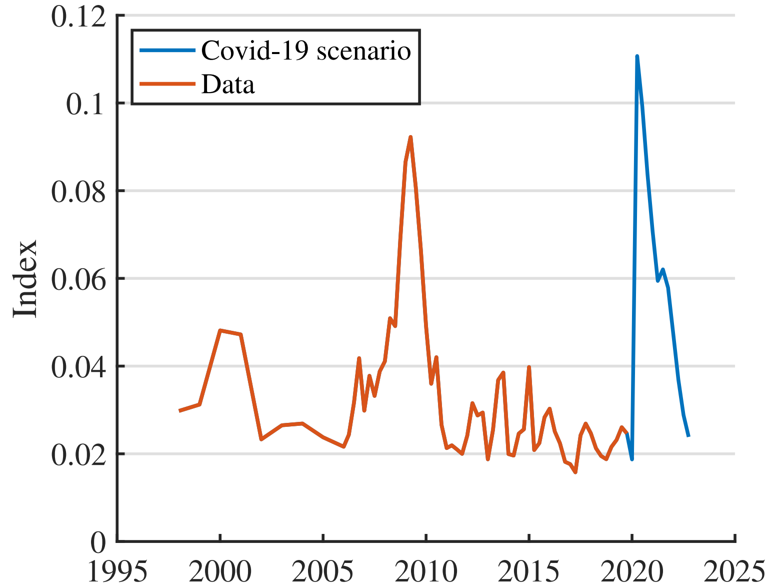
Graph 12 shows the index for the US, calculated setting $j = 4$.[29] The peak in industry growth dispersion is larger than during the GFC. Moreover, dispersion is projected to stay elevated until 2023. This may well understate the extent of industry growth dispersion over this time as it assumes no additional aggregate or industry-specific shocks.

Figure 13 gives another perspective on the changes in industry composition that could occur over the next few years. The top left panel plots the projected changes in the share of industries in value-added for the US under the baseline scenario. The other three panels plot the changes that occurred around the three most recent US recessions: the Great Financial Crisis (GFC), the early 2000s tech bust and the recession of the early 1990s.

The extent of persistent industry re-allocation induced by the Covid-19 recession in the US is similar to that which occurred in the GFC. For example, the model anticipates that three industries - social services,

[29] The index before 2006 is calculated using the dispersion of annual average growth rates, setting $j = 1$. From 2005, the index is calculated using quarterly growth rates.

