Why has GDP fallen so little in the COVID Pandemic?

“Potential Capital” and Economic Resilience*

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Abstract
The COVID-19 pandemic caused the most pronounced and widespread decline in recorded GDP in the OECD data. Yet, as catastrophic as the collapse was, it was buffered by an unprecedented and spontaneous deployment of what we call “Potential Capital,” the dwelling/residential capital and connective technologies that enabled some (fortunate) workers to work from home and others to provide remote services. We estimate the contribution of this capital, and the labor that it facilitated, to have roughly halved the decline in GDP in the seven OECD economies for which we have data, reducing the fall in GDP to 14 percent on average in 2020Q2 at the trough of the recession. Accounting for the contribution of this capital also undoes much of the estimated productivity gain in the business sector during the pandemic. Turning to the future, the pandemic demonstrated the possibility of rapid and large substitutability between workplace and home locations. As conditions recover and the pandemic recedes, this estimated substitutability could “work in reverse” as the costs of working at the workplace decline as the pandemic recedes. However, the technologies that enabled this economic resilience to remain in place, and if anything, have improved with learning and further investment.

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1 Introduction

The Covid pandemic was a large shock, the largest in three hundred years for some countries.¹ Output fell by as much as a quarter because many workplaces were closed and people were advised to stay at home and to work from home (WFH). The findings in this paper are twofold. First, judging by the drop in labor hours, output should have fallen by much more. Second, with fewer workers at the workplace, it seems very likely that capital utilization fell, and this should have resulted in a larger drop in output. Not all these findings apply to every industry or in identical amounts, but they were sufficiently influential to make a difference at the national level (Bloom et al. 2020)(Bloom, Fletcher, and Yeh 2021). Using both national and industry level data we will show that during the pandemic, businesses were remarkably adaptable in two respects: firms discovered that capital at home could give them flexibility to respond to large shocks like Covid, and that this was possible because the capital at home had connectivity with other workers making home working both possible and productive. They were able to overcome the barriers to shift from using capital at the workplace to using what we shall call ‘potential capital’ at home which then facilitated the shift from working at the workplace to working from home.²

There has already been a proliferation of literature based on survey evidence documenting the shift towards working from home ((Barrero, Bloom, and Davis 2020a);(Barrero, Bloom, and Davis 2020b; Haskel (2020); Mizen. Bloom and Taneja, 2020; Taneja, Mizen and Bloom, 2020; Taylor and Griffith 2020) and evidence of occupations and industries with a high share of tasks that can be done from home ((Bartik et al. 2020; Dingel and Neiman 2020). There is little doubt that some businesses can WFH, but there has been much little discussion of capital at home -- which facilitates the ability of labor to work off-premises. The key observation is that firms were able to shift along this second margin so quickly because there was no requirement to undertake substantial acquisition or building of new capital at home, since it already existed -- in the form of computers, office equipment, internet connections and so on. This substantial repurposing of the capital to work use helps us appreciate the value of the internet and ICT equipment, which was hitherto unrecognized. The objective of this paper is to draw out some of the implications of this observation.

Before we expand on the main themes of the paper, consider Figure 1, which shows the peak to trough (2020Q1 to Q2) actual decline in GDP across countries in red, and the decline in output

² Given this capital was pre-existing but unused, we call the capital at home “potential capital” because it was domestically-located capital and was capable of being deployed in business activities but had not previously been used for work purposes.
attributable to the decline in factors at work for the seven countries we study. In all cases, actual output fell less than output attributable to the workplace, sometimes substantially so. (We discuss individual countries and the timing of the pandemic as we proceed through the paper.) What explains this difference?

Figure 1: Actual and workplace implied output loss, 2020Q1-Q2

First, from 2019Q4 to 2020Q3, in a sample of seven advanced countries, GDP fell 6 log points, with total hours falling by 5 log points. (At the trough in Q2, the GDP decline was 14 log points and the decline in total hours was 11 log points.) But the composition of those hours changed remarkably. In January/February 2020, before lockdown, around 6% of employed adults were working from home. By 2020Q2 this was 29%, falling back to 18% in 2020Q3.

These WFH data imply a fall in hours at the workplace of 19 log points in 2020Q. With an output elasticity of 2/3rd, output should then have fallen nearly 34 log points in Q2 and 13 log points.

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3 France, Germany, Italy, Japan, Spain, UK, US.
4 For the UK, The most consistent data for WFH is set out (Felstead and Reuschke 2020) and is for working mainly from home (as opposed to sometimes, never, or in the week of the survey). The figure for mainly WFH, is 1.5% who are employed, aged 16+, of the workforce in 1981, 2.8% in 1993, 4.7% in 2019.
by Q3. Thus the first puzzle: why did output fall by so little in response to these large changes in hours at the workplace?

The second puzzle emerges if we consider capital in addition to labor. As (Mokyr 2001) documents, the history of industrialisation is that the point of going to the workplace is that workers have capital with which to work. It seems hard to believe that the economy substituted a 19 log point fall of hours with a rise in workplace capital in a matter of weeks. Rather, with fewer workers at the workplace, it seems very likely that capital utilization fell, so why didn’t output fall even further? Specifically, if utilization fell in line with declining commercial energy consumption or in line with decreased occupation of workplaces, then capital utilization would have declined by 24 log points.\(^5\)\(^6\) This would imply a further decline in output of 8 additional log points. If workplace capital is underutilized at this scale, then the first and second puzzles are extended: with these levels of capital utilization and labor at the workplace, why did output only fall by 14% and not 34+8=42% at the trough, or similarly 21% by Q3, rather than the 6 points actually observed.

These puzzles harken back to an observation already seen in an earlier industrial revolution, as (Mokyr 2001) has noted, the pre-factory era was one where capital (typically rudimentary textile equipment) was located at home. It was the rise of the factory method of production that co-located capital and labor in the workplace.

They also refer to the heart-searching around the GDP boundary, from the first days of defining the National Accounts (Coyle 2014), founded on the point that durable goods at home are a potential source of capital services for market-sector output. Industry boundaries and the production boundary are blurred with implications for the measurement of national statistics, investment and productivity, as explored in the literature on home production (as surveyed in (Coyle 2014)). Some types of capital are measured and others are not (as emphasized in the intangible capital literature, (Corrado, Hulten, and Sichel 2005; Haskel and Westlake 2017; Crouzet and Eberly 2021)) – potential capital investment may be unrecorded, but nevertheless it is an essential enabler of efficient production (at home, the new factories).

