

Supply and demand shocks in the COVID-19 pandemic: An industry and occupation perspective ^{*†}

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Abstract

We provide quantitative predictions of first order supply and demand shocks for the U.S. economy associated with the COVID-19 pandemic at the level of individual occupations and industries. To analyze the supply shock, we classify industries as essential or non-essential and construct a Remote Labor Index, which measures the ability of different occupations to work from home. Demand shocks are based on a study of the likely effect of a severe influenza epidemic developed by the US Congressional Budget Office. Compared to the pre-COVID period, these shocks would threaten around 25% of the US economy's GDP, jeopardise 22% of jobs and reduce total wage income by 16%. At the industry level, sectors such as transport are likely to have output constrained by demand shocks, while sectors relating to manufacturing, mining and services are more likely to be constrained by supply shocks. Entertainment, restaurants and tourism face large supply and demand shocks. At the occupation level, we show that high-wage occupations are relatively immune from adverse supply and demand-side shocks, while low-wage occupations are much more vulnerable. We should emphasize that our results are only first-order shocks – we expect them to be substantially amplified by feedback effects in the production network.

Keywords: COVID-19; economic growth; unemployment.

JEL codes: I15; J21; J23; J63; O49

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1 Introduction

The COVID-19 pandemic is having an unprecedented impact on societies around the world. As governments mandate social distancing practices and instruct non-essential businesses to close to slow the spread of the outbreak, there is significant uncertainty about the effect such measures will have on lives and livelihoods. While demand for specific sectors such as healthcare has skyrocketed in recent weeks, other sectors such as air transportation and tourism have seen demand for their services evaporate. At the same time, many sectors are experiencing issues on the supply-side, as governments curtail the activities of non-essential industries and workers are confined to their homes.

Many economists and commentators believe that the economic impact could be dramatic (Baldwin & Weder di Mauro 2020). To give an example based on survey data in an economy under lockdown, the French statistical office estimated on March 26 that the economy is currently at around 65% of its normal level¹. Bullard (2020) provides an undocumented estimate that around a half of the US economy would be considered either essential, or able to operate without creating risks of diffusing the virus. Inoue & Todo (2020) modeled how shutting down firms in Tokyo would cause a loss of output in other parts of the economy through supply chain linkages, and estimate that after a month, daily output would be 86% lower than pre-shock (i.e. the economy would be operating at only 14% of its capacity!). Using a calibrated extended consumption function, and assuming a labor income shock of 16% and various consumption shocks by expenditure categories, Muellbauer (2020) estimates a fall of quarterly consumption of 20%. Roughly speaking, most of these estimates, like ours, are estimates of instantaneous declines, and would translate to losses of annual GDP if the lockdown lasted for a year.

In a rare study based on aggregating industry-level shocks, the OECD (2020) estimates a drop in immediate GDP of around 25%, which is in line with our results. Another study by Barrot et al. (2020) estimates industry level shocks by considering the list of essential industries, the closure of schools, and an estimate of the ability to work from home (based on ICT use surveys); Using these shocks in a multisector input-output model, they find that six weeks of social distancing brings GDP down by 5.6%.

In this paper, we aim to provide analytical clarity about the supply and demand shocks caused by public health measures and changes in preferences caused by avoidance of infection. We estimate (i) supply-side reductions due to the closure of non-essential industries and workers not being able to perform their activities at home and (ii) demand-side changes due to peoples' immediate response to the pandemic, such as increased demand for healthcare and reduced demand for goods or services that are likely to place people at risk of infection (e.g. tourism).

It is important to stress that the shocks that we predict here should not be interpreted as the *overall impact* of the COVID-19 pandemic on the economy. Deriving overall impact estimates involves modeling second-order effects, such as the additional reductions in demand as workers who are stood down or laid off experience a reduction in income and additional reductions in supply as potential shortages propagate through supply chains. Further effects, such as cascading firm defaults, which can trigger bank failures and systemic risk in the financial system, could also arise. Understanding these impacts requires a model of the macro-economy and financial sector. We intend to present results from such an economic model in the future, but in the meantime we want to make our estimates of first order impacts available for researchers or governments to build upon or use in their own models.

Several researchers have already provided estimates of the supply shock from labor supply (Dingel & Neiman 2020, Hicks 2020, Koren & Petó 2020). Here we improve on these efforts in three ways: (i) we

¹<https://www.insee.fr/en/statistiques/4473305?sommaire=4473307>

propose a methodology for estimating how much work can be done from home based on work activities, (ii) we identify industries for which working from home is irrelevant because the industries are considered essential, and (iii), we compare our estimated supply shocks to estimates of the demand shock, which in many industries is the more relevant constraint on output.

To see why it is important to compare supply and demand shocks, consider the following thought experiment: Following social distancing measures, suppose industry i is capable of producing only 70% of its pre-crisis output, e.g. because workers can produce only 70% of the output while working from home. If consumers reduce their demand by 90%, the industry will produce only what will be bought, that is, 10%. If instead consumers reduce their demand by 20%, the industry will not be able to satisfy demand but will produce everything it can, that is, 70%. In other words, the experienced first order reduction in output from the immediate shock will be the greater of the supply shock or the demand shock. In other words, most of the first-order impact on the economy will be due to an inability of people to work rather than to consume. However, again, we expect as wages from work drop, there will be potentially larger second-order negative impacts on demand, and the potential for a self-reinforcing downward spiral in output, employment, income, and demand.

Overall, we find that the supply and demand shocks considered in this paper represent a reduction of around one quarter of the US economy’s value added, one fifth of current employment and about 16% of the US total wage income. Supply shocks account for the majority of this reduction. These effects vary substantially across different industries. While we find no negative effects on value added for industries like Legal services, Power generation and distribution or Scientific research, the expected loss of value added reaches up to 80% for Accommodation, Food services and Independent artists.

We show that sectors such as Transport are likely to experience immediate demand-side reductions that are larger than their corresponding supply-side shocks. Other industries such as manufacturing, mining and certain service sectors are likely to experience larger immediate supply-side shocks relative to demand-side shocks. Health unsurprisingly experiences an overall increase in demand for its output. Entertainment, restaurants and hotels experience very large supply and demand shocks, with the demand shock dominating. These results are important because supply and demand shocks might have different degrees of persistence, and industries will react differently to policies depending on the constraints that they face. Overall, however, we find that aggregate effects are dominated by supply shocks, with a large part of manufacturing and services being classified as inessential while its labor force is unable to work from home.

We also break down our results by occupation and show that there is a strong negative relationship between the overall immediate shock experienced by an occupation and its wage. Relative to the pre-COVID period, 38% of the jobs for workers in the bottom quartile of the wage distribution are predicted to be vulnerable. (And bear in mind that this is only a first-order shock – second order shocks may significantly increase this). In contrast, most high-wage occupations are relatively immune from adverse shocks, with only 6% of the jobs at risk for the 25% of workers working in the highest pay occupations. Absent strong support from governments, most of the economic burden of the pandemic will fall on lower wage workers.

We neglect several effects that, while important, are small compared to those we consider here. First, we have not sought to quantify the reduction in labor supply due to workers contracting COVID-19. A rough estimate suggests that this effect is relatively minor in comparison to the shocks associated with social distancing measures that are being taken in most developed countries.² We have also not explicitly

²See Appendix D.1 for rough quantitative estimates in support of this argument.

included the effect of school closures. However, in Appendix D.2 we argue that this is not the largest effect and is already partially included in our estimates through indirect channels.

A more serious problem is caused by the need to assume that that within a given occupation, being unable to perform some work activities does not harm the performance of other work activities. Within an industry, we also assume that if workers in a given occupation cannot work, they do not produce output, but this does not prevent other workers in different occupations from producing. In both cases we assume that the effects of labor on production are linear, i.e. that production is proportional to the fraction of workers who can work. In reality however, it is clear that there are important complementarities leading to nonlinear effects. There are many situations where production requires a combination of different occupations, such that if workers in key occupations cannot work at home, production is not possible. For example, while the accountants in a steel plant might be able to work from home, if workers needed to run it cannot come the plant, no steel is made. We cannot avoid making linear assumptions because as far as we know there is no detailed understanding of the labor production function and these interdependencies at an industry level. By neglecting nonlinear effects, our work here should consequently be regarded as an approximate lower bound on the size of the first order shocks.

This paper focuses on the United States. We have chosen it as our initial test case because input-output tables are more disaggregated than those of most other countries, and because the O*NET database, which we rely on for information about occupations was developed based on US data. With some additional assumptions it is possible to apply the analysis we perform here to other developed countries.

This paper is structured as follows. In Section 2 we describe our methodology for estimating supply shocks, which involves developing a new Remote-Labor Index (RLI) for occupations and combining it with a list of essential industries. Section 3 discusses likely demand shocks based on estimates developed by the US Congressional Budget Office (2006) to predict the potential economic effects of an influenza pandemic. In Section 4, we show a comparison of the supply and demand shocks across different industries and occupations and identify the extent to which different activities are likely to be constrained by supply or demand. We also explore which occupations are more exposed to infection and make comparisons to wage and occupation-specific shocks. In Section 5 we discuss our findings in light of existing research and outline avenues for future work. We also make all of our data available in a continuously updated online repository.

2 Supply shocks

Supply shocks from pandemics are mostly thought of as labor supply shocks. Several pre-COVID-19 studies focused on the direct loss of labor from death and sickness (e.g. McKibbin & Sidorenko (2006), Santos et al. (2013)), although some have also noted the potentially large impact of school closure (Keogh-Brown et al. 2010). McKibbin & Fernando (2020) consider (among other shocks) reduced labor supply due to mortality, morbidity due to infection, and morbidity due to the need to care for affected family members. In countries where social distancing measures are in place, social distancing measures will have a much larger economic effect than the direct effects from mortality and morbidity. This is in part because if social distancing measures work, only a small share of population will be infected and die eventually. Appendix D.1 provides more quantitative estimates of the direct mortality and morbidity effects and argues that they are likely to be at least an order of magnitude smaller than those due to social distancing measures, especially if the pandemic is contained.

For convenience we neglect mortality and morbidity and assume that the supply shocks are determined only by the amount of labor that is withdrawn due to social distancing. We consider two key factors: (i) the extent to which workers in given occupations can perform their requisite activities at home and (ii) the extent to which workers are likely to be unable to come to work due to being in non-essential industries. We quantify these effects on both industries and occupations. Fig. 1 gives a schematic overview of how we predict industry and occupation specific supply shocks. We explain this in qualitative terms in the next few pages; for a formal mathematical description see Appendix A.1.

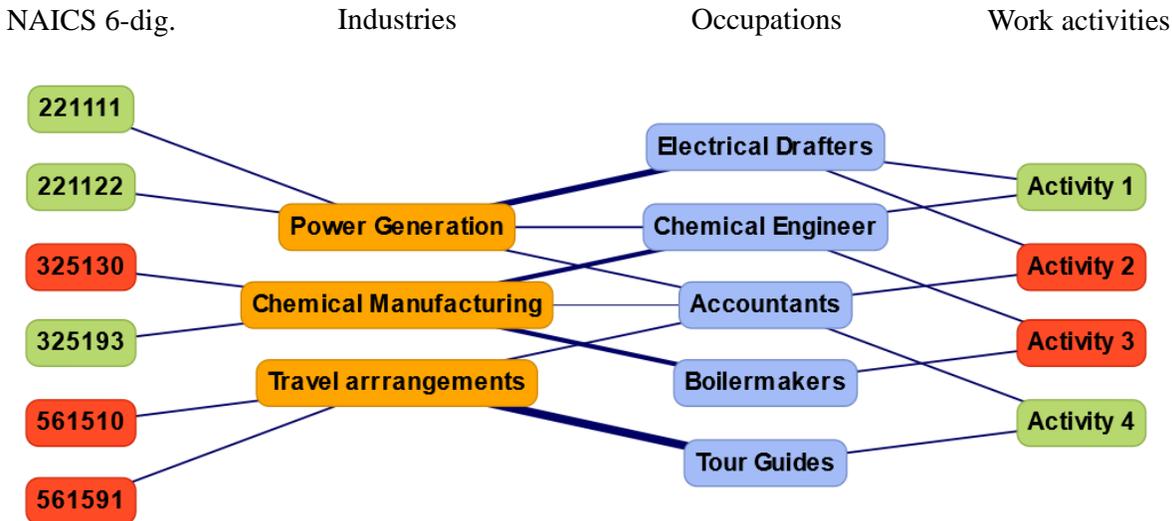


Figure 1: A schematic network representation of supply side shocks. The nodes to the left represent the list of essential industries at the NAICS 6-digit level. A green node indicates essential, a red node non-essential. The orange nodes (center-left) are more aggregate industry categories (e.g. 4-dig. NAICS or the BLS industry categories) for which further economic data is available. These two sets of nodes are connected through industry concordance tables. The blue nodes (center-right) are different occupations. A weighted link connecting an industry category with an occupation represents the number of people of a given occupation employed in each industry. Nodes on the very right are O*NET work activities. Green work activities mean that they can be performed from home, while red means that they cannot. O*NET provides a mapping of work activities to occupations.

2.1 How much work can be performed from home?

One way to assess the degree to which workers are able to work from home during the COVID-19 pandemic is by direct survey. For example, Zhang et al. (2020) conducted a survey of Chinese citizens in late February (one month into the coronavirus-induced lockdown in China) and found that 27% of the labor force continued working at the office, 38% worked from home, and 25% stopped working. Adams-Prassl et al. (2020) surveyed US and UK citizens in late March, and reported that the share of tasks that can be performed from home varies widely between occupations (from around 20 to 70%), and that higher wage occupations tend to be more able to work from home.