Figure 12: US Industry Output Growth Dispersion Index



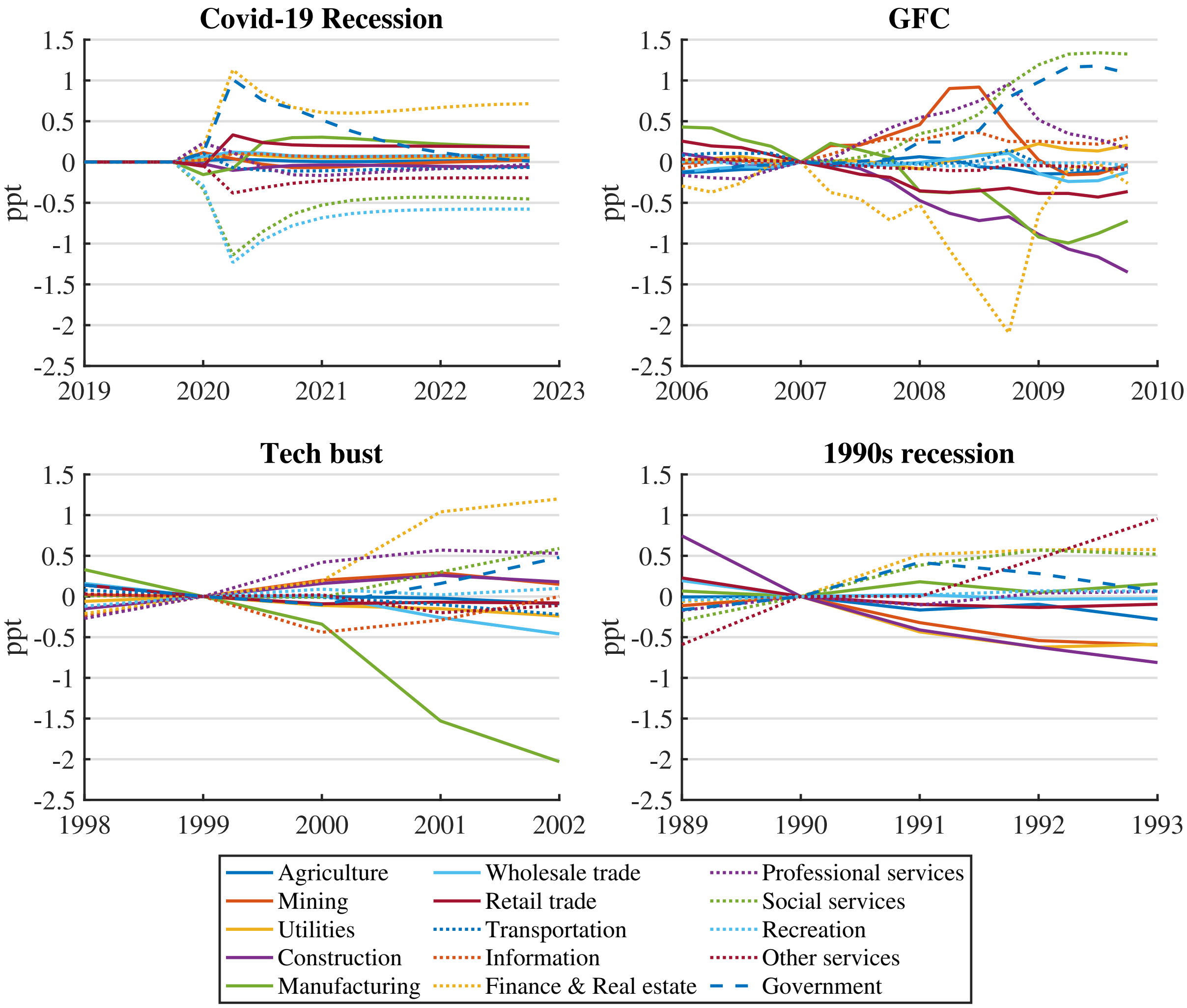
Source: Author's calculations.

recreation services and finance & real estate services - will experience persistent changes in their GDP shares of more than 0.5 percentage points over the next few years. During the GFC four industries - construction, manufacturing, social services and government services - experienced such persistent changes (although some industries, such as financial services, experienced large but less persistent changes).[30] The number of industries whose GDP share changes by more than 0.5 percentage points is at least as large as occurred following the tech bust and the 1990s recession. As in the previous example, this exercise could understate the amount of reallocation that is likely to occur as it abstracts from reallocation driven by factors other than the Covid crisis.

Another difference between the Covid crisis and past recessions is that much of the reallocation is likely to occur within the services sector. According to the model, the shares of social services and recreation services in US GDP could decline by around 1/2 percentage point over the next few years. This could be offset by an increase in the shares of real estate services and, to a lesser extent, government services. The shares of retail trade and manufacturing in value added are also expected to rise somewhat. In contrast, during the GFC-induced structural change was felt most strongly in the goods sector, at least in the US. The shares of construction, retail trade and manufacturing in GDP declined (although the latter was largely the continuation of a long-term trend). Meanwhile, the shares of social, government and professional services in GDP increased. The finance sector experienced a large decline in its GDP share in 2008, but recovered most of that ground in 2009. The early 1990s recession was also characterised by a decrease in the share of goods production in GDP and a rise in the share of services.

[30] Moreover, some of these changes, such as the decline in the manufacturing share of GDP, reflect long-run trends arguably unrelated to business cycle conditions.

Figure 13: Change in industry value-added shares around US recessions



Source: Author's calculations; Bureau of Economic Analysis.

5 Related literature

A large literature on the characteristics and economic consequences of the Covid crisis has emerged over recent months. This paper is related to three strands of this literature.

The first strand explores whether the Covid crisis is best thought of as representing a demand-side or supply-side disturbance. Papers in this literature tend to focus exclusively on economic developments in the US. For example, Baqaee and Farhi (2020) build a multi-industry model general equilibrium model similar to the one used in this paper and use it to estimate the demand and supply shocks that explain industry-level output growth outcomes in the US in 2002Q2. Brinca et al. (2020) estimate labour supply and labour demand shocks at an industry level during the peak of the crisis in March, April and May US using a Bayesian VAR model. Both papers attribute the decline in US activity in the first half of 2020 to a combination of supply- and demand-side disturbances but conclude that on net, supply-side disturbances have exerted a larger influence on economic activity.