The puzzles are also remarkably modern, as recent work on the “gig” economy has further tested the GDP boundary: the part-time driver for example who uses their domestic vehicle for commercial rides. This reflects unused capacity in passenger vehicles, used only 5% of the time (Shoup 2011), or in unused accommodation, rooms, houses, and holiday homes available for rent. Nor are these

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\(^5\) Using the traditional approach to capital utilization ((Flux 1913)), we use energy consumption by industry, which fell by 24 log points: with an output elasticity of \(1/3^{rd}\), output would fall by 8%. Another approach to capital utilization is to observe that most of (non-dwellings) capital is buildings, so the very fact that workers are not attending work must reduce the utilization of buildings at least. If workplace buildings utilization fell by the number of workers leaving the workplace, 25%, then the lowered utilization of workplace buildings should have again reduced output by 8.3%.
issues just confined to the national boundaries since offshoring is yet another instance of the geographical separation of capital and labor (although not a shift to production at home).

Yet, none of these explorations envisioned the deployment of home capital at the scale and speed, with the potential consequences, observed in the context of the Covid-19 crisis. Our contribution is to suggest the answer to the puzzles is the redeployment of potential capital at home enabling working from home on a large scale. We then draw out the implications of this episode for buffering GDP during the pandemic, the likely longer run switch to home capital, and the role played by the connective technologies, like the internet, that apparently enabled the rapid and effective switch to new methods of production. This is important not only to explain the puzzles around the pandemic but also to understand the true potential of potential capital.

First, just as working from home has buffered the impact of Covid-19 (Adams-Prassl et al. 2020) so we suspect capital at home contributed to the buffering –it was the enabler of working from home. The ability to use potential capital in ways and at a scale not previously imagined was revealed by the imperative of the Covid-19 pandemic. By examining the use of home capital, we get a more accurate picture of how the economy responded to the crisis, the changes in production wrought by the crisis, and their impact on productivity.

Second, the enormous impact and scope of the shock scaled up the use of potential capital beyond that of the gig economy, which was already the subject of study though not a large contribution to national accounts. What did the pandemic do to shock the economy in this particular way? One answer is to consider relative price changes. Assuming that the economy was in an equilibrium before the pandemic with relatively few working at home, the pandemic created a huge change in relative prices to overcome the productivity disadvantages of WFH. Another answer is to consider a coordination failure. The pandemic pushed us to bear the fixed costs of making the changes involved in WFH, and we discovered that some of the capacity to do so was already present. For example, internet access and information and communications technology (ICT) equipment that had been used previously for social purposes and home entertainment, not necessarily for work or certainly not to the extent that it was after the pandemic, could now be set to a new purpose. The costs of switching from social and entertainment use to production use were not all that large, but perhaps some other costs of ‘accepting the idea’ of working from home, production from home, or remote delivery of services required that some costs be overcome. While it may have been difficult for a few people to work from home when most others were at the workplace, once most of us were at home it engendered learning and acceptance that could not occur at a smaller scale. Examples of this abound, but are illustrated well by telehealth sales, which had not been acceptable to health care insurers in the US nor to doctors in the UK prior to the pandemic, but faced with the alternative of no service, it was quickly embraced by both when Covid-19 occurred. These and others are likely to be lasting changes, and largely irreversible especially for young people who embrace them more readily, and for working people, who benefit from the convenience.
Third, we are interested in whether working from home helps us to understand better the economic contribution of the connective technologies, such as the internet. As Mokyr has stressed, the geographical co-location in the factory helped co-ordinate capital and workers. The modern equivalent of this is networked labor and capital, most recently via the internet. The idea here is that ICT is the enabler, networker and facilitator that makes the connected capital worth more than the capital in isolation (aggregated value still less than the linked capital). And while platforms that facilitate production and trade (e.g. Amazon) have existed for some time, new examples keep appearing e.g. Etsy, the craft marketplace company in the S&P500. These networks enable companies, marketplaces and facilitators of production and sale from home by unlocking potential capital.

This then raises an interesting question: is part of the value of the internet that, although we didn’t know it, firms and households were building economic resilience in the production system to a “distance” shock, which the pandemic turned out to be? Thus this line of inquiry might contribute to the hotly contested question of the internet’s value. From a policy perspective there may then be value in public goods investment in facilities that support use of home capital e.g. faster broadband, and in intangible capital e.g. data sets, in education and healthcare.

The rest of the paper proceeds as follows. In the next section, we extend growth accounting to allow for production at work and at home and use this structure to estimate the contribution of each sector and that of TFP across a panel of seven developed economies.

Section 3 focuses on the longer run outlook for working from home. If firms pivoted to WFH largely because of the relatively high cost of working from work, then when those relative prices revert as the pandemic recedes, one would also expect a reversal of working from home. We find strong evidence of these price effects in the U.K. data, where we have more detailed data by industry to estimate the substitutability between labor at home and at the workplace. However, in addition to the price response, there is also evidence of technology on the shift to work-from-home. That is, industries with more connective technologies shifted even more to WFH than the price effects alone would indicate. Since the technology, and the learning from the WFH experience – are persistent, these results suggest a longer-run shift to working from outside the workplace and greater utilization of home and other potential capital.