Other recent work has instead drawn on occupation-level data from the Occupational Information Network (O*NET) to assess ‘work context’ characteristics to determine labour shocks due to the COVID-19 pandemic. For example, Hicks (2020) considered the degree to which an occupation is required to ‘work with others’ or involves ‘physical proximity to others’ in order to assess which occupations are likely to be most impacted by social distancing. Similarly, to identify which occupations were likely to be able to work from home, Dingel & Neiman (2020) used O*NET data on the extent to which occupations requires

daily ‘work outdoors’ or needed to engage with ‘operating vehicles, mechanized devices or equipment’.

We go to a more granular level than ‘work context’, and instead draw on O*NET’s ‘intermediate work activity’ data, which provides a list of the activities performed by each occupation based on a list of 332 possible work activities. For example, a Nurse undertakes activities such as “maintain health or medical records”, “develop patient or client care or treatment plans” and “operate medical equipment”, while a Computer Programmer performs activities such as “resolve computer programs”, “program computer systems or production equipment” and “document technical designs, producers or activities”³. In Fig 1 these work activities are illustrated by the rightmost set of nodes.

Which work activities can be performed from home? Four of us independently assigned a subjective binary rating to each work activity as to whether it could successfully be performed at home. The individual results were in broad agreement. Based on the responses, we assigned an overall consensus rating to each work activity⁴. Ratings for each work activity are available in an online data repository⁵. While O*NET maps each intermediate work activity to 6-digit O*NET occupation codes, employment information from the US Bureau of Labor Statistics (BLS) is available for the 2018 Standard Occupation Scheme (SOC) codes, so we mapped O*NET and SOC codes using a crosswalk available from O*NET.⁶ Our final sample contains 660 occupations.

From work activities to occupations. We then created a Remote Labor Index (RLI) for each occupation by calculating the proportion of an occupation’s work activities that can be performed at home. An RLI of 1 would indicate that all of the activities associated with an occupation could be undertaken at home, while an RLI of 0 would indicate that none of the occupation’s activities could be performed at home.⁷ In Table 1, we show the top 20 occupations having the highest RLI ranking. Some occupations such as credit analysts, tax preparers and mathematical science occupations are estimated to be able to perform 100% of their work activities from home. Table 1 also shows a sample of the 43 occupations with an RLI ranking of zero, i.e. those for which there are no activities that are able to be performed at home.

To provide a broader perspective of how the RLI differs across occupation categories, Fig. 2 shows a series of box-plots indicating the distribution of RLI for each 4-digit occupation in each 2-digit SOC occupation category. We have ordered 2-digit SOC occupations in accordance with their median values. Occupations with the highest RLI relate to Business and Financial, Computer and Mathematical, and Management roles, while occupations relating to Production, Installation, Maintenance and Transportation and Material Moving tend to have lower RLI.

³In the future we intend to redo this using O*NET’s “detailed” work activity data, which involves over 2000 individual activities associated with different occupations. We believe this would somewhat improve our analysis, but we also think that for our purposes here the intermediate activity list provides a good approximation.

⁴An activity was considered to be able to be performed at home if three or more respondents rated this as true. We also undertook a robustness analysis where an activity was considered to be able to be performed at home based on two or more true ratings. Results remained fairly similar. In post-survey discussion, we agreed that the most contentious point is that some work activities might be done from home or not, depending on the industry in which it is performed.

⁵<https://zenodo.org/record/3744960#.Xo4eUXVKhE>

⁶Available at <https://www.onetcenter.org/taxonomy/2010/soc2018.html>.

⁷We omitted nine occupations that had less than five work activities associated with them. These occupations include Insurance Appraisers, auto-damage; Models; Court Reporters and Simultaneous Captioners; Animal Scientists; Title Examiners Abstractors, and Searchers; Dredge Operators; Athletes and Sports Competitors; and Slaughterers and Meat Packers.

Occupation	RLI
Credit Analysts	1.00
Insurance Underwriters	1.00
Tax Preparers	1.00
Mathematical Science Occupations, All Other	1.00
Political Scientists	1.00
Social Scientists and Related Workers, All Other	0.93
Eligibility Interviewers, Government Programs	0.92
Editors	0.91
Technical Writers	0.91
Market Research Analysts and Marketing Specialists	0.90
Business Teachers, Postsecondary	0.90
Management Analysts	0.89
Marketing Managers	0.87
Mathematicians	0.87
Astronomers	0.87
Interpreters and Translators	0.87
Financial Risk Specialists	0.87
Operations Research Analysts	0.87
Anthropology and Archeology Teachers, Postsecondary	0.86
Psychology Teachers, Postsecondary	0.86
...	...
Bus and Truck Mechanics and Diesel Engine Specialists	0.00
Rail Car Repairers	0.00
Refractory Materials Repairers, Except Brickmasons	0.00
Musical Instrument Repairers and Tuners	0.00
Wind Turbine Service Technicians	0.00
Locksmiths and Safe Repairers	0.00
Signal and Track Switch Repairers	0.00
Meat, Poultry, and Fish Cutters and Trimmers	0.00
Pourers and Casters, Metal	0.00
Foundry Mold and Coremakers	0.00
Extruding and Forming Machine Setters, Operators, and Tenders, Synthetic and Glass Fibers	0.00
Packaging and Filling Machine Operators and Tenders	0.00
Cleaning, Washing, and Metal Pickling Equipment Operators and Tenders	0.00
Cooling and Freezing Equipment Operators and Tenders	0.00
Paper Goods Machine Setters, Operators, and Tenders	0.00
Tire Builders	0.00
Helpers-Production Workers	0.00
Production Workers, All Other	0.00
Machine Feeders and Offbearers	0.00
Packers and Packagers, Hand	0.00

Table 1: **Top and bottom 20 occupations ranked by Remote Labor Index (RLI)**, based on proportion of work activities that can to be performed by home. There are 43 occupations with an RLI of zero; we show only a random sample.

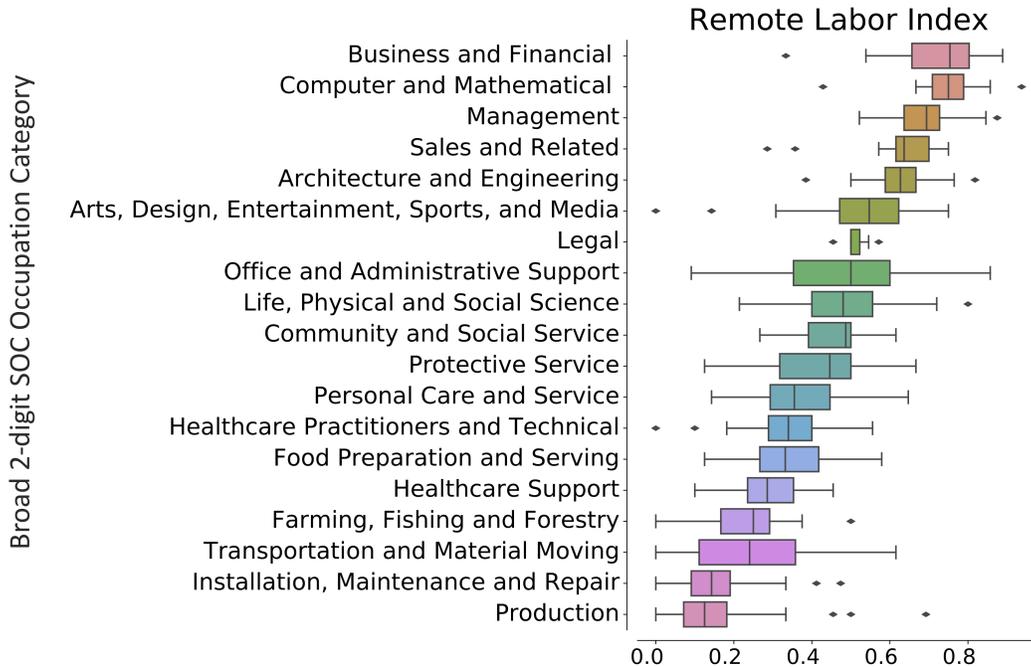


Figure 2: **Distribution of Remote Labor Index across occupations.** We provide boxplots showing distribution of RLI for each 4-digit occupation in each 2-digit SOC occupation category.

From occupations to industries. We next map the RLI to industry categories to quantify industry-specific supply shocks from social distancing measures. We obtain occupational compositions per industry from the BLS, which allows us to match our sample of 660 occupations to 277 industries⁸.

In Fig. 3, we show the RLI distribution for each 4-digit occupation category falling within each broad 2-digit NAICS category. Similar to Fig. 2, we have ordered the 2-digit NAICS industry categories in accordance with the median values of each underpinning distribution. As there is a greater variety of different types of occupations within these broader industry categories, distributions tend to be much wider. Industries with the highest median RLI values relate to Information and Finance and Insurance, while industries with the lowest median RLI relate to Agriculture, Forestry, Fishing and Hunting and Public Administration.

⁸We use the May 2018 Occupational Employment Statistics (OES) estimates on the level of 4-digit NAICS (North American Industry Classification System) which is available at <https://www.bls.gov/oes/tables.htm>. Overall, our merged dataset covers 118.5 out of 144 million employed people (82%) initially reported in the OES.

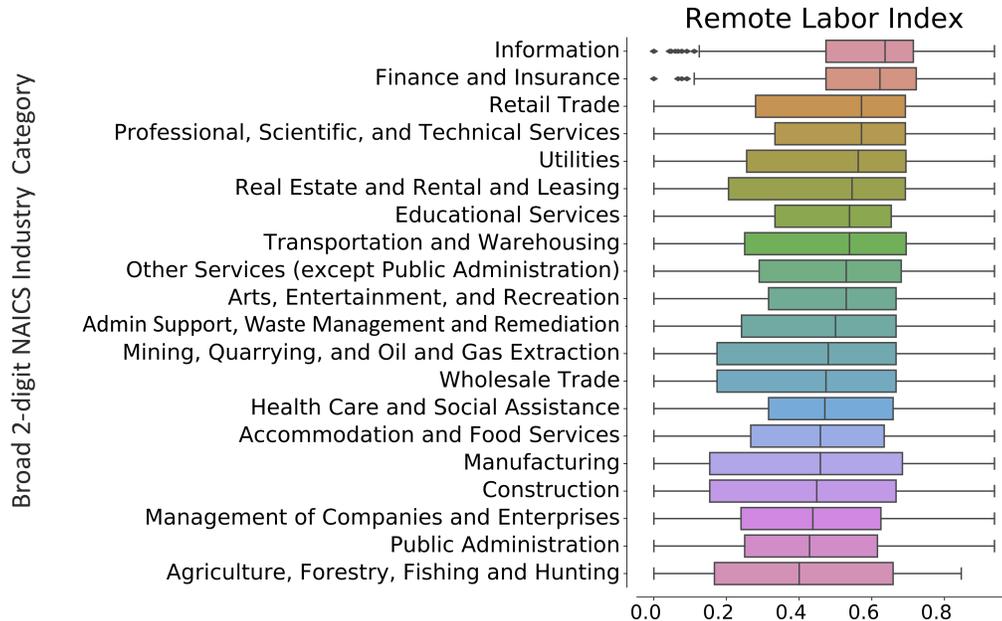


Figure 3: **Distribution of Remote Labor Index across industries.** We provide boxplots showing distribution of RLI for each 4-digit occupation in each 2-digit NAICS Industry category.

In the Appendix, we show industry-specific RLI values for the more detailed 4-digit NAICS industries. To arrive at a single number for each 4-digit industry, we compute the employment-weighted average of occupation-specific RLIs. The resulting industry-specific RLI can be interpreted as a rough estimate of the fraction of jobs which can be performed from home for each industry.

2.2 Which industries are “essential”?

Across the world, many governments have mandated that certain industries deemed ‘essential’ should remain open over the COVID-19 crisis duration. What constitutes an ‘essential’ industry has been the subject of significant debate, and it is likely that the endorsed set of essential industries will vary across countries. As the U.S. government has not produced a definitive list, here we draw on the list of essential industries developed by Italy and assume it can be applied, at least as an approximation, to other countries such as the U.S. as well. This list has two key advantages. First, as Italy was one of the countries affected earliest and most severely, it was one of the first countries to invest significant effort considering which industries should be deemed essential. Second, Italy’s list of essential industries includes NACE industrial classification codes, which can be mapped to the NAICS industry classification we use to classify industrial employment in this paper.⁹

Table 2 shows the total numbers of NAICS essential industries at the 6-digit and 4-digit level. More than 50% of 6-digit NAICS industries are considered essential. At the 6-digit level the industries

⁹Mapping NACE industries to NAICS industries is not straightforward. NACE industry codes at the 4-digit level are internationally defined. However, 6-digit level NACE codes are country specific. Moreover, the list of essential industries developed by Italy involves industries defined by varying levels of aggregation. Most essential industries are defined at the NACE 2-digit and 4-digit level, with a few 6-digit categories thrown in for good measure. As such, much of our industrial mapping methodology involved mapping from one classification to the other by hand. We provide a detailed description of this process in Appendix B.1.

are either classified as essential, and assigned essential score 1, or non-essential and assigned essential score 0. Unfortunately, it is not possible to translate this directly into a labour force proportion as BLS employment data at detailed occupation and industry levels are only available at the NAICS 4-digit level. To derive an estimate at the 4-digit level, we assume that labor in a NAICS 4-digit code is uniformly distributed over its associated 6-digit codes. We then assign an essential ‘share’ to each 4-digit NAICS industry based on the proportion of its 6-digit NAICS industries that are considered essential. (The distribution of the essential share over 4-digit NAICS industries is shown in the Appendix). Based on this analysis, we estimate that about 81 million (or 68%) of US workers are currently employed in essential industries.

