ECONOMIC STATISTICS CENTRE OF EXCELLENCE

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Janice Eberly, Jonathan Haskel and Paul Mizen

ESCoE Discussion Paper 2026-09

July 2026

ISSN 2515-4664

DISCUSSION PAPER

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JEL classification: O47, E22, E01

Paul Mizen, King’s College London
paul.mizen@kcl.ac.uk

Published by:
Economic Statistics Centre of Excellence
King’s College London
Strand
London
WC2R 2LS
United Kingdom
www.escoe.ac.uk

"Potential Capital", Working From Home and Economic Resilience*

Janice Eberly, Kellogg School of Management, Northwestern University and NBER;
Jonathan Haskel, Imperial College Business School; CEPR
Paul Mizen, King's College, London and ESCoE
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* We thank Nick Bloom, Ragu Rajan, Carmen Reinhart, and Lawrence Summers for comments on earlier work and seminar participants at the AEA meetings January 2021 and January 2022, the Federal Reserve 'Black Swans' workshop, VMACS conference, University of Chicago Booth School of Business, the Hoover Institution, LSE POID workshop, ITAM seminar, the Productivity Institute conference September 2025 and the OECD productivity workshop. We are grateful for financial support from the UKRI/ESRC grants ES/P010385/1, ES/V004387/1, ES/V009478/1 and ES/V002740/1 and EU FP7 in developing previous versions of these data and to Kyoji Fukao and Tsutomu Miyagawa for kindly supplying the Japanese data. Stuart Campbell, Shivani Taneja, Jamie Lenney and Marilyne Tolle provided excellent research assistance. This paper is part of the Economic Statistics Centre of Excellence's (ESCoE) programme of research which is supported by the Office for National Statistics. Errors and opinions are our own.

1 Introduction

Large shocks test an economy's ability to adapt, adjust, and continue production – a capability called "resilience" – in response to the unexpected. Technologies, factors, and skills may be fixed, at least in the short run. Critical infrastructure may be damaged or unavailable, leaving other systems stretched beyond capacity. Whether a natural disaster, terrorism or cyber-attacks, or a global pandemic, the severity of a crisis is determined not only by the size of the shock, but also by the resilience of the response. Accordingly, risk professionals, regulators, and others emphasize the development of resilience (or "business resilience" in the private sector) as a buffer against such shocks. This often includes redundant critical systems, cross-training employees, and interestingly, back up work locations.

Although now five years behind us, the COVID-19 economic and health crisis offers a unique opportunity to explore business resilience in the face of a shock that greatly stressed all these preparations, but in some cases also elicited unplanned capacity in unexpected places. We argue that fungibility of factors of production at different locations contributed substantially to economic resilience during the pandemic. This required not only the much-discussed ability of some (fortunate) workers to work from home, but also the capital they needed to deploy from these remote-from-work locations, including the capital that connects them to each other and the workplace. We call this "Potential Capital".[1] Conceptually, it is the equipment – home offices, laptop computers and internet connections – that can be combined with remote-from-workplace labor to produce output.

The pandemic is a useful episode to explore this phenomenon because it was one of the largest economic shocks in living memory – the largest in three hundred years for some countries.[2] The blue bars in figure 1, show the peak to trough (2020Q1 to Q2) actual decline in GDP for the thirteen countries we study in this paper. The decline is dramatic: it shows quarterly declines of between 6 and 23 log points.[3] Yet, catastrophic as the collapse was, it could have been worse. Many workplaces were closed and people were advised to isolate and to work from home (WFH). As we shall document, since much of the workforce was working from home, there was a fall in hours *at the workplace* of around 24 log points from 2020Q1 to 2020Q2 (an unweighted average in our thirteen countries). Based on an output elasticity of two-thirds, output should have fallen by 16 log points, far more than the actual (average) drop of 12 log points. Thus, the first puzzle: why did output fall by so *little* in response to these large changes in hours at the workplace? Was it buffered by economic resilience arising from remote labor?