These findings have potentially long-lived implications for production: labor, capital assets, and technology, which we explore further in the conclusions to the paper. The results suggest the potential for decoupling of the geography of labor and capital in ways not historically feasible. This is made possible by the use of new capital and technologies, but also the reallocation of capital currently in place, what we call potential capital. Most of the literature has focused on labor allocations, but the
availability and reallocation of this capital at scale has implications for asset prices (Favilukus, et al 2020) and the path of future investment. \(^7\)

2 Structure for Growth Accounting

Our first objective is to assess the use and value of capital at home. We use a standard growth accounting framework, augmented by home and work factors, to structure the analysis. We use this to address a counter-factual: what would have happened to output had everyone who was at home not had any capital with which to work? \(^8\)

2.1 Framework

Suppose the economy’s production possibility frontier defines output that can be produced by labor and capital services, and capital and labor in turn can be located at home (H) or at work (W)

\[
Y = F(K^*_W, K^*_H, L^*_W, L^*_H),
\]

where the stars denote flows of services. We will assume the standard structure for growth accounting and TFP estimation, that is, constant returns to scale, perfect competition, and optimizing behavior. \(^9\) So as to isolate the effects of interest, the only deviation is to add home versus workplace production. Changes in output are therefore changes in the inputs times their output elasticities. We suppose that labor services are hours and capital services capital (later we shall write capital services as product of capital stocks and capital utilisation: we suppress this for now to ease notation) \(^10\), where in obvious symbols

\[
\frac{p_Y Y^W}{\sum p_Y} dy^W + \frac{p_Y Y^H}{\sum p_Y} dy^H = \varepsilon_Y (\varepsilon_L^W dh^W + \varepsilon_H^W dh^H) + \varepsilon_K^H dk^W + \varepsilon_K^H dk^H
\]

\(^7\) For example, the changing relative prices of residential/dwellings capital versus commercial real estate, in particular office space, has been documented broadly, for example, by Greenstreet.

\(^8\) We will also consider a counterfactual with no work from home, as the extreme case.

\(^9\) While these assumptions are standard, they are not necessarily innocuous. (Crouzet and Eberly 2018) demonstrate the impact for TFP measurement of relaxing perfect competition and allowing for errors in capital measurement, which can be substantial.

\(^10\) There are a host of issues around utilisation and whether it should be subsumed into the capital payments term. Here we are trying to capture the idea that, say, an office building under lockdown offers fewer capital services not because the capital has been destroyed, but the utilization of such capital has changed. In Berndt-Fuss-Hulten (Berndt and Fuss 1986; Hulten 1986), such a change in capital services would be reflected in the price of such capital (which would presumably fall -- potentially drastically depending on the length of the change); the capital payments share would fall and hence the contribution of capital services in the production function (the share times the capital) would fall. With, for example, sticky rental prices, such a change might not show up in share changes.
\[ + \frac{P_Y W}{\sum P_Y} dt f p^w + \frac{P_Y H}{\sum P_Y} dt f p^h, \]

where \( \epsilon \) is an elasticity with respect to each factor, and lower case letters are logs, so \( dz \) equals change in \( \ln Z \). The growth in total nominal output (\( Y^w \) and \( Y^h \) being output produced at the workplace and home respectively) is the growth in labor hours at work and at home (\( H^w \) and \( H^h \)), times the relevant elasticities, and similarly for capital services at work and at home (\( K^w \) and \( K^h \)), plus the contributions of productivity at work and at home. If markets are competitive, and if labor and capital are paid for the use of their services, optimising owners of capital and labor implies that we can simplify to substitute labor and capital shares for the elasticities

\[
dy = s^L_{P_Y} \left( \frac{P_{L h} L^w}{\sum P_L} d h^W + \frac{P_{L h} L^H}{\sum P_L} d h^H \right) + s^K_{P_Y} \left( \frac{P_{K h} K^W}{\sum P_K} d k^W + \frac{P_{K h} K^H}{\sum P_K} d k^H \right) + dt f p
\]

where \( s^L_{P_Y} \equiv \frac{\sum P_L}{\sum P_Y} \) and \( s^K_{P_Y} \equiv \frac{\sum P_K}{\sum P_Y} \).

(3)

To get at the notion of resilience we rewrite the above in terms of the contribution of \( H \) and \( K \) at work and the additional contribution of labor at home and potential capital, namely

\[
dy = \frac{\sum P_L}{\sum P_Y} \left( d l^w + \frac{P_{L h} L^H}{\sum P_L} d (l^H / l^w) \right) + \frac{\sum P_K}{\sum P_Y} \left( d k^w + \frac{P_{K h} K^H}{\sum P_K} d (k^H / k^w) \right)
\]

(4)

The first and third terms on the right hand side are the conventional production function terms, namely that \( dy \) results from \( dl^w \) and \( dk^w \) times their output elasticities (here the shares). The second and fourth terms are the additional effects, of shifts from \( W \) to \( H \), times their output elasticities.

Equation (4) shows that output falls if \( L \) and \( K \) at work fall, which is conventional, but is offset if \( L \) or \( K \) migrates to home. The workplace-implied fall in output referred to in the introduction is the first term and the offsetting effect of working from home and “potential” capital are the second terms.

To take this structure to the data we adopt two approaches. First, we take a growth accounting approach and attempt to measure the various terms to understand the magnitudes of the contribution from potential capital. Second, we examine whether the elasticity of substitution between home and work plausibly varies with terms of economic interest.
2.2 Growth Accounting

To measure the terms in equation (4), we proceed as follows. The left-hand side is (change in log) GDP. On the right-hand side, let us set the L and K shares as 2/3rd and 1/3rd respectively. Turning to the hours terms, if we assume that labor is paid the same at home or at work, then the payments weights are the share of hours at home and at work.\(^{11}\)

The capital terms are more complicated. Starting with the capital shares, national accounts conventions includes dwellings as (residential) capital, with an associated rental price, suggesting we can measure share of \(K^H\) as the dwelling payments as a share of total capital payments. This estimate needs to be adjusted in at least two ways. First, we multiply dwellings capital by labor force participation, assuming that dwellings capital can be potentially brought into production in proportion to the fraction of the population who may potentially be working at home. Second, \(K^H\) is not just dwellings capital, but e.g. domestic computers and the internet, which are not counted as investment in national accounts but as consumption. We have no data on this currently. As a result this will appear as an error term in the equation and will contribute to total factor productivity. We return to estimating this effect later in this project.