Total 6-digit NAICS industries	1057
Number of essential 6-digit NAICS industries	612
Fraction of essential industries at 6-digit NAICS	0.58
Total 4-digit NAICS industries in our sample	277
Average rating of essential industries at 4-digit NAICS	0.56
Fraction of labor force in essential industries	0.68

Table 2: **Essential industries.** Essential industries at the 6-digit level and essential ‘share’ at the 4-digit level. Note that 6-digit NAICS industry classifications are binary (0 or 1) whereas 4-digit NAICS industry classifications can take on any value between 0 and 1.

2.3 Supply shock: non-essential industries unable to work from home

Having analyzed both the extent to which jobs in each industry are essential and the likelihood that workers in a given occupation can perform their requisite activities at home, we now combine these to consider the overall first-order effect on labor supply in the US. In Figure 4, we plot the Remote Labor Index of each occupation against the fraction of that occupation employed in an essential industry. Each circle in the scatter plot represents an occupation; the circles are sized proportional to current employment and color coded according to the median wage in each occupation.

Fig. 4 indicates the vulnerability of occupations due to supply-side shocks. Occupations in the lower left-hand side of the plot (such as Cooks, Athletes, and Stonemasons) have lower RLI scores (indicating they are less able to work from home) and are less likely to be employed in an essential industry. If we consider only the immediate supply-side effects of social distancing, workers in these occupations are more likely to face reduced work hours or be at risk of losing their job altogether. In contrast, occupations on the upper right-hand side of the plot, such as Financial Analysis, Statisticians and Tax Preparers) have higher RLI scores and are more likely to be employed in an essential industry. These occupations are less economically vulnerable to the supply-side shocks (though, as we discuss in the next section, they could still face employment risks due to first-order demand-side effects). Occupations in the upper-right hand side of the plot (such as Electricians, Orderlies, Bailiffs and Slaughterers and Meat Packers) are less likely to be able to perform their job at home, but since they are more likely to be employed in an essential industry their economic vulnerability from supply-side shocks is lower. Interestingly, there are relatively few occupations on the lower-right hand side of the plot. This indicates that occupations that are predominantly employed in non-essential industries tend to be less able to perform their activities at home.

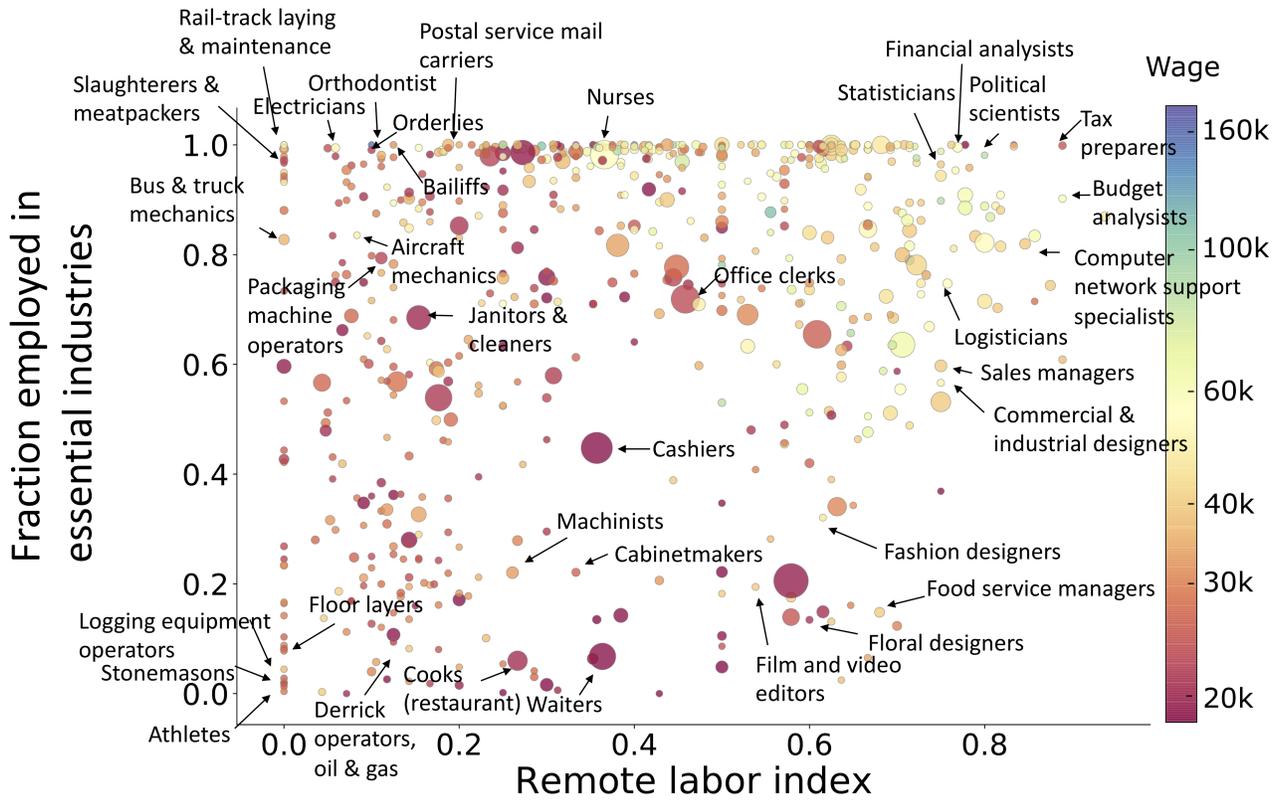


Figure 4: **Fraction employed in an essential industry vs Remote Labor Index for each occupation.** Omitting the effect of demand reduction, the occupations in the lower left corner, with a small proportion of workers in essential industries and a low Remote Labor Index, are the most vulnerable to loss of employment due to social distancing.

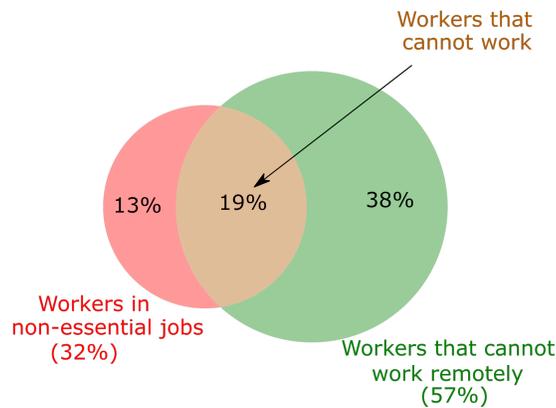


Figure 5: **Workers that cannot work.** On the left is the percentage of workers in a non-essential job (32% in total). On the right is the percentage of workers that cannot work remotely (57% in total). The intersection is the set of workers that cannot work, which is 19% of all workers. A remaining 30% of workers are in essential jobs where they can work remotely.

To help visualize the problem we provide a summary in the form of a Venn diagram in Figure 5. Before the pandemic, 32% of workers were employed in non-essential jobs. 57% of workers cannot do

their job remotely. 19% of workers are in the intersection corresponding to non-essential jobs that cannot be performed remotely. In addition, there are 30% of workers in essential industries that can also work from home.¹⁰

3 Demand shock

The pre-COVID-19 literature on epidemics and the discussions of the current crisis make it clear that epidemics strongly influence patterns of consumer spending. In addition to increasing their demand for health services, consumers are also likely to seek to reduce their risk of exposure to the virus and decrease demand for products and services that involve close contact with others. In the early days of the outbreak, stockpiling behaviour also drives a direct demand increase in the retail sector (Baker et al. 2020).

Estimates from the CBO. Our estimates of the demand shock are based on expert estimates developed by the US [Congressional Budget Office \(2006\)](#) that attempted to predict the potential impact of an influenza pandemic. Similar to the current COVID-19 pandemic, this analysis assumes that demand is reduced due to the desire to avoid infection. While the analysis is highly relevant to the present COVID-19 situation, it is important to note that the estimates are “extremely rough” and “based loosely on Hong Kong’s experience with SARS”. The CBO provides two scenarios. We take the severe scenario, which “describes a pandemic that is similar to the 1918-1919 Spanish flu outbreak. It incorporates the assumption that a particularly virulent strain of influenza infects roughly 90 million people in the United States and kills more than 2 million of them”.

In this paper, we simply take the CBO estimates as immediate (first-order) demand-side shocks. The CBO lists demand side estimates for broad industry categories, which we mapped to the 2-digit NAICS codes by hand. Table 3 shows the CBO’s estimates of the percent decrease in demand by industry, and Table 7 in Appendix E shows the full mapping to 2-digit NAICS.

These estimates, of course, are far from perfect. They are based on expert estimates made more than ten years ago for an hypothetical pandemic scenario. It is not entirely clear if they are for gross output or for final (consumer) demand. However, in Appendix E, we describe three other sources of consumption shocks (Keogh-Brown et al. 2010, Muellbauer 2020, OECD 2020) that provide broadly similar estimates by industry or spending category.

Transitory and permanent shocks. An important question is whether demand reductions are just postponed expenses, and if they are permanent (Mann 2020, Keogh-Brown et al. 2010). Baldwin & Weder di Mauro (2020) also distinguishes between “practical” (the impossibility to shop) and “psychological” demand shocks (the wait-and see attitude adopted by consumers facing strong uncertainty.) We see three possibilities: (i) expenses in a specific good or service are just delayed but will take place later, for instance if households do not go to the restaurant this quarter, but go twice as much as they would normally during the next quarter; (ii) expenses are not incurred this quarter, but will come back to their normal level after the crisis, meaning that restaurants will have a one-quarter loss of sales; and (iii) expenses decrease to a permanently lower level, as household change their preferences in view of the ‘new normal’. Appendix E reproduces the scenario adopted by Keogh-Brown et al. (2010), which distinguishes between delay and permanently lost expenses.

¹⁰In fact we allow for a continuum between the ability to work from home, and an industry can be partially essential.

Broad industry name	Severe Scenario Shock
Agriculture	-10
Mining	-10
Utilities	0
Construction	-10
Manufacturing	-10
Wholesale trade	-10
Retail trade	-10
Transportation and warehousing (including air, rail and transit)	-67
Information (Published, broadcast)	0
Finance	0
Professional and business services	0
Education	0
Healthcare	15
Arts and recreation	-80
Accommodation/food service	-80
Other services except government	-5
Government	0

Table 3: Demand shock by sector according to the Congressional Budget Office (2006)’s severe scenario.

Other components of aggregate demand. We do not include direct shocks to investment, net exports, and net inventories. Investment is typically very pro-cyclical and is likely to be strongly affected, with direct factors including cash-flow reductions and high uncertainty (Boone 2020). The impact on trade is likely to be strong and possibly permanent (Baldwin & Weder di Mauro 2020), but would affect exports and imports in a relatively similar way, so the overall effect on net exports is unclear. Finally, it is likely that due to the disruption of supply chains, inventories will be run down so the change in inventories will be negative (Boone 2020).

4 Combining supply and demand shocks

Having described both supply and demand-side shocks, we now compare the two at the industry and occupation level.

4.1 Industry-level supply and demand shocks.

Fig. 6 plots the demand shock against the supply shock for each industry. The radius of the circles is proportional to the gross output of the industry¹¹. Essential industries have no supply shock and so lie on the horizontal ‘0’ line. Of these industries, sectors such as Utilities experience no demand shock either, since immediate demand for their output is assumed to remain the same. Health experiences an increase in demand and consequently lies below the identity line. Transport on the other hand experiences a reduction in demand and lies well above the identity line. This reflects the current situation, where trains

¹¹Since relevant economic variables such as total output per industry are not extensively available on the NAICS 4-digit level, we need to further aggregate the data. We derive industry-specific total output and value added for the year 2018 from the BLS input-output accounts, allowing us to distinguish 169 private industries for which we can also match the relevant occupation data. The data can be downloaded from <https://www.bls.gov/emp/data/input-output-matrix.htm>.

and buses are running because they are deemed essential, but they are mostly empty¹². Non-essential industries such as Entertainment, Restaurants and Hotels, experience both a demand reduction (due to consumers seeking to avoid infection) and a supply reduction (as many workers are unable to perform their activities at home). Since the demand shock is bigger than the supply shock they lie above the identity line. Other non-essential industries such as manufacturing, mining and retail have supply shocks that are larger than their demand shocks and consequently lie below the identity line.