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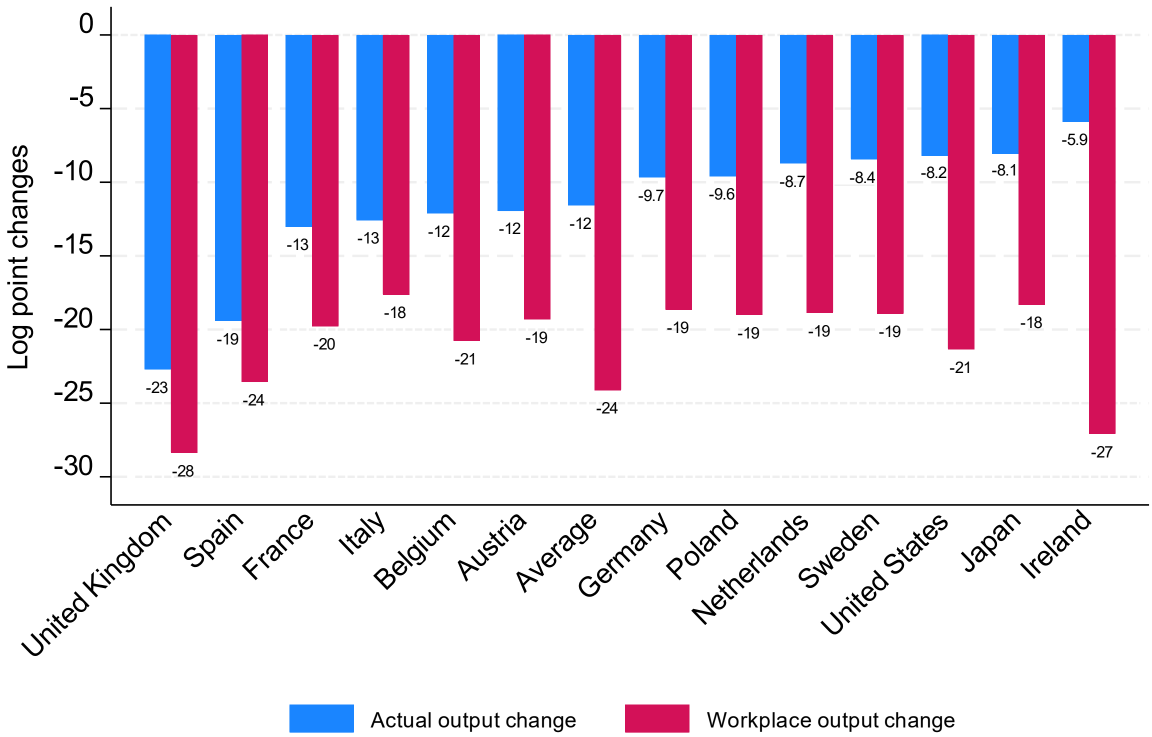
[1] Given this capital was pre-existing but unused, we call the capital at home "potential capital" because it was domestically-located capital and was capable of being deployed in business activities but had not previously been used for work purposes.

[2] Wall Street Journal Feb 12, 2021, U.K. Economy Suffers Biggest Slump in 300 Years Amid Covid-19 Lockdowns.

[3] We use natural log changes (times 100) throughout to be consistent with implementation of our growth accounting framework in section 2. For a change to y from x, the log point change = 100*ln(y/x).

A second puzzle emerges if we consider capital in addition to labor. As (Mokyr 2001) documents, the history of industrialization shows the point of going to the workplace is that workers require capital with which to work.[4] It seems hard to believe that the economy substituted a 24 log point fall of workplace hours with a rise in workplace capital in a matter of weeks. Rather, with fewer workers at the workplace, it seems very likely that workplace capital utilization also fell. Based on industrial electricity consumption, we estimate a fall in capital use at the workplace of just over 14 log points, which with an output elasticity of one-third, should have reduced output by a *further* 5 log points. Thus in Figure 1 the red bars, which are the implied workplace output changes, lie below blue bars illustrating our puzzle: why did actual output fall by so *little* in response to these large changes at the workplace? In eleven of the thirteen countries in Figure 1 the difference between actual output and workplace output averages 12 log points. Expanding our question above, was the decline in output further buffered by capital deployed from home?

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



Notes: Actual output is the decline in GDP from Q1 to Q2 of 2020 in National Accounts data. Workplace output is calculated based on factor use at the workplace, from Eurostat, BEA, National Accounts and own calculations, see data

[4] As (Mokyr 2001) also notes, 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.

appendix. Work from home from ONS and Google mobility data is described in the appendix. Average is an unweighted average of all countries.

The novelty we introduce in this paper in answer to these puzzles is that capital equipment and structures at home were brought into use for production providing the capacity to respond to a large unanticipated shock. During the pandemic, potential capital alongside labor working from home helped to offset the expected decline in output due to low workplace labor and capital utilization rates, which explains why output did not fall as much as it might have done. Production was buffered by use of capital and labor at home.

Once we recognize potential capital, it opens up new perspectives on several issues. First, it introduces a distinction that we will refer to repeatedly – that there is labor and capital in the workplace and labor and capital at home, and both can contribute to production. Not every industry is able to utilize labor at home and potential capital to the same extent, but the industries that can use them make enough of a contribution to output to make a difference at the national level (Bloom et al. 2020)(Bloom, Fletcher, and Yeh 2021). Thus, in this paper we seek to document the use of such capital at home alongside labor at home.[5]

Second, productive labor and capital at home gives firms flexibility to respond to a large shock like Covid-19. Fungibility between capital and labor at home and the workplace is often a source of economic resilience. This is made possible because the capital at home has both productive capacity (e.g. can run software) and connectivity with other workers making home working both possible and productive. It probably was not possible, or quite so productive, with technologies of earlier decades, but technology has advanced so that it is of lower cost now. One way to measure this value is to observe the value of the output that was not lost due to the resilience of the economy due to home output (as opposed to workplace output).