Turning to the change in capital data, official data suggests almost no change in capital over the period of the pandemic. This is to be expected: although there has been minimal investment over the last four or five quarters, 74% of capital is dwellings, buildings and structures which depreciate very slowly. Instead, it seems reasonable that capital utilisation has changed. One way to examine this is to look at final commercial and domestic energy use, corrected for seasonality and temperature, and excluding the output of the energy generation sector itself. Thus if we suppose that \(dk^*=dk+du\) where \(du\) is the change in log utilization, measured in turn by changes in energy use, \(de\), we write

\[
dy = \frac{2}{3}(dh^W + WFH(dh^H - dh^W)) + \frac{1}{3}\left(de^W + \frac{P^W K_{Dwell} P^W k}{\Sigma P^W k} (de^H - de^W)\right)
\]

where the W and H superscripts apply to work and home factors, as previously, and DWELL refers to dwellings, or residential, capital.

\(^{11}\) We use traditional labor shares for all the countries. We can readily use a smaller labor share for the US, reflecting evidence of declining labor share. This adjustment will raise the importance of potential capital in our calculations, but is small compared to the magnitudes we find overall. The evidence outside the US is less convincing of a change in labor shares. Regarding pay at home and at work, there is not evidence so far that wages and salaries have adjusted during the pandemic to differentiate home versus work on premises. Given our later evidence, this is an interesting topic for future work.
2.3 Results

2.3.1 International Evidence

We turn now to the results from seven advanced economies. First we compare the actual change in output to the computed changes in labor and capital, with the residual being the implied change in total factor productivity (TFP). Data are drawn from the OECD, Eurostat, ONS and Bank of England, with details provided in the data appendix.

Across all seven countries we see that output fell in 2020Q1, it did so by more in countries further east, which were affected by the virus at an earlier stage than those further west. France, Germany, Italy and Spain saw drops of -6.1%, -2.0%, -5.7% and -5.4%, respectively, while the UK saw a drop of -3.1% and the US -1.3%. By 2020Q2 the virus hit harder, lockdowns were in place in many countries and output fell in France, Germany, Italy and Spain by -14.5%, -10.2%, -13.9% and -19.7%, respectively, in the UK it fell by -20.8% and in the US by -9.4%. These were unprecedented quarterly changes in output in recent years. After lockdowns were eased in the summer output rebounded across the board.

When we look at the contributions that were made by labor and capital split according to whether they are used at home or at work, we find some startling results. First, if output had been restricted only to the workplace then output would have fallen by much more than it actually did. Total output at work would have fallen by -3.3% in 2020Q1 in the US, and by -6.6% in the UK – much larger than the actual drops in output of -1.3% and -3.1% respectively. In 2020Q2, however, the magnitudes are much larger. Output in the US would have fallen by -17.4% and in the UK by -32.8%, rather than the actual reductions of -9.4% and -20.8%. This was the effect of lockdowns and cautionary behavior, which restricted transportation, closed down production in factories and shut up retail outlets, restaurants and leisure facilities affecting both demand and supply. But from our preceding discussion we would want to include the output produced at home using the labor of those working from home and potential capital. Output from home largely offset the fall in output from work in the US (+3.0% versus -3.2%) in 2020Q1, and it made up almost 50% of lost output in 2020Q2 (+9.0% versus -17.4%), by 2020Q3 when some of the restrictions eased, output from home fell slightly as output from work recovered (-2.7% versus +8.1%). This pattern is repeated for the UK, France, Germany, Italy, and Spain with differences between countries reflecting the industrial composition between jobs that could be done from home and the timing of the spread of the virus. Clearly, working from home and potential capital averted a larger fall in output that would otherwise have occurred if all output was produced at work.

In Charts 1 – 7 we show the patterns of output from work (yellow lines) versus actual output (blue lines) and the breakdown of the contributions of output at work (yellow bars) versus output at home (red bars); these reveal that output produced from home clearly offset declines in output at work in almost all
quarters and countries. These estimates also include the contribution of potential capital to output during the pandemic, where the availability of potential capital alone contributed 2.2 and 3.0 percent, respectively, to GDP at the trough in Q2 in the US and the UK. The effects are similar in the other countries, ranging from 2.6% to 3.2% in Germany, Italy, Spain and Japan, and the largest effect of 4.7% in France.

These considerations also affect measurement of productivity, shown in Figure 8-14. Taking the residual of actual output not explained by all labor and all capital as a measure of change in TFP, we see a drop in TFP in the US and UK in 2020Q1 of -1.0% and -0.4% respectively, followed by a further fall of -1.0% in 2020Q2 in the US, but an increase of 3.3% in the UK. Productivity then rebounded in 2020Q3, as lockdowns were eased, with a 1.8% increase in the US. The UK pulled back from the sharp increase in Q2, remaining roughly flat above pre-pandemic levels. Similar patterns are observed in other European countries. But if working from home had been ignored along with potential capital, then a very different story emerges. Productivity in the US and the UK would have been exceptionally strong in 2020Q1 and 2020Q2, due to mismeasurement of labor and capital inputs to production of goods and services (due to ignoring the home production). Ignoring home capital would have been misconstrued as a productivity boom during the pandemic. Instead there were initially modest declines in TFP, followed by a recovery as labor returned to work, consistent with either other mismeasurement issues or true inefficiencies associated with working from home. In particular, the industrial composition of output changed during the pandemic; the industries most affected tended to be low productivity services, tending to increase measured TFP via a compositional effect.

3 Substitution between workplace and home employment

Substitution from work to home was crucial for the economy to respond to the pandemic quickly, and even as the pandemic ebbed, there was some return to workplaces. This substitution between home and work may also be important as the pandemic recedes to understand and predict, for example, future work patterns. The experience of the pandemic allows estimation of the substitutability between work and home, as there were both large changes in labor allocations and arguably exogenous changes in relative prices due to the pandemic. We develop a flexible framework that allows for substitution between capital and labor, home and work, and the presence of relative prices and different technologies.