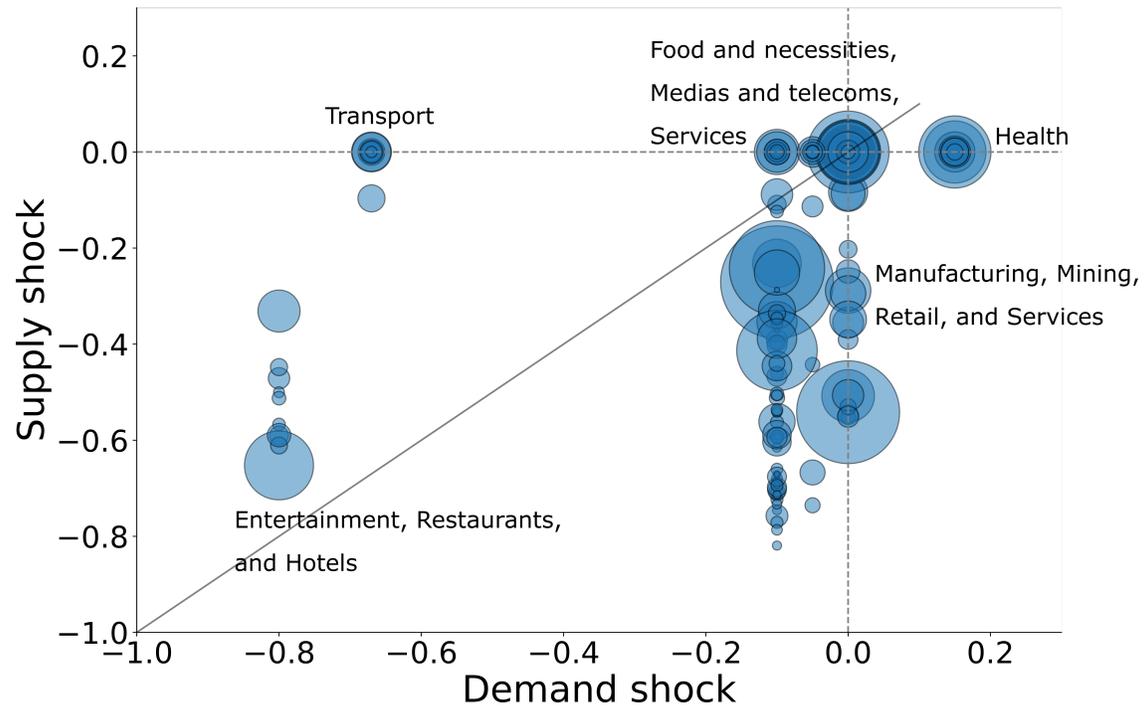


Figure 6: **Supply and demand shocks for industries.** Each circle is an industry, with radius proportional to gross output. Many industries experience exactly the same shock, hence the superposition of some of the circles. Labels correspond to broad classifications of industries.

4.2 Occupation-level supply and demand shocks.

In Fig. 7 we show the supply and demand shocks for occupations rather than industries. For each occupation this comparison indicates whether it faces a risk of unemployment due the lack of demand or a lack of supply in its industry.

Several health-related occupations such as Nurses, Medical Equipment Preparers and Healthcare Social Workers are employed in industries experiencing increased demand. Occupations such as Airline Pilots, Lodging Managers and Hotel Desk Clerks face relatively mild supply shocks and strong demand shocks (as consumers reduce their demand for travel and hotel accommodation) and consequently lie above the identity line. Other occupations such as Stonemasons, Rock Splitters, Roofers and Floor Layers face a much stronger supply shock as it is very difficult for these workers to perform their job at home. Finally occupations such as Cooks, Dishwashers, Waiters and Athletes suffer both adverse demand

¹²Some transport companies such as Transport for London have reduced their traffic, but this is a second-order impact, not a first-order shock. This decrease in output resulting from reduced demand should be modelled as an endogenous effect, not a first-order shock.

shocks (since demand for restaurants and sporting entertainment is reduced) and supply shocks (since they cannot work from home and tend not to work in essential industries).

For the majority of occupations the supply shock is larger than the demand shock. This is not surprising given that we only consider immediate shocks and no feedback-loops in the economy. We expect that once second-order effects are considered the demand shocks are likely to be much larger.

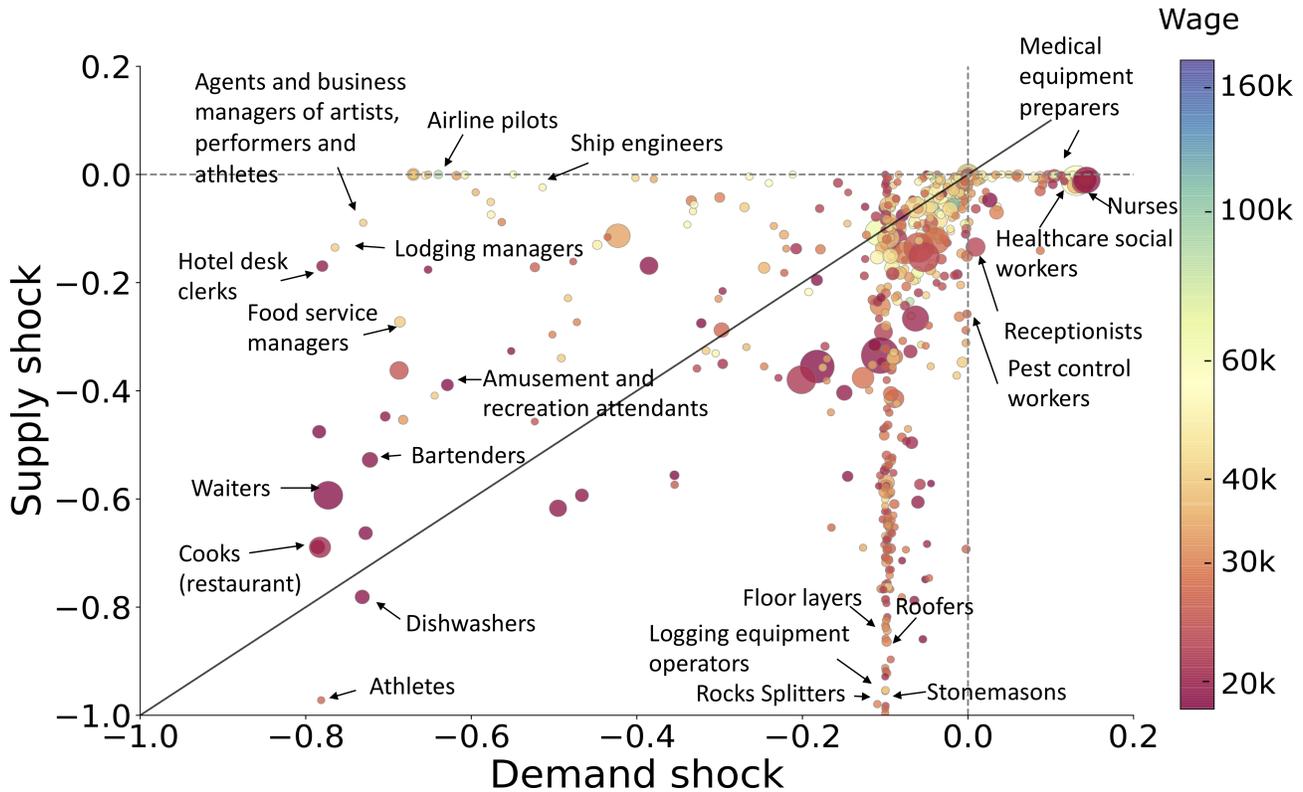


Figure 7: **Supply and demand shocks for occupations.** Each circle is an occupation with radius proportional to employment. Circles are color coded by the log median wage of the occupation. The correlation between wages and demand shocks is 0.28 and between wages and supply shocks is 0.39.

4.3 Aggregate shocks

We now aggregate shocks to obtain estimates for the whole economy. We assume that, in a given industry, the total shock will be the worse of the supply or demand and supply shock. The shock on occupations then depends on the prevalence of each occupation in each industry (see Appendix A for details). We then aggregate shocks in three different ways. First we estimate the decline in employment by weighting occupation-level shocks by the number of workers in each occupation. Then we estimate the decline in total wages by weighting occupation-level shocks by the share of occupations in the total wage bill. Finally, we estimate the decline in GDP by weighting industry level shocks by the share of industries in GDP.

Table 4 shows the results (columns labeled ‘Aggregate’). In all cases, by definition, the total shock is larger than both the supply and demand shock, but smaller than the sum. Overall, the supply shock appears to contribute more to the total shock than the demand shock does.

The wage shock is around 16% and is lower than the employment shock (22%). This makes sense, and reflects a fact already well acknowledged in the literature (Office for National Statistics 2020, Adams-Prassl et al. 2020) that occupations that are most affected tend to have lower wages. We discuss this more below.

The shock on value added (25%) is higher than the shock to the wage bill. This makes sense; because value added is the sum of the wage bill and payment to capital, this suggests that capital intensive industries are hit harder.

Shock	Employment					Wage	Value Added
	Aggregate	q_1	q_2	q_3	q_4	Aggregate	Aggregate
Supply	-19	-33	-22	-15	-6	-14	-20
Demand	-11	-25	-9	-10	-2	-8	-9
Total	-22	-38	-24	-20	-6	-16	-25

Table 4: **Aggregate shocks to employment, wages and value added.** The size of each shock is shown as a percentage of the normal, pre-pandemic value. The column q_1 shows the results for the employment shock for the 25% least paid workers, q_2 for the 25% of workers in the second quartile of wages and so on. Demand shocks include positive values for the health sector. The Total shock at the industry level is the minimum of the supply and demand shock, see Appendix A. Note that these are only first order shocks (not total impact), and instantaneous values (not annualized).

For industries and occupations in the health sector, which have experienced an increase in demand, there is no corresponding increase in supply. Table 5 in Appendix A.7 provides the same estimates as Table 4, but now assuming that the increased demand for health will be matched by increased supply. This corresponds to a scenario where the healthcare sector would be immediately able to hire as many workers as necessary and pay them at the normal rate. This assumption does not, however, make a significant difference to the aggregate total shock. In other words, the increase in activity in the health sector is unlikely to be large enough to compensate significantly for the losses from other sectors.

4.4 Shocks by wage level

To understand how the pandemic has affected workers of different income levels differently, we present results for each wage quartile.¹³ The results are in Table 4, columns $q_1 \dots q_4$.¹⁴ Our results confirm the survey evidence reported by the Office for National Statistics (2020) and Adams-Prassl et al. (2020), showing that low-wage workers are more strongly affected by the COVID crisis in terms of lost employment and lost income.

Next we estimate labor shocks at the occupation level. We define the labor shocks as the declines in employment due to the total shocks in the industries associated with each occupation. We use Eq. 14 to compute the labor shocks, which allows for positive shocks in healthcare workers, to suggest an interpretation in terms of a change in labor demand. Fig. 8 plots the relationship between labor shocks and wage. A strong positive correlation (Pearson $\rho = 0.41$) is clearly evident, with almost no high wage occupations facing a serious shock except for Airline Pilots.

We have also colored occupations by their exposure to disease and infection using an index developed by O*NET¹⁵ (for brevity we refer to this index as “exposure to infection”). As most occupations

¹³We use the BLS data to calculate the wage quartiles, weighting by the number of workers in each occupation.

¹⁴As before, Table 5 in Appendix A.7 gives the results assuming positive total shocks for the health sector, but shows that it makes very little difference.

¹⁵<https://www.onetonline.org/find/descriptor/result/4.C.2.c.1.b>

facing a positive labor shock relate to healthcare¹⁶, it is not surprising to see that they have a much higher risk of being exposed to disease and infection. However, other occupations such as janitors, cleaners, maids and childcare workers also face higher risk of infection. Appendix C explores the relationship between exposure to infection and wage in more detail.

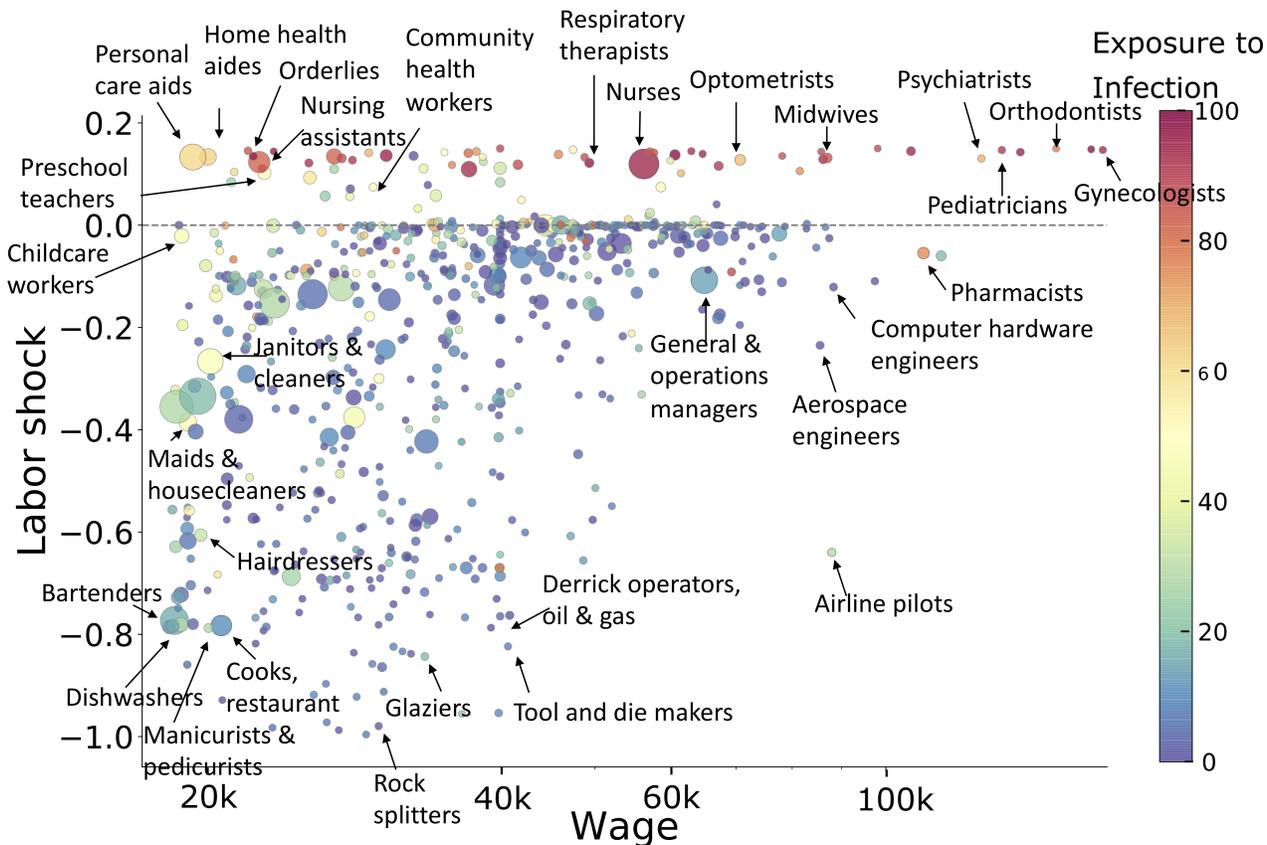


Figure 8: **Labor shock vs. median wage for different occupations.** We color occupations by their exposure to disease and infection. There is a 0.41 correlation between wages and the labor shock. Note the striking lack of high wage occupations with large labor demand shocks.