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, Davis and Meyer 2021; Haskel (2020); Mizen. Bloom and Taneja, 2020; Taneja, Mizen and Bloom, 2020; Taylor and Griffith 2020) and earlier by Bloom et al (2015), with 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 work from home, but there has been much less discussion of

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[5] This point is reminiscent of the GDP boundary issue, Coyle, 2014, namely that durable goods at home are a potential source of capital services for market-sector output. 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 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.

capital at home - which facilitates the ability of labor to work off-premises and buffers the impact of Covid-19.

Our main result is to document the extent to which labor and capital at home buffered the decline in workplace output, making aggregate output more resilient to the pandemic shock and resulting collapse in GDP, a quality emphasized by Brunnermeier (2021). We estimate that across our sample of countries, the resilience of domestic production that "saved" 12 log points of GDP 2020Q1-Q2 (Figure 1) consisted of a contribution from labor working remotely of 8 log points, and potential capital 3 log points. We further show this indicates an implied output elasticity of capital at home close to that of the value of business ICT (i.e. close to the average ICT capital rental share of GDP is 6%).

From these results we propose several areas for national statistics agencies to improve economic measurement. Our results show that TFP estimation can be distorted by ignoring output produced at home using potential capital and labor working remotely. Measured TFP growth during the pandemic was overstated in the UK and for most countries to a lesser extent when home inputs to production were not considered. The reason lies in the omission of home-produced output while fully counting employment ('as if' contributing labor entirely at the workplace). When producing future estimates of TFP steps could be taken to accurately record working from home. But this is not just an issue for the pandemic. While remote working has declined since its peak in 2020, it has not returned to pre-pandemic levels, therefore post pandemic estimates of TFP should also take into account labor that contributes to production from home. Steps to accurately record remote working, perhaps by developing labor market surveys or time use surveys, would be a welcome development, but our paper suggests a further step is required. Labor working remotely makes use of potential capital, therefore adjustment for the utilisation of domestic capital in production is also necessary to correctly compute TFP. Much of the potential capital utilized in production e.g. domestic computers and internet is currently treated as consumption expenditure, but it should be capitalised, and to do this national statistics agencies will need to undertake additional data collection to record business use of domestic capital.

The rest of the paper proceeds as follows. In the next section, we extend a growth accounting framework to allow for production at work and at home. We then use this structure to estimate TFP and the implied return to potential capital across a panel developed economies in Section 3. Section 4 draws together the findings and offers implications and conclusions.

2 Growth accounting

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. This is an extension of previous modelling in which growth accounting is robust to various types and sources of technical change (for example, Oulton (2007)), by allowing for both work-premises and home-based production. We use this to address a counter-factual: what would have happened to output had everyone who was at home had no capital with which to work?[6]

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)

$$Y = F(K^*_W, K^*_H, L^*_W, L^*_H), \tag{1}$$

where the stars denote flows of services including knowledge services. We will assume the standard structure for growth accounting and TFP estimation, that is, constant returns to scale, perfect competition, and optimizing behavior.[7] So as to isolate the effects of interest, the only deviation is to add home versus workplace production. Changes in output, Y, are therefore changes in the inputs times their output elasticities. We suppose that labor services, L^*, are hours and capital services, K^*, are capital (later we shall write capital services as product of capital stocks and capital utilization: we suppress this for now to ease notation).[8] Let superscripts W and H denotes workplace and home respectively and P_Y is the output deflator, we write

$$\frac{P_Y Y^W}{\sum P_Y Y} dy^W + \frac{P_Y Y^H}{\sum P_Y Y} dy^H = \varepsilon^L_Y \left(\varepsilon^{L^W}_L dl^W + \varepsilon^{L^H}_L dl^H \right) + \varepsilon^K_Y \left(\varepsilon^{K^W}_K dk^W + \varepsilon^{K^H}_K dk^H \right) + \frac{P_Y Y^W}{\sum P_Y Y} dtfp^W + \frac{P_Y Y^H}{\sum P_Y Y} dtfp^H, \tag{2}$$

where ε 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 (L^W and L^H), times the relevant elasticities, and similarly for capital services at work and at home (K^W and K^H), plus the contributions of total factor productivity at work and at home. If markets are competitive, and if labor and capital are paid for the use of their services, we can substitute the labor and capital elasticities for their shares giving:

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[6] We will also consider a counterfactual with no work from home, as the extreme case.