In this section we rely on UK data, referring to the economic conditions and the health data. The latter informed the government response to the pandemic, but economic conditions were also a consideration. We first discuss the course of the pandemic and lockdowns to provide context for the swings in WFH, but note that we do not identify the WFH effects from these endogenous policy changes. The
government announced a national lockdown on 23 March 2020, which came into force on 26 March until 23 June. Local lockdowns remained in place in some areas, while conditions were eased elsewhere allowing people to return to the workplace and shops and restaurants to reopen, restrictions were tightened from 22 September, and a second lockdown came into force on 5 November until 2 December. The uncertainty around these lockdowns is illustrated by the announced intention to allow families to meet in a five-day window over Christmas, subsequently reduced to one day, followed by a third lockdown imposed from 6th January 2021. On 22 February the government published a roadmap for lifting the lockdown driven by the vaccine rollout and reductions in infections, hospitalisations and deaths. Conditions also varied geographically in England, Wales, Scotland, and Northern Ireland. Importantly, we are not identifying substitution using these lockdown timings but instead using the underlying virus and economic data instead. This is consistent with the arguments and evidence in a number of research findings, suggesting that lockdowns per se did not drive economic choices and activity, so much as did the underlying dynamics and risks of the virus. These comparisons are often made comparing nearby locations in the U.S., across states for example, or nearby cities, with similar virus exposures but different policies, (Goolsbee and Syverson 2021; Gupta, Simon, and Wing 2020). In such cases, the consistent finding is that behavior changed prior to the lockdowns being put in place or relaxing.

We begin with the pre-pandemic position. Even then, workers could in principle work from home or at the workplace. Their relative productivity is now a matter of intense research scrutiny and remains unresolved: in some findings productivity is higher, some lower and in others it seems to be changing. We develop a framework that can encompass these conflicting findings and (following (Katz and Autor 1999; Johnson and Stafford 1998)) and write the production function as

\[
Y = \left( \beta_W \left( B_w \left(K_w^W L_w^W \right)^{(1-\sigma)} \right)^{(\sigma-1)/\sigma} + \beta_H \left( B_H \left(K_H^H L_H^H \right)^{(1-\sigma)} \right)^{(\sigma-1)/\sigma} \right)^{\sigma/(\sigma-1)},
\]

where \( Y, K \) and \( L \) are output, capital and labor and the subscripts \( W \) and \( H \) indicate work and home. Turning to the other terms, first, \( B_w \) and \( B_H \) are “intensive” technical levels/change i.e. change that makes capital and labor better at doing their existing tasks at work or at home (e.g. a computer that runs Stata can do it both at work and at home and so could represent an increase in both \( B_w \) and \( B_H \))

\[12\] The U.K. lockdown scenarios are summarized in greater detail here:
Second, $\beta_w$ and $\beta_h$ represent “extensive” “work-biased” and “home-biased” technical change i.e. an increase in $\beta_h$ is technical change that makes home capital relatively better at doing the work of work capital: e.g. a telecoms network with a video function that enables workers at home to see fellow workers without having to come to work.

This framework helps interpret the differing empirical evidence. A call centre worker for example who works at home might be thought of as a worker whose single task is being carried out at home, with relative productivity $\beta_h/\beta_w$. A worker who is part of a team and/or is performing a group of combined tasks faces a relative productivity $\beta_h/\beta_w$ which might be different, depend upon communication technology and might change over time with learning.

Define $a^w = (K/L)^w$ and $a^h = (K/L)^h$ (and assume for the moment these are fixed) the first order conditions are standard

$$
\frac{L_h}{L_w} = \left(\frac{P_{Lh}}{P_{Lw}}\right)^{\sigma} \left(\frac{\beta_h}{\beta_w}\right)^{\sigma} \left(\frac{B_h}{B_w}\right)^{\sigma-1} \left(\frac{a_h}{a_w}\right)^{\sigma-1},
$$

(7)

with the dynamic version being

$$
d \ln \frac{L_h}{L_w} = -\sigma d \ln \left(\frac{P_{Lh}}{P_{Lw}}\right) + \sigma d \ln \left(\frac{T_h}{T_w}\right), \quad \text{where}
$$

$$
d \ln \left(\frac{T_h}{T_w}\right) \equiv \sigma d \ln \left(\frac{\beta_h}{\beta_w}\right) + ((\sigma - 1)/\sigma) d \ln \left(\frac{a_hB_h}{a_wB_w}\right).
$$

This formulation allows us to read off the elasticity of interest, $\sigma$, the elasticity of substitution between work and home, from the relation between changes in (log) relative employment and (log) relative prices, controlling for changes in relative technology denoted, $T_h/T_w$. This equation can in principle be estimated from the log changes in labor at home and work, with estimates of the relative prices, which we describe below.

Before turning to estimation of the elasticity, however, the pandemic offers a third dimension of job outcomes that bears on the home/work allocation. The pandemic was not only a shock to the location of production, it was also a shock to its level. This choice is potentially related to the choice of location. Moreover, the availability of the furlough program offered by the U.K. government during the pandemic emphasizes this third dimension. Firms had the option to furlough, rather than lay off, workers, with
the government paying 80 percent of their wages. If workers were on furlough, however, they were not allowed to work any hours.\textsuperscript{13} We will focus on furloughs rather than layoffs, as furloughs were the dominant mode of separations and layoffs were quite small, as evidenced in Figure 2.

Figure 2: Covid Impact on Employment By Industrial Sector

<table>
<thead>
<tr>
<th>Impact of Covid-19 on employees, May 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of employees</td>
</tr>
<tr>
<td>Furloughed</td>
</tr>
<tr>
<td>Accom &amp; Food</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>Acc. &amp; Food</td>
</tr>
</tbody>
</table>

Source: Decision Maker Panel survey, Bank of England

We lay out a simple model of fixed operating costs with the choice of working at home or on premises in the appendix. The results are intuitive, implying that firms choose the allocation of labor between home and work depending on the relative productivities and relative costs of home and work production. In addition, though, if the fixed cost of operating is elevated by the pandemic, some firms choose to furlough workers. The option to furlough is more appealing the greater are the fixed costs of operating and the less productive and more costly is labor. These features interact in interesting ways, as suggested in Figure 3, and evidenced in the estimation below. We proxy for the COVID-related fixed cost by vulnerability to virus transmission, as measured by client interactions in pre-COVID worker characteristics across industries. These fixed industry characteristics are interacted with the severity of the virus over time, measured by excess deaths. This produces an industry-quarter measure of the exposure of an industry to virus transmission.

In this framework, furloughs could arise for several reasons. Most importantly, worker to customer contacts are essential to the business of some services, such as food and accommodation, so fixed costs of operating in the pandemic may be very high. Given fixed costs, protection costs per worker may be very high, suggesting a switch to WFH. However, the technological parameters could be unfavorable.