The second strand of the literature seeks to quantify the broader macroeconomic consequences of the pandemic. A key paper in this literature is McKibbin and Fernando (Forthcoming), who use a large multi-industry multi-region macroeconomic model to simulate the effects of a global pandemic on GDP growth in 2020 under a number of different scenarios. Others include Kohlscheen et al. (2020), who explore the international spillover effects of the pandemic, and Deb et al. (2020) who estimate the economic effects of containment measures.

The third strand of the literature explores the macroeconomic consequences of economic disturbances at the industry level.[31] Many of these papers, including Guerrieri et al. (2020), Faria-e-Castro (2020) and Bodenstein et al. (2020) use two or three industry models to examine how disruptions in one part of the economy influence economic conditions in other industries. An exception Kaplan et al. (2020), who use a richer multi-industry Heterogeneous Agent New Keynesian (HANK) model calibrated at the two-digit ISIC level, quantify the effect of alternative containment and fiscal strategies in the US.

The current paper extends the existing literature in several respects. One contribution is to estimate the contribution of demand- and supply-side disturbances to aggregate economic activity for three other large economies, whose experiences of the virus differed greatly from the US. The paper extends the literature on industry-level disturbances by integrating these disturbances into a macroeconomic model with a richer set of rigidities and frictions, allowing for more realistic quantitative predictions of how these disturbances could affect economic activity. In addition, the paper extends the current literature by looking beyond the near-term determinants of the Covid crisis and providing scenarios for how the economic disturbances associated with the crisis could play out in the years ahead.

6 Conclusion

The economic consequences of the Covid crisis will be felt for many years to come. Using a multi-industry general equilibrium model, I find that ongoing disruptions to customer-facing service industries could see the US, EA and Japan face a '98% economy', even if the economy-wide disturbances associated with the pandemic recede relatively quickly. Output in customer-facing service industries could remain 10-20% below its pre-Covid trajectory if ongoing constraints on work practices remain in place for three years. For China, the results point to a faster and more complete economic recovery. But even there, the recovery is projected to occur unevenly across industries.

The results of this paper have several implications for policy. The likelihood of large and persistent changes in industrial composition highlights the necessity of striking a balance between sustaining productive firms and employer-employee matches and fostering the reallocation of resources that may be required as a result of the pandemic. The importance of supply-side disturbances in driving the shortfall in activity relative to its pre-crisis trajectory also highlights the limits of demand-management policy in managing the fallout from the crisis. While ongoing policy stimulus will likely be necessary, a full economic recovery will require us to either contain the virus or find a way to live with it. Finally, the persistent slump, and its highly uneven sectoral distribution has implications for financial stability policy. The large contraction in economic activity is likely to see corporate bankruptcies rise in many economies over the coming years Banerjee et al. (2020). These bankruptcies could be particularly concentrated in those industries particularly affected

[31] Examples that pre-date the Covid crisis include Horvath (2000) and Atalay (2017).

by the pandemic, leading to elevated risks for financial institutions heavily exposed to those sectors.

There are a number of issues this paper has not considered. I have worked with a closed economy model that abstracts from from cross-border trade and financial spillovers. For large economies where trade in customer-facing services accounts for a relatively small share of output this may be a reasonable assumption. However, to examine the economic consequences of the pandemic for smaller economies, particularly those with large tourism or education sectors, it would be important to extend the model to incorporate international spillovers. The model also features a relatively sparse financial system. As such, it is not well placed to account for the economic consequences of higher private and public debt levels or increased firm bankruptcies, that could result from the pandemic. Accounting for these developments could lead to larger estimates of the macroeconomic consequences of the pandemic than presented here. Finally, the estimates of the substitutability of goods and services in production and consumption are based upon average relationships estimated under normal economic conditions. The large and abrupt changes in production and consumption patterns induced by the Covid crisis could be more costly than those which occur during normal times. Better understanding how firms and households are navigating the changes in induced by the Covid crisis at a microeconomic level would help be a useful avenue for future research.

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A Data sources

This appendix describes the data sources used to calibrate the input-output structure of the model as well as the Covid-scenario.