5 Conclusion

This paper has sought to provide quantitative predictions of the supply and demand shocks associated with the COVID-19 pandemic for the U.S. economy. To characterize supply shocks, we developed a Remote Labor Index to estimate the extent to which workers can perform activities associated with their occupation at home and identified which industries are classified as essential vs. non-essential. We also reported plausible estimates of the demand shocks, in an attempt to acknowledge that some industries will have an immediate reduction in output due to a shortfall in demand, rather than due to an impossibility to work. Putting these estimates together, we find that the first order aggregate shock to the economy represents a reduction of roughly a quarter of the economy.

¹⁶Our demand shocks do not have an increase in retail, but in the UK supermarkets have been trying to hire several tens of thousands workers (Source: BBC, 21 March, <https://www.bbc.co.uk/news/business-51976075>). Baker et al. (2020) documents stock piling behavior in the US.

This is the first study seeking to compare supply-side shocks with corresponding demand-side shocks at the occupation and industry level. At the time of writing, the most relevant demand-side estimates available are highly admittedly ‘rough’ and only available for very aggregate (2-digit) industries. Yet, this suggests that sectors such as Transport are more likely to have output constrained by demand-side shocks, while sectors relating to manufacturing, mining and services are more likely to be constrained by supply-side shocks. Entertainment, restaurants and tourism face both very large supply and demand constraints, with demand shocks dominating in our estimates.

When considering total shocks at the occupation level, we find that high-wage occupations are relatively immune from both supply and demand-side shocks, while many low-wage occupations are much more economically vulnerable to both. Interestingly, low-wage occupations that are *not* vulnerable to supply and/or demand-side shocks are nonetheless at higher risk of being exposed to coronavirus (see color code in Fig. 8). Such findings suggest that the COVID-19 pandemic is likely to exacerbate income inequality in what is already a highly unequal society.

For policymakers there are three implications from this study. First, the magnitude of the shocks being experienced by the U.S. economy is very large, with around a quarter of the economy not functioning. As Table 4 shows, even including positive shocks, our estimates of the potential impacts are a drop in employment of 22%, a decline in wages of 16%, and loss in value added of 25%. Bearing in mind the caveats about shocks vs. total impacts, if these losses were to persist, the potential impacts are a multiple of what was experienced during the global financial crisis (e.g. employment dropped 3.28%)¹⁷ and comparable only to the Great Depression (e.g. employment dropped 21.7% 1929-32 (Wallis 1989, Table 2)). Second, as the largest shocks are from the supply-side, strategies for returning people to work as quickly as possible without endangering public health must be a priority. Virus mitigation and containment are clearly essential first steps, but strategies such as widespread antibody testing to identify people who are safe to return to work, and rapid testing, tracing, and isolation to minimize future lock-downs, will also be vital until if and when a vaccine is available. Furthermore, aggressive fiscal and monetary policies to minimize first-order shocks cascading into second-order shocks are essential, in particular policies to keep workers in employment and maintain incomes (e.g. the “paycheck protection” schemes announced by several countries), as well as policies to preserve business and financial solvency. Third, and finally, the inequalities highlighted by this study will also require policy responses. Again, higher income knowledge and service workers will likely see relatively little impact, while lower income workers will bear the brunt of the employment, income, and health impacts. In order to ensure that burdens from the crisis are shared as fairly as possible, assistance should be targeted at those most effected, while taxes to support such programs be drawn primarily from those least effected.

To reiterate an important point, our predictions of the shocks are *not* estimates of the overall impact of the COVID-19 on the economy, but are rather estimates of the first-order shocks. Overall impacts can be very different from first order shocks for several reasons: First, shocks to a particular sector propagate and may be amplified as each industry faces a shock and reduces its demand for intermediate goods from other industries. Second, industries with decreased output will stop paying wages of furloughed workers, thereby reducing income and demand. Third, the few industries facing higher demand will increase supply, if they can overcome labor mobility frictions (del Rio-Chanona et al. 2019). We make our predictions of the shocks available here so that other researchers can improve upon them and use them in their own models¹⁸. We intend to update and use these shocks ourselves in our models in the

¹⁷Employment Rate, aged 15-64, all persons for the US (FRED LREM64TTUSM156N) fell from 71.51 in December 2007 to 68.23 in June 2009, the peak to through dates from the NBER.

¹⁸Our data repository is at <https://zenodo.org/record/3744960#.Xo4eUXVKhhE>, where we will post any update.

near future.

We have made a number of strong assumptions and used data from different sources. To recapitulate, we assume that the production function for an industry is linear and that it does not depend on the composition of occupations who are still able to work; we neglect absenteeism due to mortality and morbidity, as well as loss of productivity due to school closures (though we have argued these effects are small – see Appendix D.1). We have constructed our remote labor index based on a subjective rating of work activities and we assumed that all work activities are equally important and they are additive. We have also applied a rating of essential industries for Italy to the U.S. Nonetheless, we believe that the analysis here provides a useful starting point for macroeconomic models attempting to measure the impact of the COVID-19 pandemic on the economy.

As new data becomes available we will be able to test whether our predictions are correct and improve our shock estimate across industries and occupations. Several countries have already started to release survey data. New measurements about the ability to perform work remotely in different occupations are also becoming available. New York and Pennsylvania have released a list of industries that are considered essential¹⁹ (though this is not currently associated with any industrial classification such as NACE or NAICS). As new data becomes available for the mitigation measures different states and countries are taking, we can also refine our analysis to account for different government actions. Thus we hope that the usefulness of methodology we have presented here goes beyond the immediate application, and will provide a useful framework for predicting economic shocks as the pandemic develops.

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¹⁹<https://esd.ny.gov/guidance-executive-order-2026>

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Appendix

A Derivation of total shocks

A.1 Derivation of supply shocks

As discussed in the main text, we estimate the supply shock by computing an estimate of the share of work that will not be performed, which we compute by estimating the share of work that is not in an essential industry and that cannot be performed from home. We had to use several concordance tables, and make a number of assumptions, which we describe in details here.

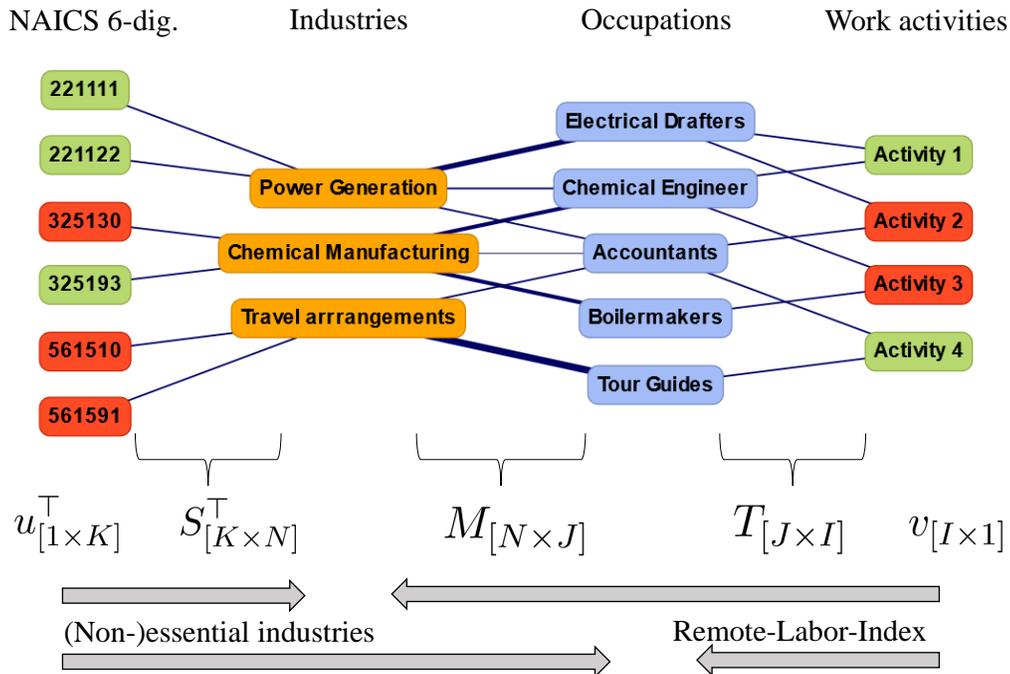


Figure 9: The same schematic network representation of supply side shocks as in the main text, but now also including mathematical notation. The K -dimensional vector u below the NAICS 6-dig. (left nodes) encodes essential industries with binary elements. This set of nodes is connected to relevant industry categories by concordance tables (incidence matrix S). Matrix M connects the N industry categories with J occupations where an element represents the corresponding employment number. The ability to perform work activities (right nodes) from home is represented in vector v , also by binary elements. We use occupation-activity mappings provided from O*NET, represented as incidence matrix T . The grey arrows show the direction of shocks to industries and employment. The shock originating from the list of essential industries is mapped directly onto the broader industry categories, before it can be computed for occupations. Conversely, the remote-labor-index is first mapped onto occupations and then projected onto industries.

Fig. 9 illustrates our method. There are four sets of nodes which are connected by three bipartite networks. The first set of nodes are the 6-digit NAICS industries which are classified to be essential or non-essential. This information is encoded in the K -dimensional column vector u which element $u_k = 1$ if NAICS 6-digit industry k is essential and 0 otherwise. Second, there are N different industry categories on which our economic analysis is based. The 6-digit NAICS codes are connected to these industries by the incidence matrix (concordance table) S . The third set of nodes are the J occupations obtained from the BLS and O*NET data. The weighted incidence matrix M couples industries with occupations where

the element M_{nj} denotes the number of people in occupation j being employed in industry n . Fourth, we also have a list of I work activities. Each activity was rated whether it can be performed from home. If activity i can be done from home, the i^{th} element of the vector v is equal 1, and otherwise it is equal to 0. The incidence matrix T denotes whether an occupation is associated with any given work activity, i.e $T_{ji} = 1$ if activity i is relevant for occupation j .

The analysis presented here is based on $I = 332$ unique work activities, $J = 660$ occupations and $K = 1,057$ 6-digit NAICS industries. When relating to industry-specific results we use the BLS industry categories of the input-output accounts, leaving us with $N = 169$ industries for which we have reliable data on value added, total output and other key statistics. Employment, occupation and wage statistics are available on a more fine-grained 4-digit NAICS level. We therefore use these $N = 277$ industries for deriving labor-specific results.

A.2 Industry-specific shocks

We can use this simple framework for deriving the supply shocks to industries.

(Non-)essential industries. To estimate the extent to which an industry category is affected by a shutdown of non-essential economic activities, we measure the fraction of its 6-digit NAICS sub-industries which are classified as non-essential. In mathematical terms, the essential-score for every industry is therefore a weighted sum which can be written compactly in matrix notation as

$$e = \tilde{S}u, \quad (1)$$

where \tilde{S} is the row-normalized version of matrix S with elements $\tilde{S}_{nk} = S_{nk} / \sum_h S_{nh}$.

Note that this assumes that the fine-grained NAICS codes contribute uniformly to the more aggregate industry categories. Although this assumption might be violated in several cases, in absence of further information, we use this assumption throughout the text.

Industry Remote-Labor-Index. We can similarly estimate the extent to which the production of occupations or industries can take place by working from home. Since work activities are linked to occupations, but not directly to industries, we need to take two weighted averages to obtain the industry-specific RLI.

For each occupation we first measure the fraction of work activities that can be done from home. We interpret this as the share of work of an occupation that can be performed from home, or ‘occupation-level RLI’. This interpretation makes two assumptions: (i) that every work activity contributes equally to an occupation, which is our best guess since we do not have better data, and (ii) that if $z\%$ of activities cannot be done from home, the other $1 - z\%$ of activities can still be carried out and are as productive as before.

For each industry i we then take a weighted average of the occupation-level RLIs, where the weights are the shares of workers employed in each occupation and in industry i . Let \tilde{T} denote the row-normalized version of matrix T , i.e $\tilde{T}_{ji} = T_{ji} / \sum_h T_{jh}$ and similarly let the element of matrix \tilde{M} be $\tilde{M}_{nj} = M_{nj} / \sum_h M_{nh}$. Then the industry-specific remote-labor-index is given by the vector

$$r = \tilde{M}\tilde{T}v. \quad (2)$$

We interpret the remote-labor-index for an industry, r_n , as the fraction of work in an industry n that can be performed from home. As for assumption (ii) above for the occupation-level RLI, this assumes that if $z\%$ of the work of occupations cannot be done, the other $1 - z\%$ of work can still be carried out.