\textsuperscript{13} A later incarnation of the furlough program allowed for workers to be partially furloughed.
to working at home (e.g. $\beta_{H} = 0$, so the productivity of work at home is zero). Cases such as these lead to corner solutions in factor choices which confound the first difference specification we propose in equation (13). Hence, we first estimate the determinants of furloughs, essentially taking into account fixed costs and virus exposure, before turning to the location estimation.

3.1 Data

We rely on data on employment by location and furloughs, as well as worker contact data and the costs of working on premises. Our data on employment is industry-quarter, for 2020Q1 to 2021Q1, and comes from the U.K. Decision Maker Panel (DMP). The DMP also includes survey data, which we discuss below, on the cost of safely equipping employees to work on premises, by industry and quarter. For data on virus risks, we have (cross-section) data from work surveys on the extent to which different industries have different contact (a) worker to worker and (b) customer to worker. These surveys were conducted in France pre-pandemic by epidemiologists to model the potential for disease spread. We measure the intensity of the virus over time using excess deaths. We also utilize data on the capital intensity of the industry, namely its tangible, ICT and intangible intensity.

Starting with the furlough margin, Figure 3 shows for each industry the average furlough/work ratio against the ICT share, tangible capital share and contact with co-workers and customers. Consider for example recreation and accommodation/food, both of which have had very high furlough rates. These industries have low ICT share, but high tangible capital share. Workers in these industries have low contact with co-workers but high contact with customers. This high contact with customers is consistent with the observation that some industries will have unfavorable technology parameters for working with home, e.g. $\beta_{H} = 0$ for face-to-face services, suggesting that the relative productivity of work at home in these industries is low. Hence, the pandemic shock means many workers are furloughed in the absence of effective safety protocols at work. Interestingly, these industries have high tangible (physical) capital, consistent with the asset price effects explored by (Favilukis et al. 2020)
Figure 3: furlough/work working and capital shares and contacts

Figure 4 shows similar data for the location of work: home/work ratios, capital shares and contacts. The standout industry is information services (newspapers etc) which has very high home/work ratios, high ICT share and low tangible capital share, medium contact with co-workers and little contact with customers. Notice in contrast to Figure 3 the small number of workers at home in accommodation and food. These data suggest the importance of distinguishing the furlough decision from the location decision. Industries with high face-to-face contacts would in principle benefit from having workers isolate at home, however, the nature of their work (that exposes them to risk) cannot be replicated at home. Hence, the technology parameters can lead to corner solutions for the factor inputs, complicating estimation of substitutability between home and work.
Figure 4: home/work working and capital shares and contacts

Turning to data on costs, we have survey data from the DMP on the following question: "Relative to what would otherwise have happened, what is your best estimate for the impact of measures to contain coronavirus (social distancing, hand washing, masks and other measures) on the average unit costs of your business in each of the following periods?" The answers, by industry and quarter, are set out in Figure 5.
Figure 5 shows that such costs vary by industry and over time, being 3% in wholesale retail and then climbing to 6% before falling to 5.5%. In Recreational Services the figure is above 15% by 2020Q4.

The survey question asks specifically about the cost of physical goods and also about measures such as social distancing. These might include, say the purchase of PPE equipment which has a price and quantity, but it might also include, say, the spacing of tables in a restaurant, extra staff to enforce distancing or the implicit costs of having reduced flows of customers. We will interpret such costs as an implicit tax on the use of factors at work relative to home, which in terms of equation (10) would be a rise in $P_{LW}$. To relate these changes in costs to relative employment at home/ work and the furlough margin, we measure labor at work using a Cobb-Douglas aggregator of the form

$$L_W = L_{WFW}^sL_{FUR}^{1-s}, \quad s = L_{WFW}/(L_{WFW} + L_{FUR})$$

where $L_{WFW}$ and $L_{FUR}$ are the numbers working from work and furloughed respectively.
3.2 Estimating Furloughs and Substitution between home and work

To explore this more formally, we first examine the furlough/work margin. We estimate

\[ \Delta(L_{FLR} / L_{WFH})_{i,t} = \gamma_1 (ICT / K)_i + \gamma_2 (K \_ tan / K)_i + \delta_1 (CtoWContact_i * \DeltaExDeath) + \delta_2 (WtoWContact_i * \DeltaExDeath) + \nu_i + \varepsilon_{i,t} \]

where ExDeath are excess deaths from COVID that varies by time (not industry) designed to capture the severity of the pandemic. The ICT and Tangible capital shares are intended to capture the technology of work, where ICT enables working from home and Tangible capital is associated with physical workplace infrastructure. Contacts are measured separately for customers (CtoW) and other workers (WtoW), where we interact with ExDeath to capture the risk engendered with contacts at different times during the pandemic.

The results are set out in Table 1. Capital intensity of either type is not significant, but as suggested above, high customer to worker contact industries are associated with high furloughs. We interpret this as a corner solution to equation (10) in which workers are furloughed rather than working from either workplace or home, due to a combination of high risk at work from face-to-face contacts and business constraints of isolating work at home. Technology that might enable either work from home or workplace does not ameliorate this effect, consistent with our interpretation of fixed costs and the nature of face-to-face services. The contact effect is quantitatively large: for industries in which daily customer contacts are 15 (accommodation & food), an increase in excess deaths of 10 percentage points raises the furlough share by 100 percent, while in industries with lower customer contacts of 3 (professional services), the same increase in mortality raises furloughs by 15 percent.14

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14 Excess deaths across countries varied widely over the pandemic, as evidenced in [https://ourworldindata.org/excess-mortality-covid](https://ourworldindata.org/excess-mortality-covid). In the U.K. first wave, estimates exceed 100 percent, while in the U.S. they reached almost 50% in the first wave and again in January 2021. In our estimation, we use quarterly changes, which dampens some of the extreme values in higher frequency data.
Table 1: Regression estimates of Furloughs

(dependent variable: DLfur/Lwfw)