[7] While these assumptions are standard, they are not necessarily innocuous. (Crouzet and Eberly 2021a, 2021b) demonstrate the impact for TFP measurement of relaxing perfect competition and allowing for errors in capital measurement, which can be substantial.

[8] There are a host of issues around utilization 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.

$$dy = s^{P_L L}_{P_Y Y}\left[\frac{P_{L_W} L^W_W}{\sum P_L L} dl^W + \frac{P_{L_H} L^H_H}{\sum P_L L} dl^H\right] + s^{P_K K}_{P_Y Y}\left[\frac{P_{K_W} K^W_W}{\sum P_K K} dk^W + \frac{P_{K_H} K^H_H}{\sum P_K K} dk^H\right] + dtfp$$

where $s^{P_L L}_{P_Y Y} \equiv \frac{\sum P_L L}{\sum P_Y Y}$ and $s^{P_K K}_{P_Y Y} \equiv \frac{\sum P_K \boldsymbol{K}}{\sum P_Y Y}$. (3)

To get at the notion of resilience we rewrite the above in terms of the contribution of labor and capital at work and the additional contribution of labor at home and "potential capital" i.e. capital at home, namely

$$\begin{aligned} dy &= s^{P_L L}_{P_Y Y}\left(dl^W + \frac{P_{L_H} L^H}{\Sigma P_L L} d(l^H / l^W) \right) \\ &+ s^{P_K K}_{P_Y Y}\left(dk^W + \frac{P_{K_H} K^H}{\Sigma P_K K} d(k^H / k^W) \right) \\ &+ dtfp \end{aligned} \tag{4}$$

The first and third terms on the right hand side are the conventional production function terms, namely that dy results from dlW and dkW 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 Y 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 in Figure 1 is the first and third term and the offsetting effect of working from home and "potential" capital are the second and fourth terms.

3 Measurement

We attempt to measure the various terms for 13 developed countries. Data are drawn from the OECD, Eurostat, ONS and Bank of England, with fuller details provided in the data appendix. To measure the terms in equation (4), we measure output on the left-hand side as (change in log) GDP. On the right-hand side, we set the *L* and *K* shares as 2/3 and 1/3 respectively and 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.[9]

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

[9] 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 no 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.

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 WFH. Second, K^H is not just dwellings capital, but also 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, which we discuss further below.

Turning to the change in capital data it seems reasonable that the major source of change has been in utilization: official data for the UK at least shows almost no change in measured capital stocks or services: see Appendix.[10] One way to examine utilization this is to look at final commercial and domestic energy use (Flux 1913), corrected for seasonality and temperature, and excluding the output of the energy generation sector itself and (the very volatile) transport sector. For domestic capital use, we found that domestic energy use had hardly changed and so proxied log changes in domestic capital use by working from home, reflecting domestic utilization. Thus if we suppose that the log change in capital services $dk^* = dk + de$ where de is the change in log utilization, measured in turn by changes in energy use at work, we write

$$dy = \frac{2}{3}\left(dh^W + \overline{WFH}(dh^H - dh^W)\right) + \frac{1}{3}\left(de^W + \left(\overline{\frac{P_K K^{DWELL}}{\Sigma P_K K}}\right)(de^H - de^W)\right) \tag{8}$$
$$+dftp$$

where W and H superscripts apply to work and home factors, as previously, and DWELL refers to dwellings, or residential, capital, an overbar is a time average and $WFH = L^H/L$.

We have survey data by sector to measure the proportion of staff in the UK that employed but unable to work (this is referred to as 'furloughed workers' defined below), and we adjust our productivity estimates accordingly.[11] Other developed economies we do not have the same information about whether workers were WFH or temporarily suspended so the estimate of the 'effective furlough' by country is based on furlough proportions of employees in the same sector in the UK rescaled using Google mobility data for each country, as described in the data appendix.