Immediate industry supply shock. To derive industry supply shocks from the scores above, we need to take into account that industries might be exposed to both effects at the same time, but with different magnitudes. For example, consider the illustrative case of *Chemical Manufacturing* in Fig. 9. Half of the industry is non-essential (red node ‘325130’) and could therefore be directly affected by an economic shutdown. But different occupations can be found in this industry that are affected heterogeneously. In this simple example, *Chemical Manufacturing* draws heavily on Boilermakers who have only work activities that cannot be done from home. On the other hand, this industry also has a tiny share of accountants and a larger share of Chemical Engineers who are able to do half of their work activities from home.

As stated above, the essential score e_n and the RLI r_n can be interpreted as shares of industry-specific work which can be performed, either thanks to being essential or thanks to being adequately done from home. To compute the share of industry-specific work that can be performed due to either effect, we interpret shares as probabilities and assume independence,

$$\text{ISS}_n = -(1 - e_n)(1 - r_n), \quad (3)$$

where ISS stands for ‘Industry Supply Shock’. We have multiplied the probability by minus one to obtain negative shocks. Although independence is a strong assumption, we have no reason to believe that the work that can be done from home is more or less likely to be judged essential. The empirical correlation coefficient of e and r is 0.07 and is far from being significant (p-value of 0.37). Under the linear assumptions about combining labor we are making here this indicates independence.

When applying these Industry Supply Shocks to value added, we make the implicit assumption that the production function is Leontief (and there was no labor hoarding before the shock): a $z\%$ decrease in labor will cause an $z\%$ decrease in value added.

A.3 Occupation-specific shocks.

We now describe how we compute shocks for specific occupations, rather than specific industries.

Occupations in (non-)essential industries. Occupations are mapped to industries through the weighted incidence matrix M , where an element denotes the number of jobs per occupation and industry. The column-normalized matrix M^* with elements $M_{nj}^* = M_{nj} / \sum_h M_{hj}$ denotes the share of an occupation carried out in a particular industry²⁰. The essential-score for occupations is taken as weighted average of the essential score for industries (computed in Eq. 1),

$$x = M^{*\top} \tilde{S}u = M^{*\top} e. \quad (4)$$

²⁰Note that we column-normalize M to map from industries to occupations and row-normalize when mapping from occupations to industries.

Occupation Remote Labor Index. As already indicated in the derivation of the industry-specific RLI, r , in Eq. (2), the occupation-specific RLI, y , is a weighted average of all the corresponding work activities that can be done from home. Formally, the occupation-based RLI is given by

$$y = \tilde{T}v. \quad (5)$$

Total supply-driven occupation shock. Following the same procedure as in Eq. 3, we can get the total immediate shock on occupations from the economy’s supply side²¹. The combined immediate shock to occupations is then given as

$$\text{OSS}_j = -(1 - x_j)(1 - y_j). \quad (6)$$

Here, the correlation between RLI and the essential-score is larger, $\rho(x, y) = 0.34$, and significant which can also be seen from Fig. 4. It should therefore be noted that the labor-specific results are expected to be more sensitive with respect to the independence assumption, as it is the case for industry-related results.

A.4 Derivation of demand shocks

Since we have demand shocks only on the 2-digit NAICS level, disaggregating them into the more fine-grained relevant industry categories is straightforward when assuming that the demand shock holds equally for all sub-industries. We let the industry demand shock in percentages for industry n be $-\text{IDS}_n$.

To map the demand shocks onto occupations, we can invoke the same matrix algebra as above. The occupation-specific shock originating from the economy’s demand side is then given by the projection

$$\text{ODS} = M^{*\top} \text{IDS}. \quad (7)$$

A.5 Total immediate (first-order) shocks

We now combine supply- and demand-driven shocks to total immediate shocks for occupations and industries.

Let us turn to industries first. As discussed in more depth in the main text, the shock experienced is likely to be the worse of the two (supply and demand) shocks. Since we have expressed shocks as negative if they lead to decrease in output, in more mathematical terms, the *industry total shock* then is

$$\text{ITS}_n = \min(\text{ISS}_n, \text{IDS}_n). \quad (8)$$

and the *occupation total shock* is

$$\text{OTS}_j = \min(\text{OSS}_j, \text{ODS}_j). \quad (9)$$

Note that under these assumptions, the health sector will not experience a positive shock. Our estimates of the shocks suggest that there is an increase in demand, but we have not described positive supply shocks for the health sector. As a result, industries and occupations in the health sector will have a non-positive total shock.

Of course, the actual production of health care is likely to go up. But this is the result of an adjustment to an increase demand, rather than a first-order shock, and is therefore not modelled here. Nevertheless, see Appendix A.7 for an alternative.

²¹To be clear, this is a product market *supply-side* shock, but this translates into a reduction in labor *demand* in each occupations.

A.6 Aggregate total shocks

To provide economy-wide estimate of the shocks, we aggregate industry- or occupation-level shocks. We do this using different set of weights.

First of all, consider the interpretation that our shocks at the occupation-level represent the share of work that will not be performed. If we assume that if $z\%$ of the work cannot be done, $z\%$ of the workers will become unemployed, we can weight the occupation shocks by the share of employment in each occupation. Using the vector L to denote the share of employed workers that are employed by occupation j , we have

$$\text{Aggregate employment shock} = \text{OTS}^T L \quad (10)$$

The Employment supply (demand) shock is computed similarly but using OSS (ODS) instead of OTS.

Instead of computing how many workers may lose their job, we can compute by how much paid wages will decrease. For each occupation, we compute the total wage bill by multiplying the number of workers by the average wage. We then create a vector w where w_j is the share of occupation j in the total wage bill. Then,

$$\text{Wage shock} = \text{OTS}^T w, \quad (11)$$

and similarly for the OSS and ODS. Note that we omit three occupations for which we do not have wages (but had employment).

Finally, to get an estimate of the loss of GDP, we can aggregate shocks by industry, weighting by the share of an industry in GDP. Denoting by Y the vector where Y_n is the VA of industry n divided by GDP²²,

$$\text{Value added shock} = \text{ITS}^T Y, \quad (12)$$

and similarly for the industry supply and demand shocks (ISS and IDS). Note that we could have used shares of gross output and compute a shock to gross output rather to GDP.

A.7 Aggregate total shocks with growth of the Health sector

Here we make a different assumption about how to construct the total shock for occupations and industries. For industries, we assume that if they experience a positive demand shock, the industries are able to increase their supply to meet the new demand. Instead of Eqs. (8) we use

$$\text{ITS}_n^h = \begin{cases} \text{ITS}_n, & \text{if } \text{IDS}_n \leq 0 \\ \text{IDS}_n, & \text{if } \text{IDS}_n > 0. \end{cases} \quad (13)$$

Since occupations are employed by different industries, the total shock to an occupation can be influenced by positive demand shocks from the healthcare sector and negative demand shocks from non-essential industries. In Eq. (9) we consider that occupations only experience the negative shocks. An alternative is to consider both the negative shock caused by non-essential industries and the positive shock caused by the health industries. This gives

$$\text{OTS}_j^h = \begin{cases} \text{OTS}_j, & \text{if } \text{ODS}_j \leq 0 \\ \text{ODS}_j + \text{OSS}_j, & \text{if } \text{ODS}_j > 0. \end{cases} \quad (14)$$

²²Our estimate of GDP is the sum of VA of industries in our sample.

In Section 4.4, specifically Fig. 8 we use this convention for the y-axis, the Labor Shock. Using Eq. (14) allows us to observe how health related occupations experience a positive shock.

In Table 5 we show the aggregate total shocks when using Eqs.(13) and (14). There is very little difference with the results in the main text. The Health sector and its increase in demand are not large enough to make a big difference to aggregate results.

Shock	Employment					Wage	Value Added
	Aggregate	Q1	Q2	Q3	Q4	Aggregate	Aggregate
Total	-20	-36	-22	-19	-4	-15	-24

Table 5: **Main results allowing for growth in the Health sector.** The results are the same as those presented in Table 4, but assuming that in industries, when demand is positive, the total shock is equal to the demand shock

B Data

B.1 Mapping NACE code to NAICS codes

The Italian list of essential industries list 2-digit, 4-digit and 6-digit industries. We automatically map industries listed at the 2 or 4-digit NACE level to NAICS 6-digit industries using the crosswalk made available by the European Commission²³. The 6-digit NACE level classification is country dependent and thus there is no official crosswalk to NAICS codes. We map the 6-digit industries by hand.

B.2 Data for occupations

Using data from O*NET we can compute the remote labor index for 779 occupations. We can match 660 of these occupations with the BLS industry employment data. Therefore our final sample is made of 660 occupations. With the occupation-industry employment data and the essential score of each industry, we estimate the share of essential jobs within each occupation. Additionally, we have wage information for most occupations. In particular, we have median and mean wage data only for 630 and 657 occupations respectively. We computed all correlations for median wage considering only the subset of occupations we had median wage data for. For the few occupations for which we did not have median wage the color coding of occupations in Figs 4, 7, and the x-axis in Fig 8 corresponds to the average median wage. We used the mean wages and the employment of occupations to define the wage quartiles of our sample. We excluded the 3 occupations for which we did not have mean wage from this calculation.

Finally, we use the O*NET data on exposure to disease and infection of occupations for the color coding in Fig 8. We explain these data further in appendix C. In the following charts we show the distribution of the remote labor index, exposure to disease and infection, supply, demand and overall shocks across occupations.

²³https://ec.europa.eu/eurostat/ramon/reactions/index.cfm?TargetUrl=LST_REL&StrLanguageCode=EN&IntCurrentPage=11

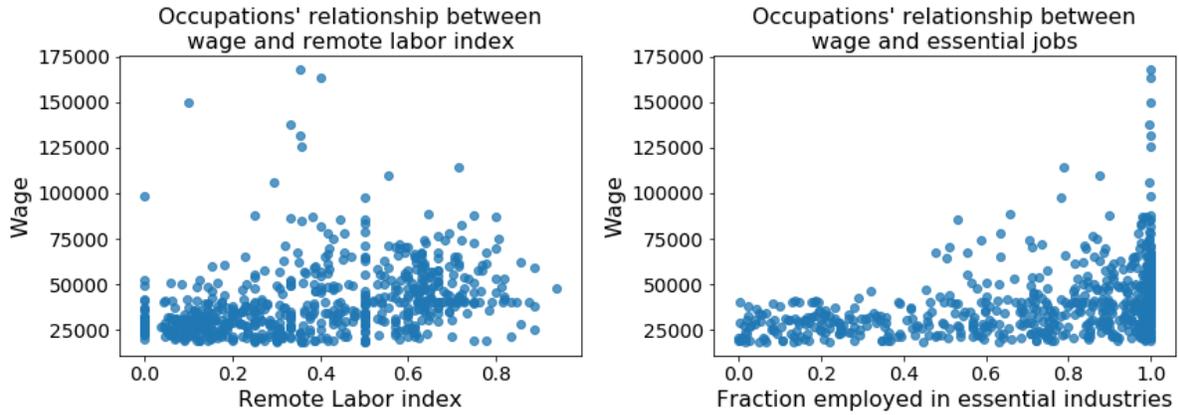


Figure 10: Left. Relationship between remote labor index and wage. The Pearson correlation is 0.36. Right. Relationship between fraction of workers in essential industries and wage. The Pearson correlation is 0.39.

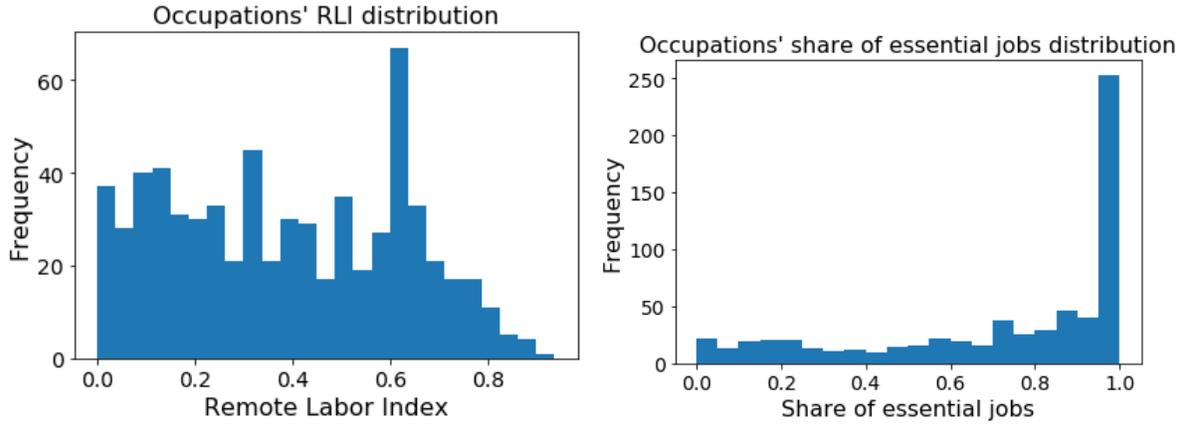


Figure 11: Left. Distribution of the remote labor index for the 660 occupations. Right. Distribution of the share of essential jobs within each of the 660 occupations.

