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Covid Economics will feature high quality analyses of economic aspects of the health crisis. However, the pandemic also raises a number of complex ethical issues. Economists tend to think about trade-offs, in this case lives vs. costs, patient selection at a time of scarcity, and more. In the spirit of academic freedom, neither the Editors of *Covid Economics* nor CEPR take a stand on these issues and therefore do not bear any responsibility for views expressed in the articles.

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The following journals have indicated that they will accept submissions of papers featured in *Covid Economics* because they are working papers. Most expect revised versions. This list will be updated regularly.

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Quarterly Journal of Economics

*Review of Corporate Finance Studies**

Review of Economics and Statistics

*Review of Economic Studies**

Review of Financial Studies

(*) Must be a significantly revised and extended version of the paper featured in *Covid Economics*.

Covid Economics
Vetted and Real-Time Papers

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Contents

Uncertainty of firms' economic outlook during the COVID-19 crisis[1]

Masayuki Morikawa[2]

This study documents firms' subjective uncertainty during the COVID-19 crisis in Japan using data from an original survey and publicly available government statistics. The contributions of this study are (1) the measurement of firms' uncertainty regarding their mid-term economic outlook as subjective confidence intervals, and (2) the comparison of firms' subjective uncertainty during the COVID-19 crisis with that of the Global Financial Crisis by using readily available official statistics. The results indicate that firms' subjective uncertainty increased substantially after the outbreak of the COVID-19 pandemic. The elevation of subjective uncertainty has been far more significant compared with the period of the Global Financial Crisis, although the deterioration of economic outlook during the COVID-19 crisis has been smaller. The COVID-19 crisis is characterized as an unprecedented uncertainty shock.

1 Introduction

This study documents firms' subjective uncertainty during the COVID-19 crisis in Japan using unique data sets. The uncertainty's negative impact on economic activities through the "wait-and-see" mechanism has been highlighted in the literature. Moreover, empirical evidence has been accumulated, particularly since the Global Financial Crisis (GFC). [3] Accurate and timely measurement of uncertainty is essential in assessing the COVID-19's impact on economic activity.

Since economic agents' subjective uncertainty is difficult to measure directly, many proxies of uncertainty have been developed and used in past empirical studies. The representative proxy measures of uncertainty are stock market volatility (e.g., VIX), prediction errors derived from econometric models (e.g., Jurado *et al*., 2015), firms' *ex-post* forecast errors (e.g., Bachmann *et al*., 2013), and an index constructed from newspaper articles' frequency regarding uncertainty (EPU Index; Baker *et al*., 2016).

These proxy measures have advantages and disadvantages. Theoretically, uncertainty measures should be ideally constructed from individual firms' point forecasts and probability distributions (Manski, 2004, 2018; Pesaran and Weale, 2006). The dispersed probability distribution can be directly interpreted as higher subjective uncertainty if such a measure is available. The Survey of Professional Forecasters in the United States, for example, has a long history of collecting forecasters' probability distributions of economic growth and inflation forecasts. At the firm- level, Guiso and Parigi (1999), Morikawa (2016), and Chen *et al*. (2020) have collected cross-sectional information about firms' probabilistic forecasts. More recently, official statistical surveys have started to ask about the subjective probability distribution of firms' business outlooks. Examples include the Management and Organizational Practices Survey (MOPS) in the United States and the JP-MOPS in Japan. Some firm surveys collect this information at monthly or quarterly frequencies (e.g., Coibion *et al*., 2018; Altig *et al*., 2020a; Bloom *et al*., 2020). [4]

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[3] See Bloom (2014) for a survey.

[4] Studies using survey questions regarding firms' subjective uncertainty, although different from subjective probability distribution, include Bontempi *et al*. (2010) and Bontempi (2016) for firms in Italy, and Buchheim *et al*. (2020a, 2020b) for firms in Germany. Bontempi *et al*. (2010) and Bontempi (2016) used the range between its minimum and maximum sales growth rate, expected one year-ahead, as the measure of uncertainty. The firm survey used in the work of Buchheim *et al*. (2020a, 2020b) questions the firms' subjective uncertainty using a scale ranging from 0 (low uncertainty) to 100 (high uncertainty).

Analyses of uncertainty during the COVID-19 pandemic have been increasing rapidly worldwide (e.g., Altig *et al*., 2020b; Baker *et al*., 2020; Ludvigson *et al*., 2020). Altig *et al*. (2020b) used monthly survey data for firms' subjective uncertainty. Specifically, the Survey of Business Uncertainty (SBU) for the United States and the Decision Maker Panel (DMP) for the United Kingdom are used in their study. They indicate that firms' subjective uncertainty over their one-year-ahead sales growth rate substantially increased in March and April 2020. However, it slightly decreased after May 2020.[5] The SBU and the DMP used in their study, which collect information about sales forecasts and their probability distributions, are ideally designed to capture firms' subjective uncertainty. However, different from other uncertainty proxies such as the VIX and EPU indices, it is impossible to compare with past uncertainty shocks, including the GFC, since these new surveys began in 2016 and 2017.

Regarding Japan, Shinohara *et al*. (2021) indicate the movements of various uncertainty measures covering the early period of the COVID-19 crisis. The measures included are stock market volatility (Nikkei Volatility Index), macroeconomic uncertainty index (Jurado *et al*., 2015), economic surprise index (Scotti, 2016), and EPU Index. All these uncertainty measures indicate an increase in uncertainty during the COVID-19 pandemic. However, firms' subjective uncertainty is not included in the analysis.

Therefore, this study documents Japanese firms' subjective uncertainty during the COVID-19 pandemic using two unique datasets. The first dataset was taken from an original firm survey which asked firms' point forecasts and subjective 90% confidence intervals regarding mid-term (five years) economic growth rate. The original firm survey was conducted before the pandemic (early 2019) and during the pandemic (late 2020). The second dataset is a long time-series of quarterly government statistics (the Business Outlook Survey) containing information about the subjective uncertainty of firms' short-term (one-quarter-ahead and two-quarters-ahead) economic outlook.

This study contributes to literature in two ways. First, it is true that firm surveys for collecting information about the subjective probability distribution of forecasts have been increasing. However, the application to firms' mid-term economic outlook before and after the COVID-19 crisis has been nonexistent. Second, a comparison of firms' subjective uncertainty during the

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[5] Altig *et al*. (2020b) documented uncertainty up to July 2020. According to the publicly available SBU and DMP data, subjective uncertainty over sales growth has continued to decrease until recently. However, the level of uncertainty is still higher than before the COVID-19 pandemic.

COVID-19 crisis and past shocks such as the GFC, using a long time-series of official statistical data, has not yet been presented.

The results indicate that firms' subjective uncertainty substantially increased after the outbreak of the COVID-19 pandemic. Although the deterioration of economic outlook during the COVID-19 crisis was less severe compared to what happened during the GFC, the increase in the subjective uncertainty was far larger. This finding indicates that these two shocks have very different characteristics. While the GFC was a huge first-moment shock, the COVID-19 crisis can be characterized as a severe second-moment (uncertainty) shock.

The remainder of this paper proceeds as follows. Section 2 explains the design of original firm survey and reports on the change in firms' mid-term economic outlook uncertainty before and during the COVID-19 pandemic. Section 3 explains the Business Outlook Survey and presents the time-series movements of firms' subjective uncertainty. Section 4 concludes the paper and discusses its implications.

2   Subjective uncertainty of mid-term economic growth forecast

2.1   Survey design

The firm-level data used in this section are taken from the "Survey of Corporate Management and Economic Policy" (SCMEP). The SCMEP is an original firm survey designed by the author. It is conducted by the Research Institute of Economy, Trade, and Industry (RIETI) from January to February 2019 and August to September 2020.[6] The 2019 SCMEP was sent to 15,000 Japanese firms. The firms were randomly selected from the registered list of the Basic Survey of the Japanese Business Structure and Activities (BSJBSA). The BSJBSA is an annual statistical survey conducted by the Ministry of Economy, Trade and Industry (METI).[7] The firms that are registered in the BSJBSA have at least 50 employees and a capital of at least 30 million yen belonging to the manufacturing, wholesale, retail, and service industries.

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[6] RIETI contracted out Tokyo Shoko Research, Ltd. to implement the survey.

[7] The SCMEP respondents were the managers themselves or departments that can write their opinions on their behalf. The results of the BSJBSA can be obtained from the METI website (https://www.meti.go.jp/english/statistics/tyo/kikatu/index.html).

The number of firms that responded to the 2019 SCMEP was 2,535. The 2020 SCMEP survey questionnaire was sent to firms that responded to the 2019 SCMEP. In the 2020 survey, the total number of firms that responded was 1,579. The following is the distribution by industry of the firms that responded to the 2020 survey: manufacturing 53.5%, information and communications 5.3%, wholesale 17.8%, retail 10.2%, service 9.0%, and others 4.2%. Concerning firm size (classified by capital over 100 million yen or less), 34.8% are large firms while 65.2% are small- and medium-sized firms.

The study's main survey items are the point forecast of Japan's economic growth rate for the next five years (on an annual basis) and the forecast's subjective 90% confidence interval. The first question is "What do you think Japan's annualized real economic growth rate will be for the next five years?" This question asks the respondent to answer with a specific figure, rounded up to the first decimal place. Concerning forecast uncertainty, the second question is "Of the following choices, what is the range wherein the forecast above has a 90% probability of being met?" The eight choices are less than ±0.1%, ±0.1-0.3%, ±0.3-0.5%, ±0.5-1.0%, ±1-2%, ±2-3%, ±3-5%, and ±5% or greater. Since some of the respondents answered the first question with extremely large absolute figures, we dropped the responses with absolute figures exceeding 10%.[8]

The 2020 survey contains a question regarding the firms' outlook for the end of the COVID-19 pandemic's timing. The question is "When do you think will the COVID-19 pandemic be resolved and when will you be able to resume business activities in the same way as you did before the COVID-19 outbreak?" The nine choices are September 2020, October–December 2020, January–March 2021, April–June 2021, July–September 2021, October–December 2021, first half of 2022, second half of 2022, and 2023 or beyond. In this study, we convert the answers to a continuous variable that indicates expected duration (quarters) of the COVID-19 crisis.[9]

2.2 Results

According to the tabulation, the means of mid-term economic growth forecasts in the 2019 and

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[8] In the 2019 and 2020 surveys, 17 and 83 observations were dropped, respectively.
[9] The length of quarters assigned to the choices are as follows: "September 2020"=0, "October-December 2020"=1, "January-March 2021"=2, "April-June 2021"=3, "July-September 2021"=4, "October-December 2021"=5, "First half of 2022"=6.5, "Second half of 2022"==8.5, and "2023 or beyond"=10.5.