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
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<tbody>
<tr>
<td>ICT.sh</td>
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<td>0.42</td>
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<tr>
<td></td>
<td>(0.11)</td>
<td>(0.17)</td>
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<tr>
<td>kw.sh</td>
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<td>(0.17)</td>
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<td>ctwcon_Ddeath</td>
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<td>0.42</td>
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<tr>
<td></td>
<td>(2.27)</td>
<td>(2.34)</td>
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<td>Yes</td>
</tr>
<tr>
<td>Industry FE</td>
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<td>No</td>
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For firms that remain open, the relevant decision in this framework is the allocation of labor between workplace and home. Using the intensive margin and turning to the elasticity of substitution when firms do substitute between production at work and at home, we estimate

\[
\Delta \ln(L_{it}/L_{it}) = \gamma_1 (ICT/K)_{it} + \gamma_2 (K_{-tan}/K)_{it} \\
+ \delta_2 (WtoWContact_{it} * \Delta ExDeath_i) + \nu_i + \epsilon_{i,t} \tag{11}
\]

Where the capital/technology and contact variables are as above, and the variable \(C_w\) is the relative cost of COVID measures at work, from the survey data described above. Typically, estimates of the elasticity of substitution using relative prices are challenged by the endogeneity of wages and potential selection of workers into different types. By using the covid shock and the additional costs associated with working at the workplace in the pandemic, we obtain plausibly exogenous changes in costs of employment that caused firms and workers to reallocate between premises and home.
Table 2: Regression estimates of WFH

(dependent variable: DLh/Lw)

<table>
<thead>
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<th>(4)</th>
<th>(5)</th>
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<td></td>
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<td>(1.30)</td>
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<td>Yes</td>
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<tr>
<td>Industry FE</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>No</td>
</tr>
</tbody>
</table>

The top row of Table 2 shows the estimated values of $\sigma$, which range from 1 to above 3 for different time periods and specifications. Taken at face value, the coefficient should be interpreted as a partial elasticity, so that a given percentage change in at-work costs has a one-to-one up to a three-fold effect on the log share of workers at home. It was not unusual to see a 10 percentage point increase in work-costs, which translates to 10 or 30 log points increase in home labor relative to work. The effects are largest in 2020 and diminish when we include 2021 data in columns (1) and (2). However, the results are not entirely driven by the second quarter, as they persist in column (6) when we omit Q2 entirely. Since the scatter plots indicate that WFH effects are particularly important in information services, we remove this industry in column (5), which has little effect on the estimated elasticity. Removing the Food and Accommodation industry results in the larger values of the elasticity for the full sample, suggesting that there was little response of WFH in this sector to relative prices, consistent with the low values of WFH in face-to-face services throughout the pandemic. Note that after the second quarter, the costs of working at the workplace and the share of workers doing so both rose and fell, so the elasticity is estimated off both positive and negative changes.

The technology parameters suggest that working at home is associated with high ICT, but no impact of tangible capital shares, though the significance (but not the positive effect) for ICT are dependent on
the inclusion of the Information Services industry (see column 5) and diminishes in later quarters. These estimates are consistent with the observation that WFH was particularly prominent in professional services, while production industries like manufacturing had intermediate levels of WFH – representing some tasks which could be done remotely, but other which required proximity to physical capital at the workplace. Using the estimates in Table 3, each percentage point increase in the share of ICT share increases the share of WFH by one to three percentage points, with higher values when excluding information services.

Figure 7 shows a scatter plot of changes in relative home/work employment and cost ratios (controlling for quarter effects and capital effects) for the full four quarters. The downward-sloping curve indicates higher home working with more costly work costs, depicting the elasticity estimated above.

**Figure 6: changes in home/work working and change in COVID costs against**

![Changes in LH/LW and changes in costs at home/work](image)

**(Costs at work are COVID-induced extra costs)**

Notes: (i) data are net of ICT, tangible capital share and quarter effects. (ii) LW is geometric average of at work and furlough.

---

15 The effect of costs is sensitive to entering this variable as DlnC rather than the absolute change which is used here. We suspect that this may be due to small absolute measurement errors from the survey data, which are magnified by the log specification. Interaction effects were insignificant, though we caution that the data set is small, so this is not dispositive.
The estimation results suggest a positive relationship, though weak, between changes in working from home and the industry’s level of intangible capital. Given that the intangible capital value is measured pre-pandemic, we also examine the correlation between an industry’s share of employees working from home and its pre-pandemic investment in intangible capital, as shown in Figure 8, where the relationship is clearly positive across industries.

Figure 7: Working from Home and Intangible Capital

3.3 Interpretation – the future of working from home?

The estimates in Table 2 provide direct evidence on the substitution from working at the workplace to working at home. There are strong effects of the relative price of working at each location, and also the technology that enables working from home.

To the extent that working from home was motivated by elevated costs of working at the workplace, these costs may well reverse, at least partially, as the pandemic recedes. A large elasticity – ranging from 1 to 3 even in the more proscribed estimation – suggests that WFH may recede along with the costs of working at the workplace. The elasticity is estimated off both positive and negative changes during the pandemic, though a more permanent reversal of costs may have a more durable and potentially larger effect on work location choices, especially if there are frictions associated with changing. Of course, the costs of working from work may not reverse entirely, as customers and workers may demand better ventilation, hand washing, and other health measures going forward.

The technology parameters may have different implications, however. The positive effect of ICT on WFH suggests that existing capacity to work remotely was crucial to enable substitution, especially
early in the pandemic (Q2) but also later in the year as the pandemic persisted. This capacity predated the pandemic (the ICT share is measured in 2019) and if anything grew larger over time, and hence is unlikely to reverse post-pandemic. One interpretation is that the pandemic revealed the capability to work from home that already existed with dwellings capital and connective technologies. The pandemic acted as a large shock and coordination device, overcoming the collective action problem needed to demonstrate the possibility of working remotely. Moreover, the sustained period of the pandemic enabled learning. Both the capacity and the learning will surely continue beyond the pandemic, enabling more persistent working from home, as argued by (Barrero, Bloom, and Davis 2020c).