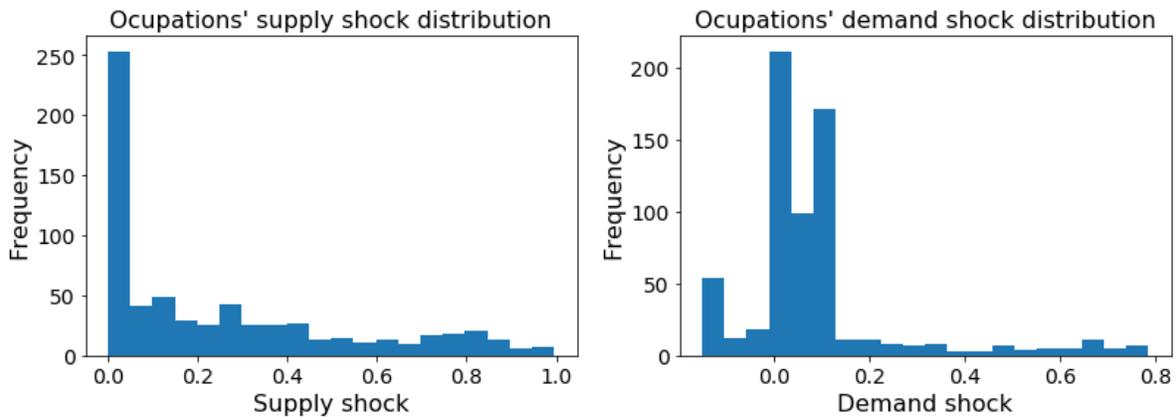


Figure 12: Left. Supply shock distribution across occupation. Right. Demand shock distribution across occupations.

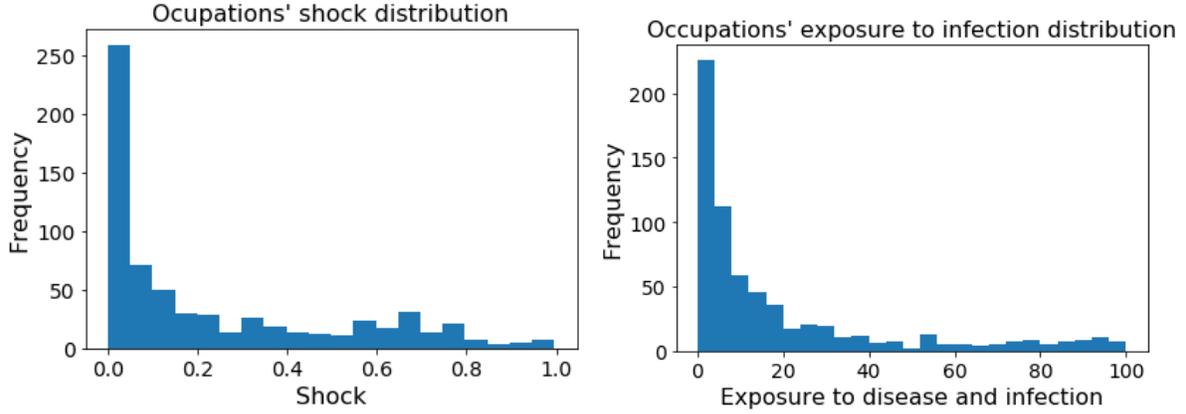


Figure 13: Left. Shock distribution for occupations. Right. Distribution of exposure to disease.

B.3 Data for industries

A key motivation of this paper is to provide relevant economic data which can be used by other researchers and policymakers to model the economic impact of the COVID-19 pandemic. We therefore bring the discussed supply and demand shock data into a format such that it matches directly to US input-output data.

As mentioned in the main text, we use the BLS input-output account of the year 2018 which allows us to discern 179 private sectors. Here, an industry category is a mixture of 2- to 6-digit NAICS industries. We are able to match occupational data to 169 of these industry categories, for which supply shocks are derived as spelled out in Appendix A.1. Since we have demand shocks only on the 2-digit NAICS level, disaggregating them into the more fine-grained BLS input-output data is straightforward when assuming that the demand shock holds equally for all sub-industries.

Fig. 14 to Fig. 16 show distributions of supply and demand shock-related variables on the industry level. Table 6 summarizes a few key statistics for these industries, when further aggregated to 72 industry categories.

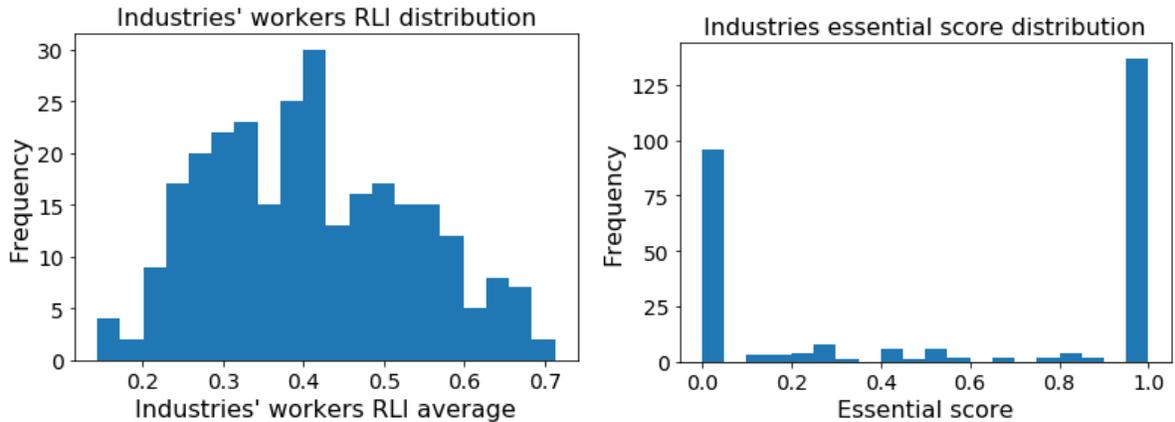


Figure 14: Left. Distribution of the remote labor index, aggregated to 169 industries. Right. Fractions of essential sub-industries per industry category.

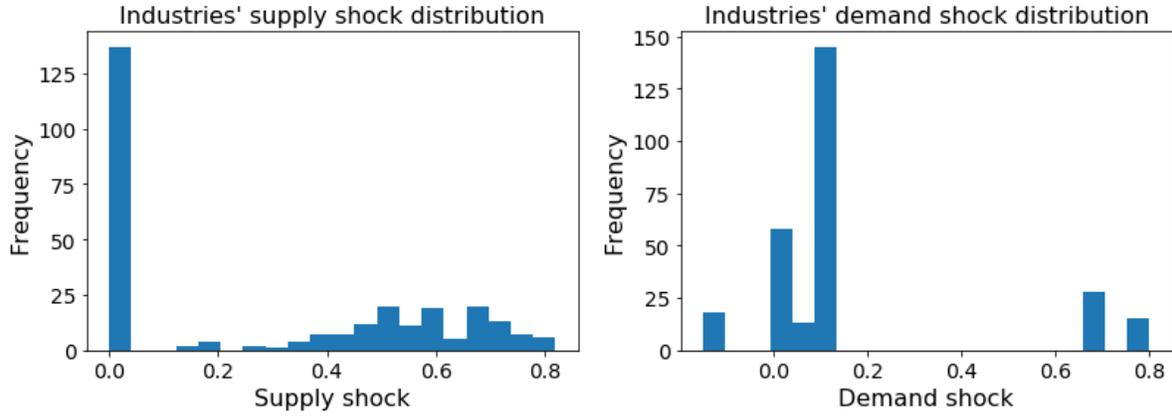


Figure 15: Left. Supply shock distribution across industries. Right. Demand shock distribution across industries.

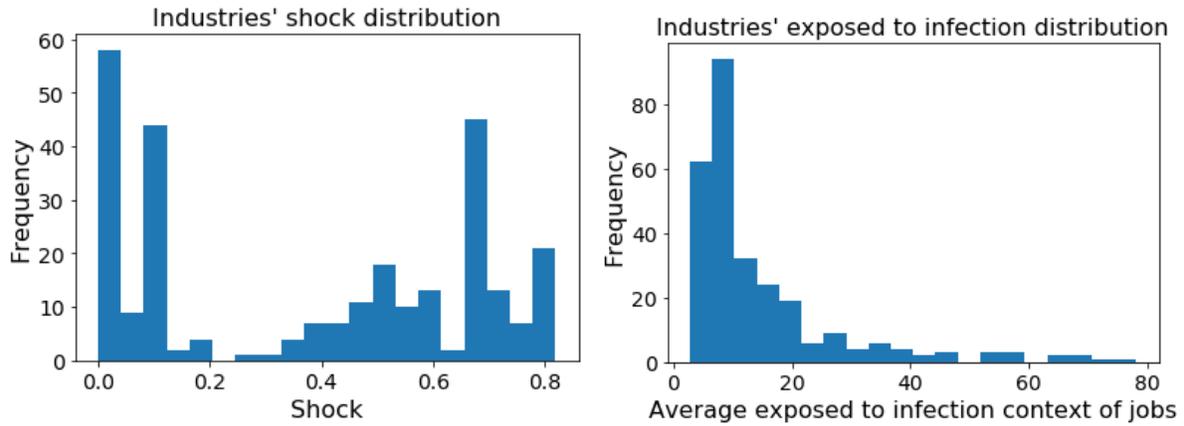


Figure 16: Left. Shock distribution across industries. Right. Distribution of exposure to disease across industries.

NAICS	Title	Outp.	Empl.	Demand	Supply	RLI	Essent.	Expos.
111	Crop Production	209	NA	-10	NA	NA	NA	NA
112	Animal Production and Aquaculture	191	NA	-10	NA	NA	NA	NA
113	Forestry and Logging	19	NA	-10	NA	NA	NA	NA
114	Fishing, Hunting and Trapping	10	NA	-10	NA	NA	NA	NA
115	Support Activities for Agriculture and Forestry	27	378	-10	0	26	100	5
211	Oil and Gas Extraction	332	141	-10	0	47	100	7
212	Mining (except Oil and Gas)	97	190	-10	-52	29	27	9
213	Support Activities for Mining	84	321	-10	-70	30	0	8
221	Utilities	498	554	0	0	42	100	10
23	Construction	1636	7166	-10	-24	30	65	8
311	Food Manufacturing	803	1598	-10	0	22	100	11
312	Beverage and Tobacco Product Manufacturing	192	271	-10	-3	35	96	8
313-4	Wholesale Trade	54	226	-10	-50	26	32	5
315-6	Management of Companies and Enterprises	29	140	-10	-68	26	9	4
321	Wood Product Manufacturing	118	402	-10	-62	26	16	6
322	Paper Manufacturing	189	362	-10	-8	23	89	6
323	Printing and Related Support Activities	80	435	-10	0	35	100	4
324	Petroleum and Coal Products Manufacturing	618	112	-10	-25	37	60	7
325	Chemical Manufacturing	856	828	-10	-2	40	96	10
326	Plastics and Rubber Products Manufacturing	237	722	-10	-8	27	89	7
327	Nonmetallic Mineral Product Manufacturing	140	NA	-10	NA	NA	NA	NA
331	Primary Metal Manufacturing	239	374	-10	-73	27	0	7

332	Fabricated Metal Product Manufacturing	378	1446	-10	-60	31	12	6
333	Machinery Manufacturing	386	1094	-10	-51	40	16	6
334	Computer and Electronic Product Manufacturing	369	1042	-10	-38	58	9	5
335	Electrical Equipment, Appliance, and Component Manufacturing	132	392	-10	-31	44	45	6
336	Transportation Equipment Manufacturing	1087	1671	-10	-58	36	9	6
337	Furniture and Related Product Manufacturing	77	394	-10	-48	33	28	4
339	Miscellaneous Manufacturing	173	601	-10	-16	38	74	12
42	Construction	1980	5798	-10	-27	50	46	8
441	Motor Vehicle and Parts Dealers	334	2006	-10	-23	42	60	11
442-4, 446-8, 451, 453-4	Wholesale Trade	1052	7731	-10	-41	50	17	21
445	Food and Beverage Stores	244	3083	-10	-35	38	43	20
452	General Merchandise Stores	240	3183	-10	-39	48	25	21
481	Air Transportation	210	499	-67	0	31	100	30
482	Rail Transportation	77	233	-67	0	40	100	10
483	Water Transportation	48	64	-67	0	38	100	10
484	Truck Transportation	346	1477	-67	0	38	100	8
485	Transit and Ground Passenger Transportation	74	495	-67	0	28	100	25
486	Pipeline Transportation	49	49	-67	0	38	100	8
487-8	Management of Companies and Enterprises	146	732	-67	-10	38	85	9
492	Couriers and Messengers	94	704	-67	0	42	100	18
493	Warehousing and Storage	141	1146	-67	0	24	100	6
511	Publishing Industries (except Internet)	388	726	0	-19	65	46	5
512	Motion Picture and Sound Recording Industries	155	428	0	-51	49	0	10
515	Broadcasting (except Internet)	196	270	0	0	56	100	6
517	Telecommunications	695	NA	0	NA	NA	NA	NA
518	Data Processing, Hosting, and Related Services	207	319	0	0	67	100	6
519	Other Information Services	192	296	0	-8	67	75	7
521-2	Construction	939	2643	0	0	65	100	12
523, 525	Wholesale Trade	782	945	0	0	68	100	5
524	Insurance Carriers and Related Activities	1231	2330	0	0	61	100	8
531	Real Estate	1842	1619	0	-54	46	0	20
532	Rental and Leasing Services	163	556	0	-55	45	0	12
533	Lessors of Nonfinancial Intangible Assets (except Copyrighted Works)	182	22	0	-35	65	0	8
541	Professional, Scientific, and Technical Services	2372	9118	0	-2	61	94	10
55	Management of Companies and Enterprises	561	2373	0	0	64	100	9
561	Administrative and Support Services	971	8838	0	-37	35	44	18
562	Waste Management and Remediation Services	109	427	0	0	30	100	23
611	Educational Services	366	13146	0	0	56	100	30
621	Ambulatory Health Care Services	1120	7399	15	0	38	100	60
622	Hospitals	933	6050	15	0	38	100	69
623	Nursing and Residential Care Facilities	262	3343	15	0	32	100	63
624	Social Assistance	222	3829	15	0	40	100	49
711	Performing Arts, Spectator Sports, and Related Industries	181	505	-80	-51	45	8	12
712	Museums, Historical Sites, and Similar Institutions	20	167	-80	-50	50	0	15
713	Amusement, Gambling, and Recreation Industries	158	1751	-80	-59	41	0	21
721	Accommodation	282	2070	-80	-33	35	49	26
722	Food Services and Drinking Places	832	11802	-80	-65	35	0	16
811	Repair and Maintenance	235	1317	-5	-3	26	96	10
812	Personal and Laundry Services	211	1490	-5	-47	35	28	28
813	Religious, Grantmaking, Civic, Professional, and Similar Organizations	260	1372	-5	0	52	100	19