2020 surveys are +0.4% and -0.5%, respectively. The forecasted mid-term economic growth rate declined by about 0.9% point after the COVID-19 pandemic. The distributions of the forecast's subjective uncertainty (90% confidence interval) are shown in **Table 1**. It is evident that the distribution shifted to the wider side of the confidence intervals. This indicates that firms' subjective uncertainty of mid-term economic growth increased substantially because of the COVID-19 pandemic.

Table 1. Distribution of subjective uncertainty in mid-term economic growth forecasts

	(1) 2019 survey	(2) 2020 survey
Less than ±0.1%	13.3%	4.5%
±0.1%～0.3%	12.8%	3.5%
±0.3%～0.5%	19.2%	13.2%
±0.5%～1%	27.2%	13.1%
±1%～2%	9.5%	14.6%
±2%～3%	4.7%	13.3%
±3%～5%	5.5%	16.7%
±5% or greater	7.6%	21.0%

Note: The categories are the annual economic growth rate's subjective 90% confidence intervals for the next five years.

When calculating the mean of confidence intervals by using the answer categories' central value (the maximum category is treated as ±6%), the figure increased from ±1.3% in 2019 to ±2.6% in 2020. The result is almost unchanged even if we limit the sample of firms responding to the two surveys. **Figure 1** depicts the means and subjective probability distributions of the representative firm's growth forecast by assuming a normal distribution. We can visually observe a large widening of the distribution's tails in 2020.

Table 2 presents the simple OLS regression results on the relationships between economic forecasts and the COVID-19 pandemic's expected duration. The coefficient of duration is negative and significant for economic growth forecast (column (1)), whereas it is negative and highly significant for forecast uncertainty (column (3)). The results are essentially unaffected when growth forecasts or uncertainty in the 2019 survey were included as control variables (columns (2) and (4)). However, the explanatory power of the expected duration until the end of the pandemic is limited as shown from the low R-squared value.

Figure 1. Representative firm's probability distribution of economic growth forecasts
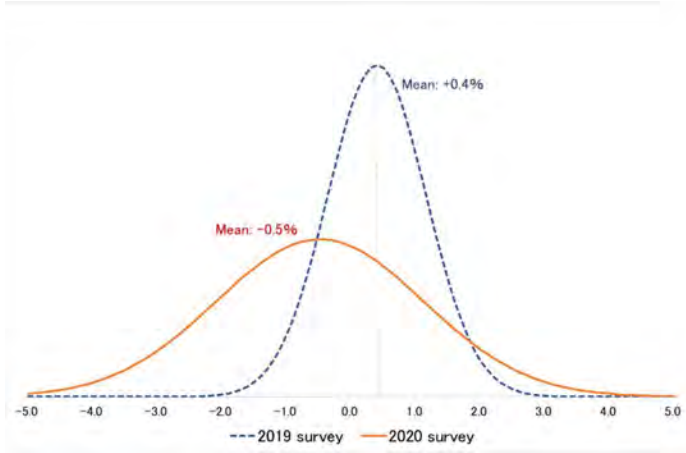
Notes: The figures are calculated from the point forecasts and 90% confidence intervals by assuming a normal distribution. The horizontal axis represents the annual economic growth rate.

Table 2. Expected duration until the end of the COVID-19 pandemic and the economic growth forecast and its uncertainty

	(1) $Growth^e_{2020}$	(2) $Growth^e_{2020}$	(3) $Uncertainty_{2020}$	(4) $Uncertainty_{2020}$
End of COVID-19^e	-0.0933 **	-0.0987 **	0.0730 ***	0.0821 ***
(Quarters)	(0.0371)	(0.0381)	(0.0232)	(0.0246)
$Growth^e_{2019}$		0.0802 ***		
		(0.0169)		
$Uncertainty_{2019}$				0.1198 ***
				(0.0404)
Nobs.	1,353	1,274	1,286	1,140
R^2	0.0046	0.0172	0.0075	0.0180

Notes: OLS estimations with robust standard errors are in parentheses. ***: <0.01, **: <0.05.

3. Long-run movements of subjective uncertainty

3.1 Business Outlook Survey

This section documents firms' subjective uncertainty using a published series of the Business Outlook Survey (BOS) from 2004Q2 to 2021Q2. The BOS, compiled jointly by the Cabinet Office and the Ministry of Finance, is a representative quarterly business survey in Japan along with the Bank of Japan's Tankan Survey (Short-Term Economic Survey of Enterprises in Japan). The BOS began in 2004 as a government statistical survey based on the Statistics Act. It covers incorporated firms with a capital of 10 million yen or more in all economic sectors. Approximately 15,000 firms were sampled in each survey. From the sample, about 80% responded on average.

The surveys were timed in the middle of February (Q1 survey), May (Q2 survey), August (Q3 survey), and November (Q4 survey). The results were released in the middle of March, June, September, and December, respectively. The BOS' questions include qualitative and quantitative items. Qualitative items include the expected business and economic conditions for the following two quarters. Quantitative items include planned and realized sales, profits, and investments. The present study focuses on the expectations for one-quarter-ahead and two-quarters-ahead domestic economic conditions.

As a unique characteristic of the BOS, the economic outlook choices include "unsure" in addition to "improvement," "no change," and "deterioration." These choices are used for calculating BSI (Business Survey Index). Specifically, BSI is calculated as the percentage of firms that chose "deterioration," subtracted from the percentages of firms that chose "improvement." Unlike other business surveys, the respondents can choose "unsure" when they are uncertain about the outlook. The percentages of firms that responded "unsure" have large time-series fluctuations. Although the BOS does not collect information on subjective probability distribution, the answer "unsure" represents subjective uncertainty about the near future of economy. [10] Since the percentage of firms responding "unsure" is being published, we can observe economic outlook (BSI) and uncertainty from the same publicly available survey data.

The BOS publishes tabulation results by firm size category (e.g., large, medium, and small) by industry (e.g., all, manufacturing, and non-manufacturing) quarterly. The present study calculates the figures for all firms by using the number of respondents, which is published by size categories,

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[10] Morikawa (2018), using BOS' firm-level panel data (2004Q2–2017Q1), indicates that the answer "unsure" is a practically useful measure of firms' subjective uncertainty. According to Morikawa (2018), the response "unsure" has positive correlations with other uncertainty proxies such as stock market volatility and the EPU index. Additionally, the response "unsure" has a negative association with the firm's actual investments.

as weights, because the results for all size categories have not been published.

It should be noted that the percentage of firms that responded "unsure" had a strong seasonality. In the case of a one-quarter-ahead outlook, the percentage of those that answered "unsure" is very high in the Q1 (February) survey. In the case of a two-quarters-ahead outlook, the percentage of firms that answered "unsure" is very high in the Q4 (November) survey. We conjecture that fiscal (accounting) years matter for observed seasonality. Second-quarter forecasts (April–June) are those for the different fiscal years at the forecasting time in most Japanese firms. Thus, it might be difficult for these Japanese firms to report a Q2 forecast based on an established annual business plan and related information.[11] Since it is preferable to adjust seasonality, we run simple OLS regressions using quarter dummies as explanatory variables and the residual series of the regressions are used for the analysis. The mean level is adjusted at the same time, because the regression includes the constant term.

3.2 Results

Figure 2 shows the BSI's time-series movements for domestic economic conditions after adjusting for seasonality. In the recent COVID-19 crisis, the BSI significantly deteriorated in the current quarter judgments. The magnitude of its deterioration was similar in size to the GFC period. However, in the cases of a one-quarter-ahead and two-quarters-ahead outlooks, the deterioration of economic outlook is more pronounced in the GFC period. **Figure 3** shows the seasonally adjusted series of the percentage of "unsure" responses, which is a measure of firms' subjective uncertainty. The figure jumped up between 2020Q1 and 2020Q2. After the first declaration of a State of Emergency in April 2020, firms' uncertainty over the Japanese Economy's future course was significantly increased.[12] The uncertainty increase for the two-quarters-ahead outlook is larger than that for the one-quarter-ahead outlook.

Similar to other major economies such as the United States, the stock market volatility (Nikkei VI) and the EPU index of Japan significantly increased in early 2020. However, these gradually decreased to the pre-pandemic levels by the end of 2020 (**Appendix Figure A1**). Conversely,

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[11] Most Japanese firms' accounting year begins in April.
[12] As stated before, the timing of the Q1 and Q2 surveys are the middle of February and May, respectively.

firms' subjective uncertainty remains at a very high level, even in 2021Q2. The recent increase in uncertainty has been far larger when compared with the periods of the GFC. On the other hand, the deterioration of one-quarter-ahead and two-quarters-ahead BSI was far larger during the GFC.

Figure 2. BSI of economic condition

Note: Seasonally-adjusted series for all size categories.

Figure 3. Uncertainty of economic condition

Note: Seasonally-adjusted series for all size categories.

Table 3 presents a comparison between the two crises. The GFC figures are the means from 2008Q3 to 2009Q2 and the COVID-19 crisis figures are the means from 2020Q2 to 2021Q2. The table suggests, from a viewpoint of business operation, that these two shocks are very different even though both shocks seriously affected the economy. Specifically, the GFC is characterized as a first-moment shock that firms predicted with certainty the economy's deterioration. However, the COVID crisis is characterized as a second-moment shock (or uncertainty shock), where the economy's future course is difficult to predict.