United States

Input-output structure

Input output data is sourced from the Bureau of Economic Analysis (BEA) 2019 input output tables at the 1-digit NAICS level. I drop the non-comparable imports and second hand scrap sectors.

Covid scenario

I source the four aggregate data series - GDP, personal consumption expenditures (PCE), gross fixed capital formation and the personal consumption expenditure deflator from the BEA national accounts. I then use the BEA PCE bridge to map changes in the PCE quantity and price indices into changes in consumption at the industry level.[32]

European Union

Input-output structure

Input-output data is sourced from the Eurostat 2015 input-output tables.

Covid scenario

I source the four aggregate series - GDP, household final consumption expenditure, gross fixed capital formation and the consumption deflator from the Eurostat national accounts.

Eurostat does not publish consumption data at a sufficiently disaggregated level to allow for estimates of EA industry-level consumption. I therefore rely on German and French household consumption expenditure estimates, published by the German Federal Statistical Office and INSEE to estimate these values. For Germany, I calculate recreation consumption as the sum of "Recreation, entertainment and culture" expenditure and "Accommodation and restaurant services" expenditure. I calculate retail expenditure as the sum of "Food, beverages and tobacco products", "Clothing and footwear" and "Furniture, lighting equipment, appliances etc." Price and quantity data are available for all of the series. For France, industry-level consumption data in real and nominal terms are directly available for all of the industries in the model.

For each industry-level consumption series, I construct a Euro-area price and quantity index by taking an equally-weighted average of the growth rates of the German and French series. The German economy is larger than the French economy, and hence accounts for a larger weight in overall EA consumption. However, the German economy was also less affected by the Covid crisis than most other economies in the Euro area. Applying equal weights to Germany and France, which was more affected by the pandemic,

[32] The PCE bridge is available at `https://apps.bea.gov/industry/xls/underlying-estimates/PCEBridge_1997-2018_SUM.xlsx`.

helps to account for this.

Japan

Input-output structure

Input-output data is sourced from the Statistics Bureau of Japan's (SBJ) 2015 input-output tables.

Covid scenario

I source the four aggregate series - GDP, household final consumption expenditure, gross fixed capital formation and the consumption deflator from the SBJ's national accounts.

As for the EA, the SBJ national accounts do not publish household consumption data at a sufficient degree of aggregation to allow for estimates of industry-level consumption in Japan. I estimate retail trade consumption using the Retail Sales data release. I estimate the other customer-facing services components using estimates from the Japan Services Industry Survey data release. Recreation services are the sum of the series "Accommodation, eating and drinking services" and "Living-related and personal services and amusement services". Transport services are equal to the series "Transport and postal activities". Social services are equal to the sum of the series "Education, learning support" and "Medical, health care and welfare". Other services are equal to the series "Services n.e.c.".

The retail trade and services data are available only in nominal terms. I use data from the Japanese Consumer Price Index (CPI) to construct price indices for these series. I use these series to construct industry-level inflation rates and use these to deflate the nominal consumption expenditure data defined above. I define the retail trade price index as a weighted average of the indices for "Fresh Food", "Furniture and household utensils", "Clothes and footwear", "Recreation goods", and "Domestic non-durable goods".[33] The transportation price index is the CPI category "Transportation and communications". The recreation services price index is the CPI category "Culture and recreation". The other services price index is a weighted average of the categories "Domestic services", "Repairs and maintenance" and "Personal care services". A series of policy changes led to large decreases in the Education component of the CPI in October 2019 and April 2020, which makes this series an unreliable guide to demand conditions in the social services sector. I therefore use the aggregate CPI as the measure of education prices.

China

Input-output structure

I construct input-output relationships for China using information from the Asian Development Bank's Multiregional Input-Output Database and the National Bureau of Statistics of China (NBSC) input-output tables, in both cases for 2015. Because the ADB tables contain more industry detail, particularly for services industries, I use this datables to construct the intermediate-input use and final use matrices. I use the NBSC database to seperate industry value added into compensation of employees and gross operating surplus, as this information is missing from the ADB database.

[33] I use relative CPI weights to construct the weighted average.

Covid scenario

The source for all data series is the NBSC. I seasonally adjust all data series using the X-12 procedure.