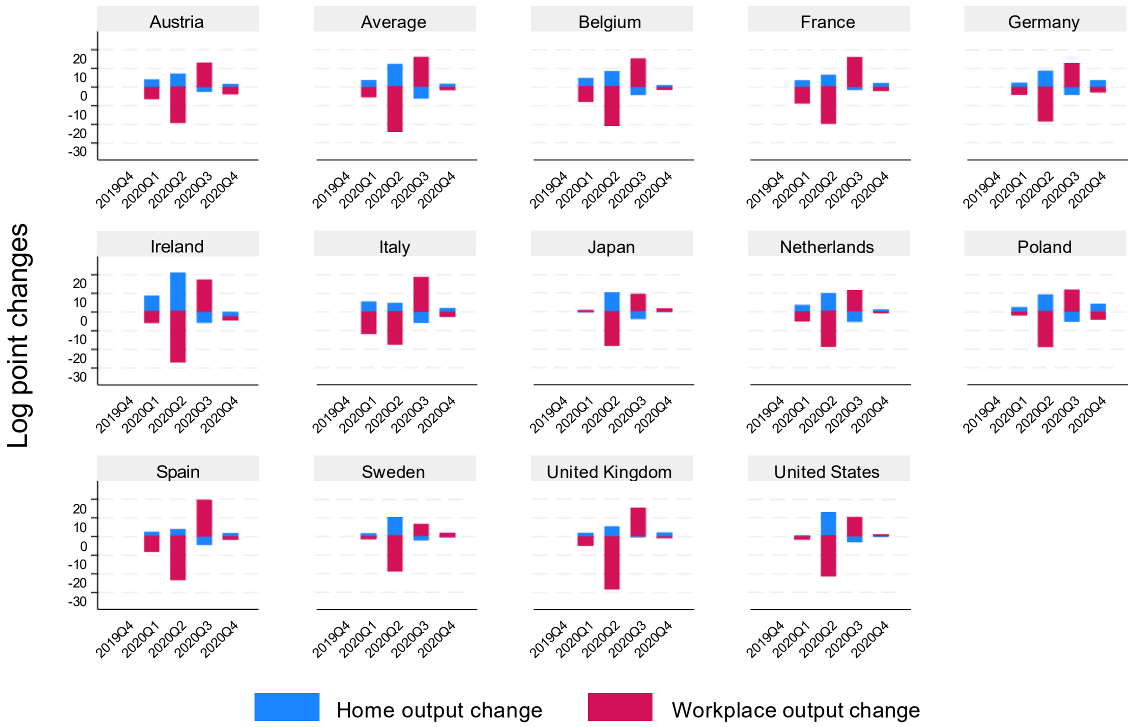
[10] The lack of change in capital over the period of the pandemic (https://www.ons.gov.uk/economy/grossdomesticproductgdp/bulletins/businessinvestment/apriltojune2021provisionalresults) is to be expected: although there has been minimal investment over the last four or five quarters, 74% of capital is dwellings, buildings and structures which depreciate very slowly. See Appendix for more details.

[11] Workers on furlough were not allowed to work. If they did work, but are not counted as working from home, we will overestimate the value created by those workers who did work from home. However, we find similar results in countries which did not have a furlough program, and where such a bias could not arise.

4 Evidence on output and TFP

We turn now to the results of the expanded growth accounting exercise. Figure 2 shows log point changes in home and workplace output, as in Figure 1, but for each quarter in 2020.[12] As the data show, in all countries, workplace output (red bars) fell in 2020Q1 and precipitously in 2020Q2 but this was offset in most countries by home working (blue bars), which meant actual output fell by less than output produced at the workplace. For example, in the UK workplace output fell by around 28 log points in 2020Q2, but this was offset by an 11 log point rise in home output. In the US, the workplace fall was 21 log points while the rise in home output was 6 log points. In Ireland, the workplace fall was 27 log points, and the rise in home output was 13 log points. After lockdowns were eased in the summer output rebounded across the board. As the blue bars show, home output rose in 2020Q1 and 2020Q2, demonstrating the resilience effect of working from home.

Figure 2: Changes in home and workplace output



[12] The "workplace output change" is the implied log change in workplace output defined as 0.66 and 0.33 times the log change in workplace labour and capital respectively (Figure 1 shows this for 2020Q2). "Home output change" is actual output change less this workplace output change.

Figure 3 shows the capital and labor contributions to changes in home output (blue bars) and workplace output (red bars).[13] As the red bars show, the use of inputs at the workplace fell in 2020Q1 and 2020Q2, rising in 2020Q3, and somewhat flatter in 2020Q4. The contributions from home inputs was the opposite: rising in 2020Q1 and Q2 and then falling. Notice that the contributions were considerable in 2020Q1 in all countries, especially in countries where the virus struck relatively early, such as Italy. The data are more mixed in 2020Q2, reflecting the later impact of the virus in the US and UK, where there was a substantial offset from the contribution of home output.