Table 3. Comparison of BSI and uncertainty in the GFC and the COVID-19 crisis

	(1) 1 quarter-ahead		(2) 2 quarters-ahead	
	BSI	Uncertainty	BSI	Uncertainty
GFC	-33.5	-2.4	-19.3	1.8
COVID-19	-13.7	10.4	-3.7	13.3

Notes: The tables are calculated from seasonally adjusted series for all size categories. GFC's percentage is the mean of the period from 2008Q3 to 2009Q2. The percentage of the COVID-19 crisis is the period's mean from 2020Q2 to 2021Q2.

Appendix Figure A2 depicts the seasonally adjusted series of one-quarter-ahead subjective uncertainty by industry (manufacturing and non-manufacturing). **Appendix Figure A3** shows the series of two-quarters-ahead subjective uncertainty. These figures indicate that the industry differences are surprisingly small. Service industries such as hotels and accommodations, restaurants, and personal transportation services were seriously affected by the pandemic's spread and the execution of policy measures that restricted the people's movement. However, the movements of subjective uncertainty of non-manufacturing industry as a whole are not significantly different from those of manufacturing industry.

Previous studies have indicated that an increase in uncertainty has a negative effect on investments through the option value mechanism of waiting.[13] We analyze the relationship between the percentage of "unsure" responses and investments to verify this relationship at the

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[13] Morikawa (2018), using firm-level micro data of the BOS, shows that the response "unsure" has a significant negative association with firms' actual investments.

aggregate level. Seasonally adjusted real quarterly investment and GDP data are taken from the National Accounts (Cabinet Office). The log-transformed series of investment are used as the dependent variable ($lnINV_t$). The explanatory variables are the percentage of "unsure" responses ($Unsure_{t, t+n}$), BSI index ($BSI_{t, t+n}$), log GDP ($lnGDP_t$) of the current quarter, and lagged investment ($lnINV_{t-1}$). "Unsure" responses and the BSI are for the one-quarter-ahead (n=1) or two-quarters-ahead (n=2) economic conditions. This specification is based on the idea that investments depend on the economic activity's (GDP) current level, inertia in investments, expectation of future economic conditions (BSI), and uncertainty. Hence, the equation to be estimated is expressed as follows:

$$lnINV_t = \alpha lnGDP_t + \beta lnINV_{t-1} + \gamma BSI_{t, t+n} + \delta Unsure_{t, t+n} + \varepsilon_t \tag{1}$$

Table 4. Firms' subjective uncertainty and investment

	(1)	(2)
$lnGDP_t$	0.5647 ***	0.5063 ***
	(0.0893)	(0.0753)
$BSI_{t, t+1}$	0.0003 **	
	(0.0001)	
$Unsure_{t, t+1}$	-0.0016 ***	
	(0.0005)	
$BSI_{t, t+2}$		0.0005 **
		(0.0002)
$Unsure_{t, t+2}$		-0.0013 ***
		(0.0004)
$lnINV_{t-1}$	0.7435 ***	0.7517 ***
	(0.0400)	(0.0364)
Nobs.	67	67
R^2	0.9535	0.9537

Notes: OLS estimations with robust standard errors are in parentheses. ***: 0.01, **: <0.05. The dependent variable is the current quarter's log investment ($lnINV_t$). $BSI_{t, t+1}$ and $BSI_{t, t+2}$ denote one-quarter and two-quarters-ahead economic condition BSI (seasonally adjusted), respectively. $Unsure_{t, t+1}$ and $Unsure_{t, t+2}$ denote quarter-and two-quarters-ahead uncertainty (seasonally adjusted), respectively.

Table 4 presents the results of the OLS estimation. As expected, the *BSI* coefficients are positive and the *Unsure* coefficients are negative. Both are significant in one-quarter- and two-quarters-ahead outlook for economic conditions. The results suggest that heightened uncertainty over future economic conditions suppresses investments in the current quarter. However, the quantitative impact of uncertainty on investments is not large, at least at the aggregate level. A one-standard-deviation greater uncertainty is associated with approximately 0.7% lower investments. As reported in **Table 3**, "unsure" responses are 10.4% points (one-quarter-ahead outlook) and 13.3% points (two quarters-ahead outlook) higher than the historical average during the COVID-19 crisis period (2020Q2–2021Q2). According to the estimated *Unsure* coefficients, elevated uncertainty's impacts in this period may have reduced aggregate investments by about 1.6–1.7%.

4 Conclusion

This study presents descriptive observations of Japanese firms' subjective uncertainty during the COVID-19 pandemic. It used micro data from an original firm survey and publicly available aggregate data from government statistics. The contributions of this study are (1) the measurement of firms' uncertainty regarding their mid-term economic outlook as subjective confidence intervals, and (2) the comparison of firms' subjective uncertainty during the COVID-19 crisis with that of the GFC by using representative and readily available official statistics.

The main results are summarized as follows. First, firms' subjective uncertainty for mid-term economic growth, measured as point forecasts' subjective confidence intervals, substantially increased after COVID-19's outbreak. Second, firms' subjective uncertainty has continued to be high even in 2021. This finding is distinct from the observations from other uncertainty proxies such as stock market volatility and the EPU index. Third, although the economic outlook's deterioration during the COVID-19 crisis has been less severe than the GFC period, the elevation of the subjective uncertainty has been far more significant. This finding indicates that the two shocks are very different from a viewpoint of business operation. While the GFC was a huge first-moment shock, the COVID-19 crisis can be characterized as an unprecedented second-moment (uncertainty) shock.

The results of this study imply that the "unsure" response in the BOS contains valuable

information to capture firms' subjective uncertainty. An essential advantage of this publicly available data is its immediate availability at the time of release without waiting for the next quarter. This is different from uncertainty measures based on *ex-post* forecast errors. An obvious policy implication is that it is desirable to avoid the further increase in economic agents' uncertainty when designing policy measures in tackling the pandemic, even though huge uncertainty is inevitable.

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Appendix Figure A1. Movements of Nikkei Volatility Index and EPU Index for Japan
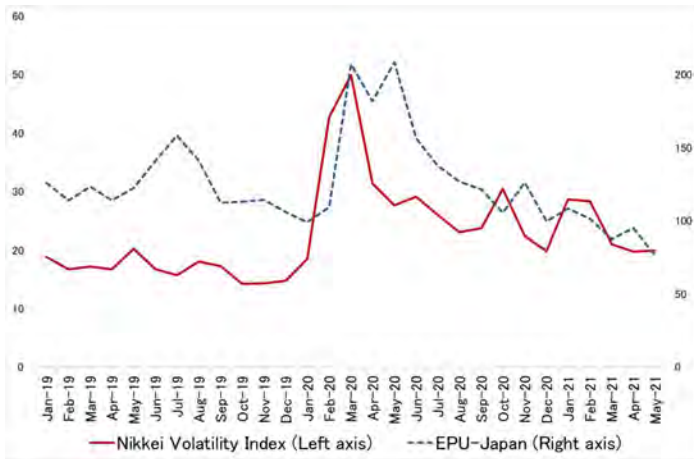
Note: The construction of the EPU-Japan Index is documented in Arbatli *et al*. (2017).

Appendix Figure A2. One-quarter-ahead uncertainty by industry

Note: Seasonally-adjusted series for all size categories.

Appendix Figure A3. Two-quarters-ahead uncertainty by industry
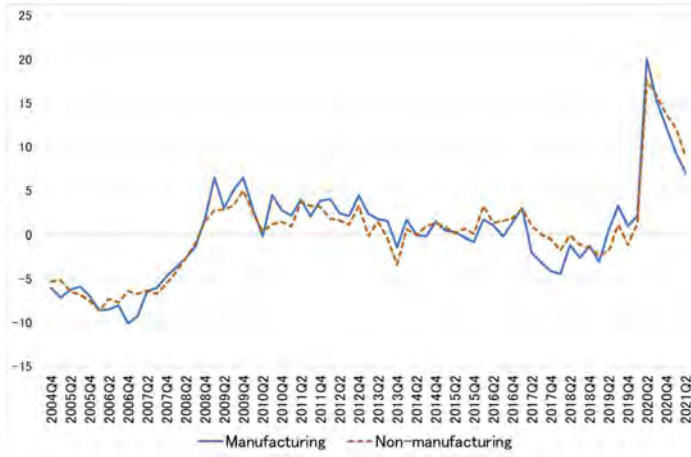
Note: Seasonally-adjusted series for all size categories.

Neither backlash nor convergence: Dynamics of intra-couple childcare division after the first COVID-19 lockdown and subsequent reopening in Germany

Christina Boll,[1] Dana Müller[2] and Simone Schüller[3]

Using unique monthly panel data (IAB-HOPP) covering the immediate post-lockdown period from June to August 2020, we investigate opposing claims of widening/closing the gender gap in parental childcare during the COVID-19 pandemic in Germany. We consider pre-pandemic division as a reference point and provide dynamics rather than snapshots. Our results suggest a slight shift toward a more egalitarian division in June that, however, faded out in subsequent months. Starting from a fairly "traditional" pre-pandemic childcare division, the lockdown stimulus was not nearly strong enough to level the playing field. Subgroup analysis differentiating between individual lockdown-specific work arrangements shows that the drivers of the observed shift were mothers with relatively intense labor market participation who cannot work from home. Fathers' work arrangement instead did not play a significant role. We conclude that the shift emerged out of necessity rather than opportunity, which makes it likely to fade once the necessity vanishes.

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1 Introduction

Recent efforts toward gender equality within society at large and the vital debate on digitization as a potential gender equalizer during the pandemic and thereafter stand in stark contrast to the persistent gender inequalities present in the private sphere. The unequal division of childcare attracts particular attention since childcare is – unlike housework – of limited substitutability, scalability and delay. At the same time, locked-down daycare facilities and schools have put parents of young children under particularly high pressure during the ongoing pandemic. Surrounding the effects of the COVID-19 crisis on the childcare division among couples, the scientific debate stretches between two opposed expectations, namely, the 'backlash notion' and the 'convergence notion'. On the one hand, it is hoped that a considerable number of bread-earning fathers will get to know and appreciate family care work at home and thus permanently increase their share of such work (Alon *et al.*, 2020; Arntz *et al.*, 2020; Hupkau/Petrongolo, 2020). On the other hand, there are fears of a massive relapse into a traditional pattern of behavior (Allmendinger, 2020; Kohlrausch/Zucco, 2020; Müller *et al.*, 2020). To date, most studies only provide snap shots of the acute lockdown situation; if they longitudinally incorporate the prepandemic situation, they seldom take couple constellations into account.