Quarterly aggregate GDP is available directly from the national accounts. For consumption expenditure I use the series "Consumption Expenditure of Urban Households". For investment I use the series "Fixed Asset Investment". My measure of consumption inflation is the consumer price index. For China I use measures of value-added by industry, rather than household consumption. For the transport industry I use the series "Value added by Transport, Storage and Post". For the retail trade industry I use the series "Value added by Wholesale and Retail Trade". For the recreation industry I use the series "Value added by Accommodation and Catering Trade". For other services I use the series "Value added by Other".

I construct industry-level inflation using data from the Chinese Consumer Price Index (CPI). For retail trade I use the series "Clothing". For transportation I use the series "Transportation and Communication". For recreation I use the series "Education, Culture and Recreation". For other services I use the series "Miscellaneous Goods and Services".

B Structural change algorithm

This appendix describes the sequence of structural changes that I use to account for the Covid crisis and its aftermath.[34]

Up to and including 2019Q4 the structure of the economy is described by the system of equations:

$$\mathbf{A}x_t = \mathbf{C} + \mathbf{B}x_{t-1} + \mathbf{D}\mathbb{E}_t\{x_{t+1}\} + \mathbf{F}\varepsilon_t \tag{B.1}$$

where x_t is the vector of model variables and ε_t is a vector of exogenous i.i.d. shocks. The matrices $\mathbf{A}$, $\mathbf{B}$, $\mathbf{C}$, $\mathbf{D}$ and $\mathbf{F}$ are the equation coefficients consistent with the initial structure of the economy.

If it exists and is unique, the standard rational expectations solution to Equation (B.1) is the VAR:

$$x_t = \mathbf{J} + \mathbf{Q}x_{t-1} + \mathbf{G}\varepsilon_t \tag{B.2}$$

where the reduced form matrices $\mathbf{J}$, $\mathbf{Q}$ and $\mathbf{G}$ are constant, consistent with the stable economic structure.

In 2020Q1, the economic structure changes to:

$$\bar{\mathbf{A}}x_t = \bar{\mathbf{C}} + \bar{\mathbf{B}}x_{t-1} + \bar{\mathbf{D}}\mathbb{E}_t\{x_{t+1}\} + \bar{\mathbf{F}}\varepsilon_t \tag{B.3}$$

where $\bar{\mathbf{A}}$, $\bar{\mathbf{B}}$, $\bar{\mathbf{C}}$, $\bar{\mathbf{D}}$ and $\bar{\mathbf{F}}$ are the equation coefficients consistent with the structure of the economy that prevailed in 2020Q1.

I assume that in 2020Q1 agents expected the economic structure to be temporary and revert to its initial structure in 2020Q2. In this case, the reduced form solution is:

$$x_t = \bar{\mathbf{J}} + \bar{\mathbf{Q}}x_{t-1} + \bar{\mathbf{G}}\varepsilon_t \tag{B.4}$$

where:

$$\bar{\mathbf{J}} = \left(\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q}\right)^{-1}\left(\bar{\mathbf{C}} + \bar{\mathbf{D}}\mathbf{J}\right) \tag{B.5}$$

$$\bar{\mathbf{Q}} = \left(\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q}\right)^{-1}\bar{\mathbf{B}} \tag{B.6}$$

$$\bar{\mathbf{J}} = \left(\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q}\right)^{-1}\bar{\mathbf{F}} \tag{B.7}$$

where $\bar{\mathbf{Q}}$ and $\bar{\mathbf{J}}$ are the reduced form solution matrices from Equation (B.2).

In 2020Q2 and 2020Q3, the structure of the economy changes once more. The latter structure prevails until some future period $\mathbf{T}$. These changes are anticipated in 2020Q2. For these periods, the reduced form solution matrices can be calculated recursively.