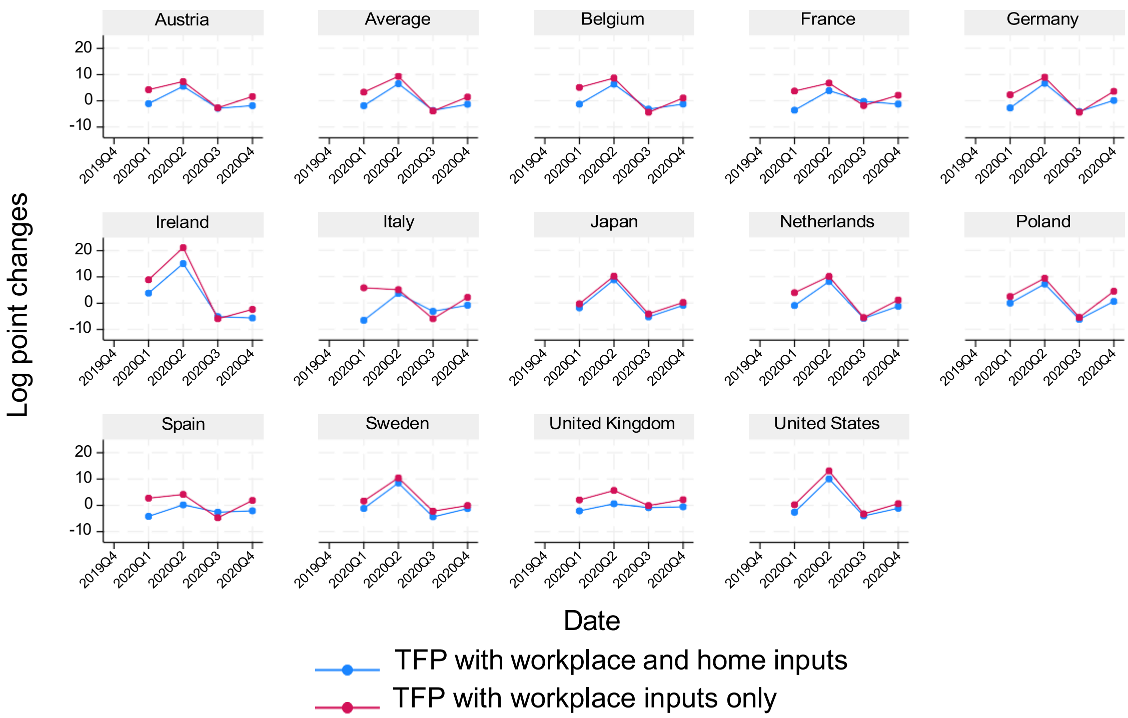
Figure 3: Capital and labor contributions to home and workplace output

Figure 4 plots the effect on TFP. We plot actual TFP with workplace and home inputs (blue lines) and TFP with only workplace inputs (red lines). Looking at the red lines, this generates an apparent rise in TFP in Italy, Spain and the UK in 2020Q1 and raises the productivity a degree in other many other countries. The average shows that all countries overstate the TPI increase if using only the workplace inputs (red lines) over the period 2020Q1 – 2020Q4, since most countries had a cushion from working from home that is unrecorded in this measure of TFP. That is, in those countries the “hidden” input from working from home is added to, and causes an apparent rise in, TFP. In subsequent quarters there is a

[13] These are calculated as, respectively, as 0.66 times the log changes in home and workplace labour and 0.33 times the log changes in home and workplace capital. The workplace contributions are therefore the same as workplace output changes in Figure 3.

large drop in workplace-based TFP that brings it back to the level for workplace and home inputs by 2020Q3, as resources switch back to the workplace. As the graph shows (blue lines), TFP calculated by observing actual output from workplace and home are lower in all cases for 2020Q2, and the almost the same or higher in 2020Q3. It is worth noting that Ireland is an outlier, with a productivity increase twice the size of the average in 2020Q2 and a decline in the following quarter that is also larger relative to the average. In subsequent analysis of changes in TFP we will look at results with and without Ireland.

Figure 4: TFP with and without home inputs



In sum, if WFH had been ignored along with potential capital, measured productivity internationally would have appeared to be exceptionally *strong* in 2020Q1 and 2020Q2, due to mismeasurement of labor and capital inputs to production of goods and services. Ignoring home capital would have been misconstrued as a productivity boom during the pandemic.

5 The Value of Potential Capital

So far we have used the value of dwellings to proxy the value of capital at home. But, as described, consumers have more capital at home than dwellings: the internet, home computers etc. On the assumption that consumers and not firms pay for this capital, it is a spillover to firms. We may ask: what is the implied value of that spillover? As a spillover it is part of measured TFP growth and so we attempt to value it as follows. The changes in capital at home that we measure (since we proxy by changes in home utilization) are changes in both dwellings (dk^{HD}) and non-dwellings (dk^{HxD}) capital, but weighted equally by the value of dwellings capital, so that measured capital services are

$$dk^{M} = s_K^W dk^W + s_K^H (dk^{HD} + dk^{HxD})$$
$$\text{where}$$
$$s_K^W = \left(\frac{P_K K^W}{P_K K^W + P_K K^H} \right), s_K^H = \left(\frac{P_K K^H}{P_K K^W + P_K K^H} \right) \tag{10}$$