This study provides novel evidence on the effect of the COVID-19 crisis on intracouple childcare division. Referring to the theoretical underpinnings of intracouple bargaining over childcare division, the current study makes two contributions to the literature. First, we use prepandemic childcare division as a reference point to elucidate behavioral changes over time. Second, a high-frequency longitudinal scope allows us to investigate the dynamics and the durability of the observed changes approximately five months beyond the acute lockdown, i.e., until August 2020.

We employ unique monthly panel data covering the period of gradual reopening after Germany's first COVID-19 lockdown in spring 2020 up until August. Based on a sample of about 1,120 parents, we find an only small and temporary shift toward increased paternal childcare participation. The main driver for this shift consists of mothers with relatively intense labor market participation who cannot work from home. The work arrangement of fathers instead does not play a significant role, which suggests that the small shift we observe emerged out of *necessity* (since mothers cannot take over childcare) and not out of *opportunity* (enabling fathers to increase their share). It comes as no surprise that such shift may fade once the necessity vanishes. Overall, our results support neither the 'backlash' nor the 'convergence' notion put forward in the current debate, but rather evidence a striking degree of stability in intracouple childcare arrangements.

The paper is structured as follows: Section 2 reviews the theoretical background and empirical findings on intracouple childcare division and develops hypotheses for the pandemic context; Section 3 introduces the data used and describes sample selection and variables; Section 4 presents the empirical setup; and Section 5 reports and discusses the results. The final section concludes.

2 Theories on Intracouple Childcare Division and Empirical Findings

Among the most influential theories for the division of labor in couples documented in the literature are the relative time budget of the partners, the relative human capital of the partners (education, income) and the gender norms prevailing in the couple (e.g., Boll, 2017; Beblo/Boll, 2014; Beblo, 2001). The time mechanism is grounded in the '*time availability*' approach (Shelton, 1992). The higher one's involvement in gainful employment is, the less time one has available for unpaid work. This approach emphasizes the importance of path dependence and the inertia of adjustment mechanisms resulting from habituation to established patterns and adjustment costs

(e.g., when changing employment contracts). Partners' relative earnings, in combination with their relative productivity for domestic work, give rise to the comparative advantage of partners for market or domestic work, based on the *unitary model of new household economics* (Becker, 1965). *Cooperative bargaining theories* (McElroy/Horney, 1981; Manser/Brown, 1980) come to the same conclusion, albeit based on a different rationale; here, higher human capital reflects a higher bargaining position within the couple in regard to (re)negotiations of domestic work. *'Gender display' or 'doing gender' theories* assume that behavior constructs gender identity and that people therefore prefer behavior that conforms to gender stereotypes, thereby avoiding stereotype-averse behavior (West/Zimmermann, 1987; Berk, 1985). Traditional gender roles are still quite common in Germany, more so in the western part of the country than in the eastern part (Schmitt/Trappe, 2014; Wenzel, 2010; Cooke, 2007).

The aforementioned theories differently advocate the arguments exchanged in the current COVID-19 debate that juggle between 'backlash' and 'convergence'. Referring to prevalent traditional norms, proponents of the 'backlash' thesis argue that women will be held responsible to address the "sudden spike in childcare needs" (Alon *et al.,* 2020, p. 11f.), which will result in the retraditionalization of formerly egalitarian couples during the lockdown (in a similar vein: Kohlrausch/Zucco, 2020). In fact, survey results for Germany from the early phase of the pandemic suggest that working mothers reduced their workload relatively more than did fathers to meet the additional childcare needs caused by the pandemic (Bünning *et al.* 2020), that teleworking mothers spent more hours on childcare than did teleworking fathers (Adams-Prassl *et al.*, 2020), and that full-time employed mothers increased their time spent on childcare in April 2020 by more than fathers, compared to the previous year (Zinn, 2020). Consequently, mothers were more likely (than before the pandemic and more likely than fathers) to feel heavily stressed with childcare tasks

(Fuchs-Schündeln/Stephan, 2020). Time availability and economic rationales are further plausible explanations for the observed care arrangements; women have been hit harder by employment drops than men in the current crisis (Hammerschmid *et al*., 2020). Marginal employment (so-called 'Minijobs'), in which women prevail, has been significantly reduced under the pandemic (Deutsche Rentenversicherung Knappschaft Bahn-See/Minijobzentrale, 2020a). Depending on the household context, it can be assumed that some women will refrain from a new job search upon economic recovery if the money is not needed to make ends meet (Fuchs *et al*., 2020). Due to traditional gender roles and a persistent earnings disadvantage against men, women are still lagging behind in terms of career perspectives. Thus, for some couples, having the mother step in seems economically reasonable.[1]

However, the results from surveys during the first COVID-19 lockdown indicate that fathers also expanded the time they spent with their children (Kreyenfeld/Zinn, 2021, Hank/Steinbach, 2020) and that a higher share of fathers – and a lower share of mothers – saw themselves in the role of primary caregivers compared to the prepandemic period (Kohlrausch/Zucco, 2020 for the time from 3 to 14 April, 2020; similarly Zinn *et al.*, 2020). These empirics motivate the 'convergence notion' by suggesting that increased paternal engagement could help to narrow down the gender divide in childcare responsibilities. The related optimism is further grounded in the fact that women are overrepresented in systemically relevant jobs, which cannot be done from home. This holds true for occupations in the health care and social sector, where 77 percent of the employees are women (Bundesagentur für Arbeit, 2019). Based on SOEP 2018 data, the share of couples in which only the mother has a systemically relevant job is approximately 16 percent (Boll/Schüller,

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[1] For an evaluation of the economic situation of families between mid-March and mid-May 2020 see, e.g., Boll (2020), and for a discussion of political measures with respect to gender equality Schmieder and Wrohlich (2020).

2020). It is exactly this situation […] "where the father is able/forced to work from home during the crisis, while the mother is not" […] from which Alon *et al.* (2020, p. 21f.) expect the biggest impact on the intracouple labor division. However, though quite optimistic regarding the upward shift in fathers' participation, the authors do not rule out that the phenomenon could be temporary (p. 22).

Indeed, referring to the theoretical literature, couples' initial conditions should matter. The formation of expectations regarding the parental division of labor after the COVID-19 crisis requires an analysis of the prepandemic constellations. Behavioral adjustments, i.e., learning new role models within the couple, entails symbolic and/or economic costs.[2] Paternal agents might avoid those costs and, instead, frame their additional childcare engagement as temporary "emergency care", which ends when the emergency ends, i.e., after the reopening of daycare facilities and schools. It is therefore by no means evident, either in the short-term or the medium-term, that paternal care will increase in cases where there was little involvement prepandemic ('convergence notion') or that paternal care will decrease where childcare arrangements were previously more egalitarian ('retraditionalization notion').

This study makes a twofold contribution to the literature. First, unlike previous studies, which mostly provide snapshots of the situation during the pandemic, we observe and employ the prepandemic couple division of childcare as a reference point to evaluate the dynamics over time and to scrutinize possible retraditionalization and convergence trends. Second, the high-frequency

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[2] Cognitive psychology points to further barriers to behavioral adjustments (cf. Caspi/Moffitt, 1993, p. 247f.); people's interpretation of new experiences is influenced by pre-existing schemes that help us categorize and organize (Nisbett/Ross, 1980) and maintaining organism integrity (Menninger, 1954). In uncertain situations, with a strong press to behave, learning a new response might be costly and the second best strategy only if innate defense reactions are unavailable or prove to be unsuccessful (Bolles, 1970).

panel data covering the period of gradual reopening after Germany's first COVID-19 lockdown until August 2020 allow us to test the sustainability of short-term shifts in the medium term.

Hypotheses

H1. (Childcare specificity) We suppose for the aforementioned reasons that the childcare shift is greater than the shift in other forms of unpaid work.

H2. (Initial conditions) We expect that initial conditions in terms of norms and relative resources that shape parental behavior prepandemic and are proxied by the initial childcare division remain decisive under the crisis. Specifically, the more pronounced the gender asymmetry in childcare division was prepandemic, the less likely and the less persistent the significant change should be thereafter. This also means that there should be no significant shift for previously egalitarian couples.

H3. (Dynamics: Opportunities and necessities arising from work arrangements) Both a low labor market involvement in terms of employment status and hours and the opportunity to work from home during the lockdown provide additional time resources that should relate to a more strongly increased childcare involvement of the respective parent, hence to a more (less) equal division of childcare, compared to the prepandemic situation, in case that the parent is a father (mother). This is what we would expect short-term. A persistent childcare shift would require a permanent shift in parents' relative resources.

3 Data, Sample and Variables

3.1 Data

To investigate the postlockdown dynamics of the division of labor within parental couples in Germany, we employ unique data from the IAB High-Frequency Online Personal Panel (HOPP), which is a monthly[3] online panel survey developed by the Institute for Employment Research (IAB). This panel survey has been developed to investigate how the COVID-19 pandemic affects individuals in the German labor market (Sakshaug *et al.*, 2020).[4] HOPP is based on a random sample of 200,000 individuals, which was drawn from the Integrated Employment Biographies (IEB) of the IAB. The IEB includes the universe of employees subject to social insurance contributions, registered unemployed individuals, unemployment and welfare benefit recipients, and job seekers. Thus, HOPP is representative of the employable population in Germany. Furthermore, the survey data can be linked to the administrative data of the IAB if the respondents provided informed consent for such linkage. The data and data documentation will be provided internationally at the Research Data Centre (FDZ) of the German Federal Employment Agency (BA) at the Institute for Employment Research (IAB) in the near future.

We use the 2020 May, June, July, and August waves, in which approximately 11,500 individuals (mainly employees subject to social insurance contributions) participated at least once in the survey and reported changes in their social, family and working lives in the course of the COVID-19 pandemic.