Specifically, assume that the structure of the economy prevailing between 2020Q3 and $\mathbf{T} - 1$ is:

$$\tilde{\mathbf{A}}x_t = \tilde{\mathbf{C}} + \tilde{\mathbf{B}}x_{t-1} + \tilde{\mathbf{D}}\mathbb{E}_t\{x_{t+1}\} + \tilde{\mathbf{F}}\varepsilon_t \tag{B.8}$$

[34] A description of these approaches in a more general setting is available in Kulish and Pagan (2017).

where $\tilde{\mathbf{A}}$, $\tilde{\mathbf{B}}$, $\tilde{\mathbf{C}}$, $\tilde{\mathbf{D}}$ and $\tilde{\mathbf{F}}$ are the equation coefficients consistent with the structure of the economy that prevail from 2020Q3. And assume that agents expect that at some future period $\mathbf{T}$ the economy will revert to the economic structure that prevailed prior to the crisis. The solution to the model between 2020Q3 and $\mathbf{T}$ is a time-varying VAR of the form:

$$x_t = \mathbf{J}_t + \mathbf{Q}_t x_{t-1} + \mathbf{G}_t \varepsilon_t \tag{B.9}$$

where the time-varying reduced form matrices are given by:

$$\mathbf{J}_t = (\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q}_{t+1})^{-1}(\bar{\mathbf{C}} + \bar{\mathbf{D}}\mathbf{J}_{t+1}) \tag{B.10}$$

$$\mathbf{Q}_t = (\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q}_{t+1})^{-1}\bar{\mathbf{B}} \tag{B.11}$$

$$\mathbf{G}_t = (\bar{\mathbf{A}} - \bar{\mathbf{B}}\mathbf{Q}_{t+1})^{-1}\bar{\mathbf{F}} \tag{B.12}$$

As we know the values of $\mathbf{Q}_{\mathbf{T}}$ and $\mathbf{J}_{\mathbf{T}}$, one can solve this system of equations recursively to derive the sequence of reduced form matrices from the start of the crisis to its resolution.

The solution for the reduced form solution matrices in 2020Q2 is a straightforward application of the recursions defined above to the economic structure that applies in 2020Q2.

C Industry value-added decomposition

This appendix describes the decomposition of industry-value added in Section 4.3.

I start with the definition of industry value-added:

$$\underbrace{y^{va}_{j,t}}_{\texttt{Value-added}} = \underbrace{c_{j,t} + i_{j,t} + g_{j,t}}_{\texttt{Final demand}} + \underbrace{\sum_{k}^{\mathcal{F}} x_{k,j,t}}_{\substack{\texttt{Intermediates} \\ \texttt{demand}}} - \underbrace{\sum_{k}^{\mathcal{F}} x_{j,k,t}}_{\substack{\texttt{Intermediate} \\ \texttt{inputs}}} \tag{C.1}$$

where the second term from the right refers to demand for the output of good j as an intermediate input and the final term refers to intermediate inputs used in the production of good j.

Define $fd_{j,t} = c_{j,t} + i_{j,t} + g_{j,t}$ as the final demand for the output of industry j. Using the fact that in the initial steady state all relative prices equal 1, I define the income component of final demand as:

$$fd^{y}_{j,t} = \omega_{c,j} C_t + \omega_{i,j} I_t + \omega_{g,j} G_t \tag{C.2}$$

where $\omega_{c,j}$, $\omega_{i,j}$ and $\omega_{g,j}$ are the weights of the output of industry j in the aggregate consumption, investment and public demand bundles. I then define the substitution component of final demand as the residual between $fd_{j,t}$ and $fd^{y}_{j,t}$:

$$fd^{s}_{j,t} = fd_{j,t} - fd^{y}_{j,t} \tag{C.3}$$

Finally, I allocate intermediate inputs into production to the final demand and intermediate input components to express value added output as the sum of value-added demand:

$$y^{va}_{j,t} = fd^{y,va}_{j,t} + fd^{s,va}_{j,t} + \sum_{k}^{\mathcal{F}} x^{va}_{k,j,t} \tag{C.4}$$

where:

$$fd^{y,va}_{j,t} = fd^{y}_{j,t} - \frac{fd^{y}_{j,t}}{y_{j,t}} \sum_{k=1}^{\mathcal{F}} x_{j,k,t} \tag{C.5}$$

$$fd^{s,va}_{j,t} = fd^{s}_{j,t} - \frac{fd^{s}_{j,t}}{y_{j,t}} \sum_{k=1}^{\mathcal{F}} x_{j,k,t} \tag{C.6}$$

$$x^{va}_{k,j,t} = x_{k,j,t} - \frac{x_{k,j,t}}{y_{j,t}} \sum_{k=1}^{\mathcal{F}} x_{j,k,t} \tag{C.7}$$

where $y_{j,t} = fd_{j,t} + \sum_{k=1}^{\mathcal{F}} x_{k,j,t}$ is gross output.

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