Suppose however the true flow of capital services from non-dwellings home capital has a different elasticity, which we write as an addition/subtraction, γ, from the dwellings elasticity

$$dk^T = s_K^W dk^W + s_K^H (dk^{HD} + (1+\gamma) dk^{HxD}) \tag{11}$$

Measured TFP growth reflects this excess elasticity (along with other sources of mismeasurement) in the term scaled by γ

$$dtfp^M = dtfp + \gamma (s_K^H dk^{HxD}) \tag{12}$$

If we can proxy for underlying TFP and can estimate γ, then we can compute the capital elasticity and output elasticity of non-dwellings home capital, respectively $(1+\gamma)$ and $(1+\gamma)*(1/3)$, with the latter assuming that the total capital elasticity is one-third. This provides our estimate of the elasticities for potential capital. Thus our regression model is

$$dtfp^M_{i,t} = \gamma (s_K^H dk^H)_{i,t} + v_t + v_i + e_{i,t} \tag{13}$$

If *dtfp* and other country effects are captured by country/time dummies we can obtain an estimate of γ. The regressor is $s_K^H dk^H$ (in practice with no change in dwellings capital over this short time period, dk^{HxD} is driven by increased use of non-dwellings home capital).[14] Thus the identifying variation in this exercise is the large and unexpected change to working from home: our results would be upward-biased to the extent that households endogenously built up more domestic capital in anticipation of such a change.

[14] Other country effects, such as skilled labor or human capital, that might affect TFP, should be captured in the fixed effect dummies, as well.

The results of this exercise are set out in Table 1, where columns 1 and 2 include and exclude Ireland, respectively (as is well known, Irish capital stock and GDP is strongly affected over the cycle by changes in capital flows and our TFP charts earlier showed Ireland to be an outlier relative to the cross country average).

Table 1: Regression estimates of *(13)*

(dependent variable: $dtfp_{i,t}$)

VARIABLES	(1) With Ireland	(2) Without Ireland
$s_H{}^K dk^H$	-0.553*	-0.774***
	(0.268)	(0.166)
Quarter FE?	Yes	Yes
Observations	52	48
Number of ctry	13	12
R-squared	0.777	0.882
Implied output elasticity	*0.15*	*0.08*

Notes to table. Robust t statistics in brackets: *** p<0.01, * p<0.1. Estimation period: 2020Q1 to 2020Q4. Estimation by random effects.

In both cases, the coefficient on the share $s_H{}^K dk^H$ is negative suggesting that non-dwellings home capital has a lower capital elasticity than dwellings capital, i.e. 1 + (-0.56) = 0.44, and 1 + (- 0.77) = 0.23 meaning a capital elasticity around one half to one fifth of dwellings capital. The implied output elasticity is one-third of this, see the final row, giving an implied “value” of non-dwellings home capital of about 8-15%, though the standard errors are large. For reference, the output elasticity of business ICT, as measured by the ICT rental factor share, is around 6% in advanced economies ((Oulton 2012, Chart 1), so, interestingly, the lower estimate suggests a near-equal contribution from home non-dwellings capital.

6 Conclusions

Home capital and home working proved over the pandemic to be a source of economic resilience. Following one of the largest economic shocks in living memory, our results emphasize the quantitative effects were not as large as they might have been due to the large-scale restructuring of production at pace. While these findings are instructive for our understanding of the pandemic episode itself, 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 safe working was nearly impossible during the pandemic. The correlation between WFH, 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 WFH may later manifest more broadly as remote work and outsourcing, from home or elsewhere or abroad.

Second, the pandemic has revealed under-utilized capital across the economy and across the globe. The gig economy previously uncovered and deployed some of this capacity, such as the part-time driver who uses their domestic vehicle for commercial rides. This reflects unused capacity in passenger vehicles, used only 5 percent of the time (Shoup 2011), or in unused accommodation, rooms, houses, and holiday homes available for rent. 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 pandemic . It 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 steady migration from in-person to online shopping, which was accelerated 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 is their preference ((Barrero, Bloom, Davis and Meyer 2021)), 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 connective technology is crucial. A desk and computer at home has little use for many of the production processes we describe unless it can reliably connect to other workers and their computers. This has been a defining feature of WFH since 2020, as compared to earlier, when we might have been using dial-up connection and analog phones. As Mokyr (2001) 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. ICT is the enabler, networker and facilitator that makes the connected capital worth more than the capital in isolation. 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.

The implications of all this are that improvements to our understanding of home production using potential capital and labor working remotely, require efforts on the part of the national statistics institutions to measure more accurate the amount of remote working that takes place and the domestic capital in business use. This will require new survey data on time use, labor markets and capital assets separated into location as well as type.