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[3] After the August 2020 wave, the panel became bimonthly.
[4] A short survey description can be found at https://www.iab-forum.de/glossar/hopp-befragung/?pdf=17949 and several data tables on special content are available at http://doku.iab.de/arbeitsmarktdaten/ADuI_hopp_aktuell.xlsx (only in German).

3.2 Sample

We restrict our analysis sample to couples with at least one child below the age of 12 because those children are defined as being necessitative of childcare, according to the Infection Protection Act (§56, Abs.1a). We consider two subsamples. The first subsample is an unbalanced panel of mothers and fathers who were interviewed at least in May and June 2020, including a total of 2,795 person-period observations (1,120 individuals). The second subsample is a balanced panel of 269 mothers and fathers, who were interviewed in all waves between May and August, resulting in 1,075 person-period observations (see Table 1 for summary statistics). When considering lockdown-specific work arrangements, the sample slightly reduces to 1,112 (267) mothers and fathers in the unbalanced (balanced) version. In line with the literature, we consider the time before 19 March 2020 as the prepandemic period. Although the reopening after the first COVID-19 lockdown started at the end of April 2020, this reopening was gradual, and the reopening of childcare facilities was especially prolonged – in a phase of "extended emergency childcare" – over the entire month of May before most federal states switched to a phase of "restricted normal operation" (see Figure 1). Thus, we define the period spanning from 19 March to the end of May 2020 as the (extended) lockdown period.

Table 1. Summary statistics.

	Full Sample				Mothers				Fathers			
	unbalanced		balanced		unbalanced		balanced		unbalanced		balanced	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Parental division of childcare*	3.786	0.948	3.797	0.954	3.886	0.970	3.916	0.978	3.674	0.916	3.647	0.907
Parental division of childcare, dichotomized (in Percent)⌁:												
Predominantly/entirely father	7.084	25.660	7.342	26.095								
Predominantly/entirely mother	62.075	48.529	62.361	48.471								
Entirely mother	25.581	43.640	26.487	44.147								
Both parents equally	30.841	46.192	30.297	45.976								
Parental division of housework*	3.772	0.886	3.787	0.920								
Parental division of shopping*	3.264	1.214	3.367	1.220								
Female	0.523	0.500	0.554	0.497								
Lockdown-specific work arrangements (as of HOPP wave May 2020)												
>20 work hrs, remote work possible					0.362	0.481	0.372	0.484	0.610	0.488	0.622	0.485
>20 work hrs, remote work not possible					0.129	0.335	0.122	0.327	0.246	0.431	0.252	0.435
<=20 work hrs					0.322	0.467	0.304	0.460	0.098	0.297	0.092	0.290
not employed					0.187	0.390	0.203	0.402	0.046	0.210	0.034	0.180
Age 18–29	0.041	0.199	0.041	0.199	0.057	0.231	0.059	0.236	0.024	0.153	0.019	0.136
Age 30–39	0.502	0.500	0.514	0.500	0.557	0.497	0.551	0.498	0.441	0.497	0.472	0.500
Age 40–49	0.378	0.485	0.366	0.482	0.350	0.477	0.338	0.474	0.408	0.492	0.396	0.490
Age 50–59	0.069	0.253	0.062	0.241	0.031	0.174	0.044	0.206	0.112	0.315	0.085	0.279
Age>60	0.010	0.098	0.016	0.127	0.005	0.068	0.007	0.086	0.015	0.123	0.028	0.166
Age youngest child in household	5.059	3.362	5.175	3.309	5.213	3.330	5.216	3.177	4.872	3.380	5.042	3.437
Child aged 0-3 in household	0.400	0.490	0.387	0.487	0.369	0.483	0.365	0.482	0.435	0.496	0.420	0.494
No. children <age 18 in household	1.736	0.747	1.736	0.691	1.715	0.735	1.716	0.689	1.758	0.758	1.756	0.698
N	2,795		1,076		1,457		592		1,317		476	
No. individuals	1,120		269		580		148		532		119	

Source: IAB High-Frequency Online Personal Panel (HOPP), own calculations.

Notes: *measured on a 5-point scale from 1 "entirely father" to 5 "entirely mother". ⌁ does not add up to 100% since the category "entirely mother" is included in two dichotomizations.

Figure 1. Utilized childcare capacity in Germany during the first COVID-19 lockdown in early 2020 and the subsequent reopening.
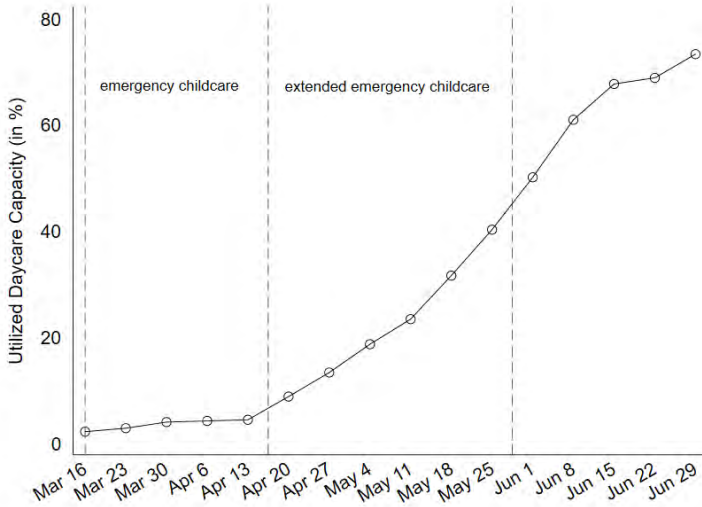
Source: DJI-RKI (2020); own calculations.

Note: Utilized childcare capacity represents the share of children who are currently in childcare among those children who were registered in childcare by March 2020. DJI-RKI (2020) reports these shares weekly by federal state based on communications of the respective federal state ministries; we subsequently aggregate those shares to the national level. We define the timing of transition from emergency childcare to extended emergency childcare and from extended emergency childcare to the phase of (restricted) normal operation as the week where more than five observed federal states switch status, based on information from DJI-RKI (2020, Table 1).

3.3 Dependent variable

Due to the lockdown and associated daycare facility and school closures, parents were more strongly forced to renegotiate childcare; thus, compared to other forms of unpaid care, childcare is our main dependent variable. Such care has to be analyzed separately from housework (Sullivan, 2013), which we do; we consider housework and (grocery) shopping, which are scaled and recoded in the same way as our main dependent variable. Regarding childcare, the respective survey question has been posed to a subgroup of respondents who state that their partner and at least one child born after 2005, i.e., under the age of 15, live in their household. The question reads as

follows: "*How do you and your partner currently organize childcare? This is about the time that children are not taken care of in school, kindergarten, etc., but by you and/or your partner.*" Responses are measured on a five-point scale: 1 "(almost) entirely my partner", 2 "predominantly my partner", 3 "approximately 50/50", 4 "predominantly myself", 5 "(almost) entirely myself". For the purpose of our analysis, we recoded the responses according to the respondent's gender to obtain a measure of the gender pattern in childcare division within the couple.[5] The recoded five-point scale then ranges from 1 "(almost) entirely the father" to 5 "(almost) entirely the mother". We additionally examine dichotomized versions of the outcome. Importantly, only in the June wave were the respondents additionally asked to report the division of unpaid labor in the immediate prepandemic period, which we used as a reference point in our analysis.

3.4 Explanatory variables

As we are interested in the postpandemic dynamics of parental childcare division, we employ month dummies for June, July and August 2020 and used the respective prepandemic division as a reference. We consider the main possible types of lockdown-specific work-care arrangements among parental couples. The relevant coping strategies that addressed work-care conflicts in the immediate lockdown were (not) working at all, switching to remote work and reducing one's working hours. Specifically, we use information on whether one's employer offered the possibility of working from home (rather than actual usage), assuming that anyone with the possibility of working from home did do so in the acute lockdown period when schools and daycare facilities were closed and employees were ordered to work from home whenever possible. Similarly, we rely on information about actual working hours in the work week prior to the interview (including

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[5] The data does not contain information about the gender of the partner; however, we impose the assumption that there are no same-sex couples in the sample.

overtime, etc.). Since we do not observe actual work-care arrangements during the acute lockdown in March/April 2020, we employ survey information from the May 2020 HOPP wave for approximation. We thereby assume that individuals tended to maintain their lockdown-specific care-work arrangements in the subsequent phase of stepwise reopening of schools and daycare facilities, which lasted at least until the beginning of June 2020.

We do not distinguish by the possibility of working from home if an individual worked less than or equal to 20 hours weekly, since we assume that leisure time at home is more strongly expected to be devoted to childcare tasks than work time at home. Whether with or without the possibility of working remotely, the parent who reduced their work time was likely be the main caregiver. We focus on these four main types of lockdown-specific work-care arrangements since the limited sample size prevents us from a more detailed specification regarding working time. Note that as we do not observe prepandemic work arrangements of both partners, we are unable to measure respective changes.

When analyzing lockdown-specific work arrangements, we show results for mothers and fathers separately because we do not have partner information on employment status, working from home and working hours from the May 2020 HOPP wave. Consequently, the work-care arrangements we can investigate concern the individual and not the couple. That is, we employ the following arrangements for mothers and fathers: (a) more than 20 working hours <u>without</u> the possibility of working from home, (b) more than 20 working hours <u>with</u> the possibility of working from home, (c) less than or equal to 20 working hours, and (d) not employed.

Overall, we examine the dynamics over three consecutive monthly waves of the HOPP survey (June, July and August) in which questions on the intracouple division of childcare were included

for the first time.[6] Information on the pre-COVID-19 division of childcare is taken from the June survey. The prepandemic period is used as a separate reference period preceding the others; hence, our analysis spans four periods in total. We additionally employ the first HOPP wave administered in May 2020 to examine the division-of-childcare dynamics for subgroups of mothers and fathers according to their lockdown-specific work arrangements. Note also that there is no systematic (household) linkage between the fathers and the mothers in our sample. Table 2 depicts the information we use and the wave from which it is retrieved.

Table 2. Utilized survey information.