4 Conclusions

These results emphasize the quantitative effects of the large scale restructuring of production during the COVID-19 pandemic. The findings have potentially long-lived implications for production: labor, capital assets, and technology. First, as a growing literature has emphasized, labor dynamics are likely to be deeply moved by the pandemic experience, with profound impacts on distribution. Employees able to work remotely have been advantaged by this shift in production, while face-to-face workers have been laid off or furloughed as safely working was nearly impossible during the pandemic. The correlation between remote work, human capital, and income has been well-documented and reinforces questions about skill development and distribution. Moreover, while we emphasize capital and labor at home, there is nothing in remote work that limits geographies, necessarily. What we observe now as work from home may later manifest as work from abroad (which may be home or not).

Second, the pandemic has revealed under-utilized capital across the economy and across the globe. The gig economy uncovered and deployed some of this capacity, but the pandemic revealed unused capacity as a macroeconomic phenomenon. While crucial for allowing production to proceed during the pandemic, on-going substitution between home and work reverberates in capital markets. The retail sector was already disrupted by the shift from in-person to online shopping, which was accelerated massively by the pandemic. To the extent that other goods and services can also be produced from home (not just retailed online) the shift away from business capital will continue and potentially accelerate. Recent work ((Favilukis et al. 2020) and Branzoli, Rainone, and Supino (2021), for example) already documents the lower utilization of business capital, especially structures and real estate, being priced into valuations and rents. This is not necessarily to ring the death knell of urban business centers or their buildings. Even if workers continue to work partially at home, as surveys currently indicate their preference to be (DMP, (Barrero, Bloom, and Davis 2020c)), they will still need offices and services at work, and may even demand part-time dwellings in city-centers, if they are commuting from
further distances. Production has already been revealed to be surprisingly resilient and flexible when technology allows – one would be surprised if the pandemic was the last chapter in this story.

Finally, the technology is crucial. A desk and computer at home has little use for many of the production processes we describe unless it can robustly connect to other workers and their computers. This has been a defining feature of WFH in 2020 and 2021, as compared to earlier, when we might have been using dial-up connection and analog phones. The existence of this technology allowed economic resilience in the pandemic that we estimate accounted for 8 to 14\textsuperscript{17} percent of GDP in the trough of the COVID recession. While the on-going economic impact of new digital technologies has been controversial and difficult to measure, the pandemic may have been the moment that demonstrated the value of this resilience.

\textsuperscript{17} Excluding Japan, which has even larger values.
Chart 1-7 Contributions to Output Growth (log changes), by Home and Work

Chart 1.
Italy

Actual Output

Output from Work

Italy

Total H

Total W

dTFP
Charts 8-14 Productivity (TFP) versus Productivity at Work
Chart 15: Covid impact on Sales by Industrial Sector

Covid-19 impact on sales in 2020 Q2 by industry, May 2020

Percentage impact of Covid-19 on sales in 2020 Q2
References


Data Sources:

International Data:
Quarterly data on output (GDP), employed persons and average hours worked are drawn from Eurostat. Energy use to infer the capital used at work is drawn from Eurostat. For Spain we rely on electricity usage data for firms, from (Bover et al. 2020)
Dwellings/residential capital is drawn from National Accounts data.
Google mobility data (for transportation to and from the workplace) is used to infer working from home/office hours for all countries except the UK, where Decision Maker Panel and ONS data are used. The Google mobility data were calibrated to the UK work from home data, where both are available, and then Google mobility is used to estimate work from home for the other countries.

UK Industry Data
Quarterly data for growth in sales revenue and employment split into 13 sectors is drawn from the Decision Maker Panel (DMP), Bank of England. Similarly, we use DMP to derive industry breakdowns of unit costs, employees working from home, working in the workplace, ill or isolating and on government sponsored furlough schemes (employed but doing zero hours of work).

Health and Infection Data
“Excess deaths” is measured from the Oxford University database on excess mortality ((Ritchie et al. 2020; Roser et al. 2020), https://ourworldindata.org/excess-mortality-covid

Contact rates are derived from a survey conducted in 2012 in (Béraud et al. 2015)

The worker-to-worker matrix defines contacts made between workers within a sector, applicable to individuals while at the workplace. The worker-to-consumer matrix is diagonal and defines contacts experienced by workers from consumers within each sector.

These data are also described in (Haw, Forchini, and Christen 2020).
Appendix: Allowing for fixed costs of production:

Static operating condition: operating profits >0,

\[ F(K, L, A) - wL - uK - C(A) > 0 , \]

where in L is (vector) employment and we will think of (vector) K as quasi-fixed for this period (rent, overhead).

Standard optimization requires that the scale of production (L,K) be high enough to justify paying the fixed cost, C, and conditional productivity A. The dependence of the fixed cost on A is useful dynamically so that the fixed cost scales with the size of the firm, but is not necessary in the current setting. This follows from the first-order conditions for K and L that arise from optimizing over the factor inputs in the above.

With COVID, there is both the choice to operate or not, which can send workers to furlough, and also the choice of L at home and at work. For simplicity, we embed normal fixed operating costs in the uK term, and assume that K is quasi-fixed over the course of the pandemic. During COVID, an additional non-capital fixed costs CC(A) depend on costs of mitigating exposure to the virus. These are fixed costs and not per-worker costs. (Per worker costs are measured in c>1, our unit cost measure of workers at work during the pandemic, which would count as a premium on wages in the budget constraint equation.) We measure the fixed costs using customer to worker contacts and excess deaths – so the interaction of virus exposure by industry and intensity of the virus over time. These costs are avoided by furloughing workers. Covid thus adds two types of costs to the budget constraint: unit costs which effectively add to wage costs of Lw, and fixed costs of operating (L>0), CC. Allowing for these Covid costs we rewrite

\[ F(K, L, A) - w_H L_H - w_W c L_W - uK - C(C|L > 0) > 0 , \]

First order conditions wrt LH and Lw respectively provide

\[ F_{Lh}(K, L, A) = w_H \]
\[ F_{Lw}(K, L, A) = w_W c \]

To solve, solve for the max over two potential modes of operation in the solution:

1. Hybrid operation: If operate hybrid, pay the CC cost, choose labor at home and at work based on the first order condition, and hire labor if fixed costs are covered.
2. Furlough: If the fixed costs are too high and/or productivity too low to cover CC and normal operating costs, cease operations and furlough. Most likely if
B low for remote workers, and cost of premises is high both per unit and high CC cost.