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Appendices

Appendix 1. International Data:

Quarterly data on output (GDP) from OECD's Quarterly National Accounts dataset, indexed to Q4 2019 within each country; employed persons and average hours worked are drawn from Eurostat. Person hours are predicted quarterly based on an OLS model regressing calendar- and seasonally- adjusted person hours (from the OECD Quarterly National Accounts dataset) on the same controls used for the proportion worked from home estimates. They are indexed to Q4 2019 within each country. The labour force participation data are for 2019 and come from the World Bank.

The proportion of people who work from home in each country is predicted quarterly, based on an OLS model regressing the proportion worked from home for France, Germany, Italy, Japan, Spain, the United Kingdom, and the United States (as estimated in Eberly et al, 2019), on the relative use of workplaces (from the Google mobility data), excess deaths as a proportion of national population in 2019 (from Our World in Data and the World Bank), and the share of job postings which have the option of remote work (from the OECD-Indeed remote postings dataset), for the full set of countries in our analysis, with country and quarter fixed effects.

Energy use to infer the capital used at work is drawn from UK government data for UK and Eurostat, indexed to Q4 2019 within each country. For Spain we rely on electricity usage data for firms, from (Bover et al. 2020). The energy use data are estimated quarterly and are regressed on the same controls used for the proportion worked from home estimates.

Dwellings/residential capital for 2015 is drawn from the OECD and national accounts. The data for Japan and the USA are re-scaled.

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.

Appendix 2. Effects of missing capital and labor services contributions.

Recall our main equation

$$\begin{aligned} dy = {} & \frac{\Sigma P_L L}{\Sigma P_Y Y}\left\{ dl^W + \frac{P_{L^H} L^H}{\Sigma P_L L} d(l^H / l^W) \right\} \\ & + \frac{\Sigma P_K K}{\Sigma P_Y Y}\left\{ dk^W + \frac{P_{K^H} K^H}{\Sigma P_K K} d(k^H / k^W) \right\} \\ & + dtfp \end{aligned}$$

We measure $L^W = (1-WFH)H, L^H = (WFH)H,$ where WFH is share of the labor force working from home and H total hours worked. For capital we measure $K^W = K^{xD} * E^W, K^H = K^D * PART * WFH$ where K^{xD} and K^D are capital excluding dwellings and dwellings respectively, E^W energy use at work and PART labor force participation. K^{xD} and K^D and PART are assumed constant in our sample. Thus for both capital and labor services we do not use payment weights for home and work, but quantity weights. To get a sense of the possible biases involved, suppose we can write labor services in terms of their heads and "quality" of heads $dl = dn + dq^L$. On the capital side, we have used energy to measure utilization. thus we can write

$$dy = \frac{2}{3}\left(dh^W + \cancel{WFH}(dh^H - dh^W)\right) + \frac{1}{3}\left(de^W + \left(\frac{P_K K^{DWELL}}{\Sigma P_K K} \right)(de^H - de^W) \right)$$

$$+dftp$$

$$+\frac{2}{3}\left(q^L + (s^{L^*,L^H} - s^{N,N^N})(dh^H - dh^W)\right) + \frac{1}{3}(dk)$$

$$where$$

$$s^{L^*,L^H} = \frac{P_{L_H} L^H}{\Sigma P_L L}, s^{N,N^N} = \frac{N^H}{\Sigma N}$$

Thus on the labor side, we have used labor quantities instead of services and labor quantity weights instead of service weights, thus our measured TFP is biased to the extent of (1) omitted quality changes and (2) differences between service and quantity weights. On the capital side, we have used utilization instead of capital services and hence our measured TFP is biased to the extent of omitted capital services not captured by utilization.

Regarding capital, the UK ONS produces quarterly capital services estimates (https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/multifactorproductivityexperimentalestimatesreferencetables) and (https://www.ons.gov.uk/file?uri=%2feconomy%2feconomicoutputandproductivity%2fproductivitymeasures%2fdatasets%2fmultifactorproductivityexperimentalestimatesreferencetables%2fcurrent/050721mfp01unlinked.xlsx), and finds contributions of capital services growth to be very small over the period with quarterly growth rates, in percentage points, starting 202Q1 of 0.1, -0.1. -0.03, 0.03, -0.12 (growth of capital services are almost exactly three times these numbers). This suggests omitted capital services growth, at least for the UK is small.

The contribution of labor composition is 0.45, 1.91, 0.14, -0.06, 0.08. Thus it is much larger in 2020Q2, mostly due to a very large rise in labor composition in arts, entertainment, recreation, which was the sector with the most furloughs (a quarterly rise of 6pppa against a pre-pandemic average change of 0.17pppa)).

There are two additional factors that might bias the results. First, if hours are not well measured. If total hours are measured as average hours per person pre-pandemic times persons, and if average hours per person have fallen over the pandemic, which they have, then total hours are wrong. Second, to measure trends in WFH outside the UK we use outside UK mobility data.