HOPP Wave	May	June	July	August
Prepandemic childcare division		x		
Lockdown-specific individual work arrangements of mothers and fathers	x			
Current childcare division		x	x	x
Current division of housework and doing the errands		x	x	x
Prepandemic division of housework and doing the errands		x		

Source: IAB High-Frequency Online Personal Panel (HOPP).
Notes: Prepandemic childcare division: "*Thinking about the time before the COVID-19 crisis: How did you and your partner organize childcare? This question aims at the time, when the kids where not looked after at school, kindergarten, etc., but by you and/or your partner.*" - This was done…[1] (almost) completely by partner, [2] mostly by partner, [3] about half – half, [4] mostly by me, [5] (almost) completely by me. Lockdown-specific individual work arrangements of mothers and fathers: "*And if you think about your last working week: How many hours did you actually work, including regular overtime, extra work, etc.? Note: If you do not have a fixed working time, enter the average hours over several weeks.*", "*Do you have the possibility of working from home?*". Current childcare division: "*How do you and your partner organize childcare at the moment? This question aims at the time when the kids are not looked after at school, kindergarten, etc., but by you and/or your partner.*" Current division of housework and doing the errands: "*How do you and your partner split the work currently? - Housework (laundry, cooking, cleaning, tidying up) – Shopping (groceries)*". Prepandemic division of housework and doing the errands: "*Thinking about the time before the COVID-19 crisis: How did you and your partner split the work in the following fields? – Shopping (groceries)*".

4 Empirical Setup

Our descriptive investigation of the intrahousehold division of childcare in the aftermath of Germany's first COVID-19 lockdown in spring 2020 mainly aims to explore two types of research questions. The first question concerns the overall dynamics of the intrahousehold division of childcare: did the lockdown,—i.e., school and childcare closures—significantly affect the

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[6] May is not included since the intracouple division of childcare was not surveyed in the HOPP May wave.

gendered pattern in childcare provision, and if so in what direction? To examine these questions, we run linear regressions of the following type:

$$Y_{it} = \alpha + \beta_1 \, June_t + \beta_2 \, July_t + \beta_3 \, August_t + u_i + \epsilon_{it} \qquad (1),$$

where Y represents the childcare division among parents reported by individual i in period t (with t=["Pre-COVID-19", June 2020, July 2020, August 2020]). $June_t$, $July_t$ and $August_t$ are dummy variables indicating the interview wave. u_i is an individual fixed effect, and ϵ_{it} is a time-varying random error term. Throughout the article, all standard errors are clustered at the individual level and are robust to heteroscedasticity. The parameters β_1, β_2 and β_3 represent the postlockdown changes of the childcare division among parents with respect to the reference period "Pre-COVID-19".

The second research question concerns the postlockdown dynamics of parental childcare division across specific subgroups: have changes in the intracouple childcare division been driven by specific work arrangements during the period where (extended) emergency childcare was in place (termed as "extended lockdown" before)? We run regressions of the following type separately for mothers and fathers:

$$Y_{it} = \theta + \boldsymbol{Wave'}_t \boldsymbol{\delta}_0 + [\boldsymbol{Work}_i \times \boldsymbol{Wave}_t]' \, \boldsymbol{\delta}_1 \, + u_i + \epsilon_{it} \qquad (2),$$

where Y represents the intracouple childcare division reported by mothers or fathers. $Wave_t$ is a vector of dummy variables indicating the interview wave. The equation again includes individual fixed effects (u_i) and a time-varying random error term (ϵ_{it}). The interview wave indicators ($Wave_t$) are now interacted with $Work_i$, which is a vector of mutually exclusive dummy variables for mothers' (fathers') individual lockdown-specific work arrangements (a)-(d), as delineated in

Section 3. We provide results on both models (1) and (2), each on the balanced and the unbalanced sample, as well as with and without individual fixed effects.

5 Results and Discussion

5.1 Overall dynamics

We start with the estimation results of equation (1) in Section 4. Relative to the precrisis work division, the respondents reported a shift toward a greater paternal share of childcare in these postlockdown months. However, this shift was rather small and decreased over time, as depicted in **Figure 2,** where we plot the period effects from a simple OLS model on the unbalanced panel.

Figure 2. Overall postlockdown dynamics of parental division of childcare.
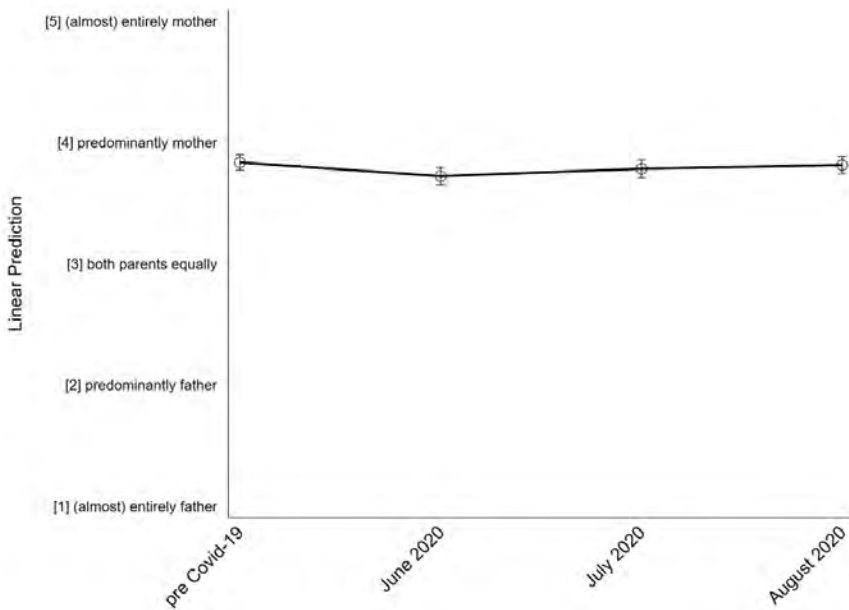
Source: IAB High-Frequency Online Personal Panel (HOPP), own calculations.
Notes: This figure plots period effects based on regression results presented in Column 1 of Table 3.

This fact is evident from the regression results presented in **Table 3**, also with individual fixed effects and based on the balanced panel. Longer-term period effects for July and August 2020 are statistically significant only when individual fixed effects are included. Specifically, by August 2020, we observe a shift in parental division of childcare toward fathers that amounts to approximately 0.07-0.1 points on a 6-point scale.[7] Further activities that might likewise be subject to intracouple bargaining, such as housework and shopping, show no significant (housework) or only small and very temporary shifts (shopping), thereby supporting hypothesis **H1**.

Table 3. Postlockdown dynamics of parental division of childcare (housework, shopping).

Parental division of labor wrt.:	Childcare			Housework	Shopping
	(1)	(2)	(3)	(4)	(5)
Pre-COVID-19 (ref.)					
June 2020	-0.113***	-0.123***	-0.156***	-0.047	-0.115**
	(0.031)	(0.031)	(0.055)	(0.040)	(0.056)
July 2020	-0.052	-0.104***	-0.138***	0.053	-0.045
	(0.041)	(0.036)	(0.053)	(0.046)	(0.051)
August 2020	-0.021	-0.069*	-0.100**	0.057	-0.019
	(0.041)	(0.035)	(0.047)	(0.045)	(0.051)
Female respondent	0.208***				
	(0.053)				
Constant	3.726***	3.859***	3.896***	3.771***	3.412***
	(0.042)	(0.020)	(0.033)	(0.028)	(0.033)
Individual FE	*no*	*yes*	*yes*	*yes*	*yes*
No. individuals	1,120	1,120	269	269	269
N	2,795	2,795	1,076	1,075	1,074
Sample	unbalanced	unbalanced	balanced	balanced	balanced

Source: IAB High-Frequency Online Personal Panel (HOPP), own calculations.
Notes: Parental division of childcare measured on a 5-point scale from 1 "entirely father" to 5 "entirely mother". Cluster-robust standard errors at the individual level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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[7] The sizeable and significant female respondent coefficient in Table 3 hints at the importance of gendered reporting behavior with respect to the levels of childcare division. Gender biases in childcare levels are, however, fully controlled for in regressions including individual fixed effects, where we look at intrapersonal changes only.

In the following, we take a closer look at where childcare division shifts toward slightly more paternal care originate from, i.e., traditional or rather more egalitarian couples. We rerun fixed-effects regressions on the balanced panel (Column 3 of Table 3) for a variety of dichotomized outcomes. We employ binary variables indicating whether childcare was provided (i) entirely by the mother, (ii) predominantly or entirely by the mother, (iii) by both parents equally, or whether childcare was delivered (iv) predominantly or entirely by the father. We then multiply these binary indicators by 100 for the period effects to represent percentage-point changes. **Table 4** presents the results, which indicate that the traditional childcare constellation remained remarkably stable over time. Within the balanced sample, the probability of a mother being entirely responsible for childcare (approximately 28 percent prepandemic) did not significantly change in the aftermath of the COVID-19 lockdown (Column 3). The small changes we observe instead originate from constellations, in which mothers are still the main caregivers but fathers were already considerably involved in childcare duties prepandemic. The results presented in Column 2 of Table 4 indicate that the probability of predominantly or sole maternal caregiving statistically significantly decreased from approximately 66 percent prepandemic by 5.6 (4.5, 5.2) percentage points in June (July, August) 2020.

On the flipside, this shift led to an increased probability of fathers taking over the main caregiver role rather than to an increased probability of egalitarian care divisions by June 2020. Moreover, the egalitarian constellation was 2.6 percentage points less likely to occur with respect to a 30.5-percent likelihood prepandemic, albeit not statistically significant, whereas the paternal caregiver constellation increased by statistically significant 8.2 percentage points with respect to a prepandemic likelihood of 3.3 percent. These dynamics are still visible and significant in July and August; with respect to the prepandemic situation, fathers were still 5.2 (2.6) percentage points

more likely to be in the main caregiver role by July (August) 2020). However, there are obvious backward dynamics over time in this group; moreover, the group is rather small. Given that both egalitarian constellations and sole maternal caregiver constellations lack significant changes in prevalence over time and since maternal main caregiver constellations still constitute the large majority, our hypothesis **H2** is fully supported.[8] The dynamics in parental childcare after the first COVID-19 lockdown in Germany seem quite limited in size.