Table 6: Key statistics for different 2- and 3-digit NAICS industries. Column ‘Outp.’ refers to total output of the industry in current billion USD (2018). ‘Emp.’ is total employment in thousands. ‘Demand’ is the immediate severe demand shock in % obtained from the CBO. ‘Supply’ is the immediate supply shock in % derived from the Remote Labor Index and the list of essential industries. ‘RLI’ is the industry-specific Remote Labor Index in %. ‘Essent.’ is the share of sub-industries being classified as essential in %. ‘Expos.’ denotes the industry-aggregated infection exposure index from O*NET which ranges from 0 to 100 and is explained in Appendix C. We make more disaggregated data with further details available in the corresponding data publication.

C Occupations most at risk of contracting SARS-CoV-2

O*NET make available online work context data for occupations that describe the physical and social factors that influence the nature of work. The “Exposed to disease and infection” work context²⁴, which we refer to as ‘exposed to infection’ for short, describes the frequency with which a worker in a given occupation is exposed to disease or infection. It ranges from 0 to 100, where 0 means “never” and 100 “everyday”; a 50 exposed to infection rating means an exposure of “once a month or more but not every week” and a 75 context means “Once a week or more but not every day”. We have exposure to infection data for 597 of the 660 occupations in our sample. For those occupations for which we did not have the exposure to infection, when colored them as if they had zero exposure to infection.

As we see in Fig. 17 there is a U shaped relationship between wages and exposure to infection. There is 0.19 correlation between wages and exposure to infection, but this is misleading²⁵. Though many high wage occupations are highly exposed to infection (high paid doctors), there are also many low wage occupations with high probability of infection.

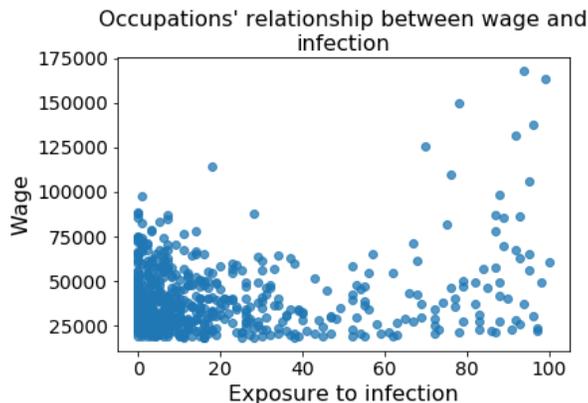


Figure 17: Relationship between wage and probability of infection in linear and log scale. The Pearson correlation is 0.19. However we this correlation is mostly driven by high salaries in the health sector, but there are many low-wage occupations with a significant exposure to infection.

D Discussion of labor supply shocks which we do not include

D.1 Labor supply shocks from mortality and morbidity

Typical estimates. McKibbin & Fernando (2020) considers attack rates (share of population who become sick) in the range 1-30% and case-fatality rates (share of those infected who die) in the range 2-3%. From attack rates and case fatality rates, they compute mortality rates. They also assume that sick people stay out of work for 14 days. A third effect they assume is that workers would be care givers to family members.

For their severe scenario of an influenza pandemic, Congressional Budget Office (2006) assumed

²⁴<https://www.onetonline.org/find/descriptor/result/4.C.2.c.1.b?s=2>

²⁵For example, Adams-Prassl et al. (2020), using survey evidence for ~4000 US individuals, found that workers without paid sick leave are more likely to go to work in close proximity to others, which may have suggested a negative correlation between wages and exposures. Note however that our correlation based on occupations, not individuals, and that wages are not necessarily an excellent predictor of having paid sick leave or not.

that 30 percent of the workers in each sector (except for Farms, which is 10%) would become ill and would lose 3 weeks or work, at best, or die (2.5% case fatality rate).

Best guess for current effect of COVID-19. In the case of COVID-19, estimating a labor supply shock is made difficult by several uncertainties. First of all, at the time of writing there are very large uncertainties on the ascertainment rate (the share of infected people who are registered as confirmed cases), making it difficult to know the actual death rate.

We report the result from a recent and careful study by [Verity et al. \(2020\)](#), who estimated an infection fatality ratio of 0.145% (0.08-0.32) for people younger than 60, and 3.28% (1.62-6.18) for people aged 60 or more. The age bracket 60-69, which in many countries will still be part of the labor force, was reported as 1.93% (1.11–3.89).

Taking the infection fatality ratio for granted, the next question is the attack rate. In [Verity et al. \(2020\)](#), the infection fatality ratios are roughly one fourth of the case fatality ratios, suggesting that 3/4 of the cases are undetected. For the sake of the argument, consider Italy, a country that has been strongly affected and appears to have reached a peak (at least of a first wave). There are at the time of writing 132,547 cases in Italy²⁶ In 2018 the population of Italy²⁷ was 60,431,283. If we assume that Italy is at the peak today and the curve is symmetric, the total number of cases will be double the current number, that is 265,094, which is 0.44% of the population. If we assume that the true number of cases is 4 times higher, the attack rate is, roughly speaking, 1.76%. These numbers are more than an order of magnitude smaller than the number who cannot work due to social distancing.

Thus, while it is clear that the virus is causing deep pain and suffering throughout Italy, the actual decrease in labor supply, which is massive, is unlikely to be mostly caused by people being sick, and is much more a result of social distancing measures.

Uncontrolled epidemic. Now, it may be informative to consider the case of an uncontrolled epidemic. If we assume that the uncontrolled epidemic has an attack rate of 80% (a number quoted in [Verity et al. \(2020\)](#)), an infection fatality ratio for people in the labor force of 1% (an arbitrary number between 0.145% for people younger than 60, and 1.93% for the 60-69 age bracket) implies an 0.8% permanent decrease of the labor force. If we assume that those who do not die are out of work for 3 weeks, on an annual basis of 48 worked weeks, we have $(3/48) \cdot (0.80 - 0.01) = 4.94\%$ decrease of the labor supply.

Overall, this exercise suggests that left uncontrolled, the epidemic can have a serious effect on labor supply. However, in the current context, the effect on the economy is vastly more a result of social distancing than direct sickness and death.

D.2 Labor supply shocks from school closure

School closures are a major disruption to the functioning of the economy as parents can no longer count on the school system to care for their children during the day.

[Chen et al. \(2011\)](#) surveyed households following a school closure in Taiwan during the H1N1 outbreak, and found that 27% reported workplace absenteeism.

[Lempel et al. \(2009\)](#) attempted to estimate the cost of school closure in the US in case of an influenza pandemic. They note that 23% of all civilian workers live in households with a child under 16

²⁶<https://coronavirus.jhu.edu/map.html>

²⁷<https://data.worldbank.org/indicator/SP.POP.TOTL?locations=IT>

and no stay-at-home adults. Their baseline scenario assumes that around half of these workers will miss some work leading to a loss 10% of all labor hours in the civilian U.S. economy, for as long as the school closure lasts.

Some of these effects would already be accounted for in our shocks. For instance, some workers are made redundant because of a supply or demand shock, so while they have to stay at home to care for their children, this is as much a result of labor and supply shock as a result of school closure. For those working from home, we might expect a decline in productivity. Finally, for those in essential industries, it is likely that schools are not close. For instance, in the UK, schools are opened for children of essential workers. Our list of essential industries from Italy includes Education.

Overall, school closure indeed have large effects, but in the current context these may already be accounted for by supply and demand shocks, or non-existent because schools are not fully closed. The loss of productivity from parents working from home remains an open question.

E Additional estimates of demand or consumption shocks

In this appendix we provide additional data on the demand shock. Table 7 shows our crosswalk between the Industry classification of the [Congressional Budget Office \(2006\)](#) and NAICS 2-digit industry codes, and, in addition to the “severe” shocks used here, shows the CBO’s “mild” shocks. We have created this concordance table ourselves, by reading the titles of the categories and making a judgement. Whenever NAICS was more detailed, we reported the CBO’s numbers in each more fine-grained NAICS.

We also provide two sources of consumption shocks (in principle, these estimates are meant to reflect actual decreases in consumption rather than shifts of the demand curve). Table 8 shows the consumption shocks used by [Keogh-Brown et al. \(2010\)](#) to model the impact of potential severe influenza outbreak in the UK. Table 9 shows the consumption shocks used by [Muellbauer \(2020\)](#) to model the impact of the COVID-19 on quarterly US consumption. [OECD \(2020\)](#) provided two other sources. The first one, Table 10, is based on assumptions of shocks at the industry level, while Table 11 shows assumptions of shocks by expenditure categories.

NAICS	NAICS	CBO	Severe	Mild
11	Agriculture, Forestry, Fishing and Hunting	Agriculture	-10	-3
21	Mining, Quarrying, and Oil and Gas Extraction	Mining	-10	-3
22	Utilities	Utilities	0	0
23	Construction	Construction	-10	-3
31	Manufacturing	Manufacturing	-10	-3
32	Manufacturing	Manufacturing	-10	-3
33	Manufacturing	Manufacturing	-10	-3
42	Wholesale Trade	Wholesale trade	-10	-3
44	Retail Trade	Retail trade	-10	-3
45	Retail Trade	Retail trade	-10	-3
48	Transportation and Warehousing	Transportation and warehousing (including air, rail and transit)	-67	-17
49	Transportation and Warehousing	Transportation and warehousing (including air, rail and transit)	-67	-17
51	Information	Information (Published, broadcast)	0	0
52	Finance and Insurance	Finance	0	0
53	Real Estate and Rental and Leasing	NA	0	0
54	Professional, Scientific, and Technical Services	Professional and business services	0	0
55	Management of Companies and Enterprises	NA	0	0
56	Administrative and Support and Waste Management and Remediation Services	NA	0	0
61	Educational Services	Education	0	0
62	Health Care and Social Assistance	Healthcare	15	4
71	Arts, Entertainment, and Recreation	Arts and recreation	-80	-20
72	Accommodation and Food Services	Accommodation/food service	-80	-20
81	Other Services (except Public Administration)	Other services except government	-5	-1
92	Public Administration (not covered in economic census)	Government	0	0

Table 7: Mapping of CBO shocks to NAICS 2-digits

Industry	Consumption shock	Only postponed?
Food, drink, alcohol and tobacco	0	NA
Clothing and footwear	-50	yes
Housing, heating, etc.	0	NA
Goods and services (furniture, etc.)	-80	yes
Transport - buying cars	-100	yes
Transport services and car use	-50	no
Recreation and culture - durables	-100	yes
Recreation and culture - games and pets	0	NA
Recreation and culture - sport and culture	-100	no
Recreation and culture - newspapers and books	0	NA
Restaurants, hotels and net tourism	-100	no
Miscellaneous (incl health, communication education)	0	NA

Table 8: Demand shock from Keogh-Brown et al. (2010). The first column gives the percentage decrease, while the second column gives the percentage of the first column will be recouped in future quarters.

Industry	Consumption shock
Restaurants and Hotels	-71
Transport services	-70
Recreation services	-63
Food at home	43
Healthcare	18

Table 9: Consumption shock from Muellbauer (2020).

ISIC.Rev4	shock
manufacturing of transport equipment (29-30)	-100
construction (VF)	-50
wholesale and retail trade (VG)	-75
air transport (V51)	-75
accommodation and food services (VI)	-75
real estate services excluding imputed rent (VL-V68A)	-75
professional service activities (VM)	-50
arts, entertainment and recreation (VR)	-75
and other service activities (VS).	-100

Table 10: Industry shocks from OECD (2020).

COICOP	shock
clothing and footwear (3)	-100
furnishings and household equipment (5)	-100
vehicle purchases (7.1)	-100
operation of private vehicles (7.2)	-50
transport services (7.3)	-50
recreation and culture excluding package holidays (9.1-9.5)	-75
package holidays (9.6)	-100
hotels and restaurants (11)	-75
personal care services (12.1).	-100

Table 11: Expenditure shocks from OECD (2020).