Table 4. Postlockdown dynamics of parental division of childcare. Dichotomized outcome.

Parental division of childcare	Predom./entirely father	Predom./entirely mother	Entirely mother	Both parents equally
	(1)	(2)	(3)	(4)
Pre-COVID-19 (ref.)				
June 2020	8.178***	-5.576**	0.00000	-2.602
	(2.116)	(2.642)	(2.474)	(2.860)
July 2020	5.204***	-4.461*	-3.346	-0.743
	(1.799)	(2.459)	(2.953)	(2.689)
August 2020	2.602*	-5.204**	-2.230	2.602
	(1.529)	(2.337)	(2.686)	(2.497)
Constant	3.346***	66.171***	27.881***	30.483***
	(1.165)	(1.595)	(1.710)	(1.699)
Individual FE	*yes*	*yes*	*yes*	*yes*
No. individuals	269	269	269	269
N	1,076	1,076	1,076	1,076
Sample	balanced	balanced	balanced	balanced

Source: IAB High-Frequency Online Personal Panel (HOPP), own calculations.
Notes: Dichotomized outcomes have been multiplied by 100 for the period effect estimates to display percentage-point changes. Cluster-robust standard errors at the individual level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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[8] Strikingly, those couples that shift back over time do not seem to readopt maternal main caregiver constellations, but rather remain in an egalitarian division of childcare labor (albeit without statistical significance).

5.2 Childcare dynamics by work-care arrangements during the lockdown

We now turn to determining the drivers of the shift toward paternal childcare with respect to lockdown-specific work-care arrangements, as denoted in equation (2) in Section 4. Tables 5 and 5 show the postlockdown dynamics with respect to the intracouple division of childcare for mothers and fathers, respectively.

Figure 3. Overall postlockdown dynamics of the parental division of childcare by mothers' lockdown-specific work arrangements.
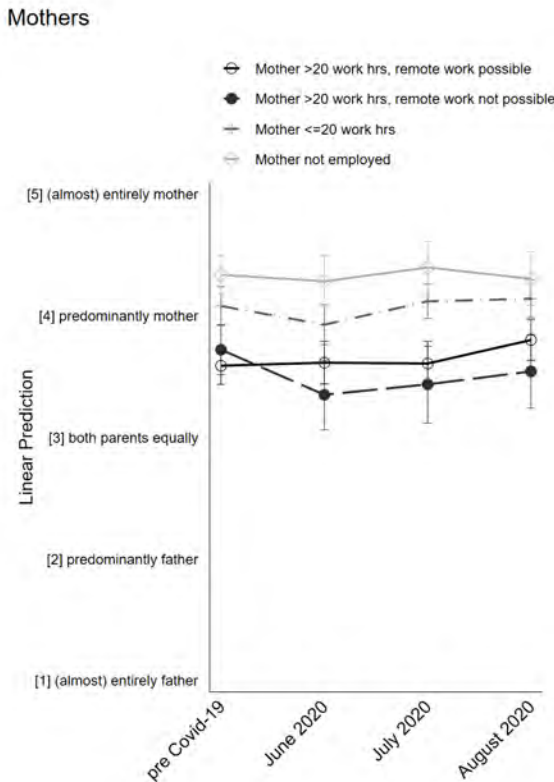
Source: IAB High-Frequency Online Personal Panel (HOPP), own calculations.
Notes: This figure plots group-specific period effects based on regression results presented in Column 1 of Table 5.

Figure 3 graphically displays the maternal group-specific dynamics in childcare division based on OLS results from the unbalanced panel. As a first result, we identify the group of mothers with more than 20 actual working hours per week who cannot work remotely as potential candidates to show significant shifts toward stronger paternal participation in childcare. From the cross-sectional perspective, it becomes evident that the lower the level of mothers' paid work involvement is, the less symmetrical their pre- and postpandemic childcare division is within the household.

Next, we provide a regression-based test to verify the aforementioned shift. We focus on the individual fixed effects regressions presented in Columns 2 and 4 in **Table 5**. It becomes evident that the main dynamics indeed stem from the group of mothers who work more than 20 actual working hours per week without any possibility of working from home, while mothers who work similar hours but *can* work remotely show no significant shifts. That is, **H3** is confirmed for mothers. Note that these two groups of mothers are rather similar in their division of childcare prepandemic (see Figure 3), which indicates that this result is unlikely to be driven by selection into remote work. The shift toward increased paternal caregiving for mothers who *cannot* work from home amounts on average to 0.427 (0.669) points on the 5-point scale (ranging from 1 "*entirely father*" to 5 "*entirely mothe*r") for the unbalanced (balanced) sample by June 2020 and decreases to 0.233 (0.425) by August (becoming statistically insignificant for the unbalanced sample). None of the remaining groups of mothers shows significant persistent changes in the division of childcare with respect to the prepandemic situation.[9] The indication that working from home does not bring a relief for mothers fits into the results for parental stress based on the first HOPP wave in May, according to which mothers who worked from home in the week before the

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[9] The only temporary and marginally significant improvement—for June only in the unbalanced sample—refers to mothers with less than 20 weekly work hours.

survey had an above-average likelihood of reporting an increase in parental stress compared to the total of mothers and a higher likelihood of doing so than did fathers who worked from home (Fuchs-Schündeln/Stephan, 2020). The OLS regression results on the unbalanced and balanced panels (Columns 1 and 3, respectively) support the relevance of maternal time availability for the postpandemic (a) symmetry of childcare division.

Although we cannot accurately model the reduction in working hours before and after the pandemic, it can be assumed that a notable portion of women fell below this hours threshold due to the crisis. According to the *Böckler-Erwerbspersonen-Befragung*, the mean actual working hours of mothers with children in need of care declined from 31 pre-COVID to 24 in April (WSI, 2020). In May 2020, 22 percent of male and 19 percent of female employees subject to social insurance contributions were in short-time work (Kruppe/Osiander, 2020). Moreover, mothers had higher odds of being suspended from work during the early phase of the lockdown than men (Möhring *et al.,* 2021), and mothers were more strongly affected by the significant decline in marginal employment between 31 March 2019 and 31 March 2020 (Deutsche Rentenversicherung Knappschaft Bahn-See/Minijobzentrale, 2020a) and during the second quarter of 2020 (Deutsche Rentenversicherung Knappschaft Bahn-See/Minijobzentrale 2020b).

For fathers, **Figure 4** graphically displays the group-specific dynamics in childcare division based on OLS results from the unbalanced panel. Here, we may tentatively identify the groups of unemployed fathers and fathers with a maximum of 20 actual weekly working hours as the main potential candidates to show significant shifts toward increased male caregiving.

Table 5. Mothers—Postlockdown dynamics in parental division of childcare by lockdown-specific work arrangements.

	(1)	(2)	(3)	(4)
Pre-COVID-19 (ref.)				
June 2020	0.025	0.032	-0.109	-0.109
	(0.083)	(0.082)	(0.142)	(0.142)
July 2020	0.018	0.016	-0.127	-0.127
	(0.097)	(0.083)	(0.133)	(0.133)
August 2020	0.211**	0.126	0.036	0.036
	(0.095)	(0.081)	(0.114)	(0.114)
Mother >20 work hrs, remote work possible (ref.)				
Mother >20 work hrs, remote work not possible	0.132		0.012	
	(0.131)		(0.207)	
Mother ≤20 work hrs	0.491***		0.545***	
	(0.113)		(0.170)	
Mother not employed	0.748***		0.812***	
	(0.113)		(0.174)	
June 2020 × Mother >20 work hrs, remote work not possible	-0.396**	-0.427**	-0.669*	-0.669*
	(0.178)	(0.177)	(0.346)	(0.345)
July 2020 × Mother >20 work hrs, remote work not possible	-0.303	-0.312*	-0.317	-0.317
	(0.202)	(0.166)	(0.299)	(0.298)
August 2020 × Mother >20 work hrs, remote work not possible	-0.390**	-0.233	-0.425**	-0.425**
	(0.194)	(0.158)	(0.198)	(0.198)
June 2020 × Mother ≤20 work hrs	-0.178*	-0.197*	-0.024	-0.024
	(0.107)	(0.106)	(0.167)	(0.167)
July 2020 × Mother ≤20 work hrs	0.021	-0.075	0.016	0.016
	(0.132)	(0.110)	(0.162)	(0.161)
August 2020 × Mother ≤20 work hrs	-0.151	-0.096	0.075	0.075
	(0.137)	(0.112)	(0.146)	(0.146)
June 2020 × Mother not employed	-0.078	-0.074	0.242	0.242
	(0.118)	(0.118)	(0.189)	(0.189)
July 2020 × Mother not employed	0.042	0.111	0.127	0.127
	(0.160)	(0.162)	(0.238)	(0.238)
August 2020 × Mother not employed	-0.245	-0.120	-0.036	-0.036
	(0.155)	(0.134)	(0.177)	(0.177)
Constant	3.585***	3.911***	3.655***	3.986***
	(0.078)	(0.028)	(0.131)	(0.046)
Individual FE	*no*	*yes*	*no*	*yes*
No. individuals	580	580	148	148
N	1,457	1,457	592	592
Sample	unbalanced	unbalanced	balanced	balanced

Source: IAB High-Frequency Online Personal Panel (HOPP), own calculations.

Notes: Dependent variable parental division of childcare measured on a 5-point scale from 1 "entirely father" to 5 "entirely mother". Cluster-robust standard errors at the individual level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Figure 4. Overall postlockdown dynamics of parental division of childcare by fathers' lockdown-specific work arrangements.
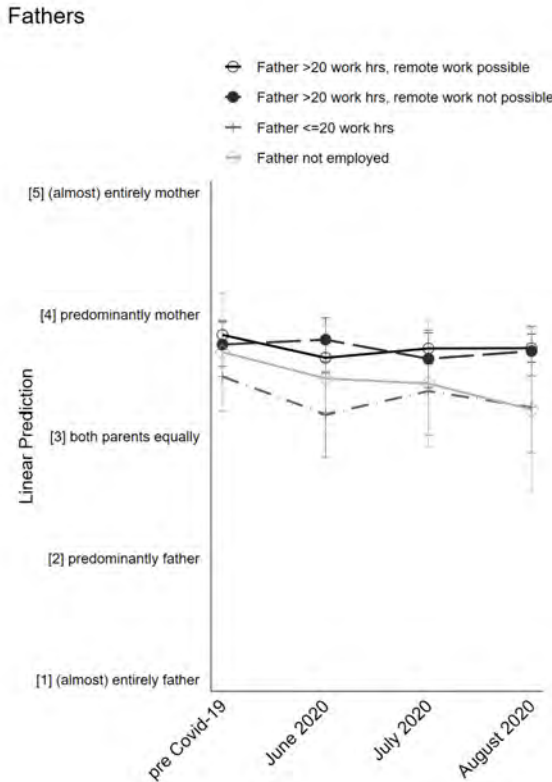
Source: IAB High-Frequency Online Personal Panel (HOPP), own calculations.
Notes: This figure plots group-specific period effects based on regression results presented in Column 1 of Table 6.

However, the regression results, including individual fixed effects (Columns 2 and 4 of **Table 6**), reveal that all groups of fathers contribute equally to a shift toward increased male childcare participation. The size of the shift oscillates at approximately 0.2 and seems to be rather stable over time. Temporarily, in June 2020, fathers who worked more than 20 hours weekly but were not able to work from home did not participate in the shift.

Table 6. Fathers—Postlockdown dynamics in parental division of childcare by lockdown-specific work arrangements.

	(1)	(2)	(3)	(4)
Pre-COVID-19 (ref.)				
June 2020	-0.188***	-0.187***	-0.203*	-0.203*
	(0.054)	(0.053)	(0.110)	(0.110)
July 2020	-0.111	-0.199***	-0.149	-0.149
	(0.075)	(0.064)	(0.101)	(0.100)
August 2020	-0.109	-0.208***	-0.203**	-0.203**
	(0.072)	(0.066)	(0.096)	(0.095)
Father >20 work hrs, remote work possible (ref.)				
Father >20 work hrs, remote work not possible	-0.078		-0.112	
	(0.110)		(0.194)	
Father ≤20 work hrs	-0.342**		-0.515**	
	(0.155)		(0.223)	
Father not employed	-0.141		-0.378	
	(0.254)		(0.580)	
June 2020 × Father >20 work hrs, remote work not possible	0.227***	0.216***	0.203	0.203
	(0.084)	(0.083)	(0.154)	(0.154)
July 2020 × Father >20 work hrs, remote work not possible	-0.007	0.005	0.015	0.015
	(0.144)	(0.128)	(0.145)	(0.145)
August 2020 × Father >20 work hrs, remote work not possible	0.054	0.040	-0.097	-0.097
	(0.126)	(0.116)	(0.153)	(0.152)
June 2020 × Father ≤20 work hrs	-0.121	-0.166	-0.252	-0.252
	(0.193)	(0.189)	(0.265)	(0.264)
July 2020 × Father ≤20 work hrs	-0.008	0.056	-0.033	-0.033
	(0.203)	(0.164)	(0.156)	(0.155)
August 2020 × Father ≤20 work hrs	-0.144	-0.023	0.021	0.021
	(0.225)	(0.178)	(0.201)	(0.200)
June 2020 × Father not employed	-0.029	-0.063	-0.047	-0.047
	(0.246)	(0.249)	(0.437)	(0.436)
July 2020 × Father not employed	-0.148	-0.196	-0.351	-0.351
	(0.350)	(0.305)	(0.579)	(0.577)
August 2020 × Father not employed	-0.365	-0.034	-0.297	-0.297
	(0.384)	(0.426)	(0.578)	(0.577)
Constant	3.828***	3.805***	3.878***	3.790***
	(0.060)	(0.028)	(0.103)	(0.048)
Individual FE	*no*	*yes*	*no*	*yes*
No. individuals	532	532	119	119
N	1,317	1,317	476	476
Sample	unbalanced	unbalanced	balanced	balanced

Source: IAB High-Frequency Online Personal Panel (HOPP), own calculations.

Notes: Dependent variable parental division of childcare measured on a 5-point scale from 1 "entirely father" to 5 "entirely mother". Cluster-robust standard errors at the individual level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The fact that a father's work arrangement seems to have played no role in the dynamics over time contradicts hypothesis **H3** for fathers. Analogous to mothers, we would have expected a negative association of fathers being offered telework with the maternal share on the overall childcare burden. H3 focuses on these dynamics over time and not on the differences between groups. Note,

however, that the OLS results retrieved from the unbalanced and balanced panels (Columns 1 and 3, respectively) show that working less than 20 hours a week is significantly associated with higher paternal childcare involvement in the cross-sectional perspective. While this result is in line with that for mothers, things are different for nonemployment. Paternal nonemployment is not significantly associated with parental childcare division.

6 Conclusion

Overall, our findings indicate that while the pandemic has not changed much in regard to the childcare division of parental couples, we can observe at least temporary shifts for childcare but not for other forms of unpaid work, thereby supporting our first hypothesis. Furthermore, the main driver for the small shifts toward increased paternal childcare participation that we observe consists of mothers with relatively intense labor market participation who cannot work from home. On the other hand, none of the work-care arrangement groups of fathers can be clearly identified as a main driver. Thus, our third hypothesis gains support from our data for mothers but not for fathers. Taken together, our findings suggest that the small shift we observe is a shift that emerged out of *necessity* (since mothers cannot take over childcare) and not out of *opportunity* (of remotely working fathers and/or fathers with reduced hours). Hence, such a shift is likely to fade once the necessity vanishes. That is, in the context of a pronounced asymmetry in childcare division along the lines of prepandemic routines, stimuli are only short-lived. Our results therefore neither support the notion of a retraditionalization nor of an equalization of unpaid work among genders. Rather, they emphasize the overwhelming role of the initial conditions, which force a reset of childcare arrangements as soon as the emergency vanishes. All in all, childcare arrangements show a striking degree of stability.

Our results are in line with some previous findings but different from others. We confirm the 'stability notion' made by Globisch and Osiander (2020) based on the first two waves of our data; however, with our longer time horizon, we are able to trace the fading-out of the stimulus until August 2020. Different from Hank and Steinbach (2020), we do not find shifts at the extremes of the distribution. Neither couples with previously egalitarian arrangements nor those in which the mother was entirely responsible show significant dynamics over time in our study. This is what we expected and confirms our second hypothesis. Furthermore, although our results build on previous findings that observed an increased involvement of fathers during the pandemic (e.g., Kreyenfeld/Zinn, 2021; Hank/Steinbach, 2020; Kohlrausch/Zucco, 2020; Zinn *et al.*, 2020), our data indicate that a respective shift in childcare division toward a more equal divide faded out in the months thereafter, with the only group persistently showing a slight shift being the couples in which the mother was previously predominantly responsible but where the father was already somewhat engaged. Apparently, these couples underwent a supportive change in relative resources and/or followed sufficiently egalitarian role models.

Regarding the role of telework, our findings support previous results stating that maternal telework does not decrease the childcare burden for mothers but rather entails an increase (Fuchs-Schündeln/Stephan, 2020). Paternal telework does not relate to a particular level of paternal childcare engagement in our study, which is in contrast to earlier studies that in this case find a lower likelihood of sole maternal care (Zoch *et al.*, 2020) or a decreased maternal share of the overall childcare burden (Hank/Steinbach, 2020). These deviations may to some extent be driven by methodological differences, e.g., with respect to the measure (offer vs. use of telework), earlier period of observation, and sample size. However, for example, the finding in Hank and Steinbach (2020) that the maternal childcare burden was only reduced if the father alone (and not the mother)

switched to remote work is in line with our conclusion that the remote work of fathers plays no role *per se* but is important only through its association with maternal behavior. Recent evidence reports a similar finding for Austria (Derndorfer *et al.,* 2021).

There are some significant limitations of our study. First, due to a lack of information on the couple's work constellation before and during the lockdown, we do not observe parents' relative resources; thus, we cannot identify the role of comparative advantage. Second, the results for mothers who worked a high number of hours and had no opportunity to work from home could to some extent be affected by social desirability reporting bias. In the context of traditional gender roles, this is the only work arrangement in which a decreased level of maternal childcare involvement might be socially tolerated. The insensitivity of paternal work arrangements with respect to childcare involvement perfectly fits into this notion.

Acknowledgments

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To mask or not to mask

Travis Ng[1]

Beyond showing scientifically masks block virus transmissions, what else is needed before mask mandates are called for? I endogenize mask-wearing in a model in which non-altruistic players know a mask protects people around the wearer more than it protects the wearer herself. The strategic interactions among people hinges on a proxy of population density, which determines whether mask-wearing behaviors are discouraged by free-riding or mutually reinforced by strategic complementarity. The existence of multiple equilibria under some parameter space explains why polar opposite mask-wearing behaviors can be observed among crowded cities that are not much different from one another. Mask mandates are shown to work precisely when they refine equilibrium away from the socially inferior one. While social and private incentives of mask-wearing always diverge, the model gives the specific conditions under which mask mandates are called for. When those conditions fail to hold, mask mandates are either unnecessary, socially inefficient, or incentive-incompatible. Some empirical implications of the model concerning mask-wearing and infection rate are discussed.

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1. Introduction

"Listen to the scientists!" appears to some as the only sensible way for the society to tackle a public health crisis. In the current pandemic it is especially true for mask-wearing, an issue involving quite a lot of politics, making the listening sounds all the more sensible.

To listen, understand the scientists' experiments and mathematical modeling. Wear a mask if their conclusions suggest we should. Here are two examples. To prove the effectiveness of masks, Chan *et al.* (2020) place infected and healthy hamsters in separate cages side-by-side. The team blew air from the former to the latter. After a certain period of time, the infection rates are: 66.7% if no mask, 33.3% and 16.7% if a mask is placed on the cage of the healthy and infected hamsters, respectively. Eikenberry *et al.* (2020) develops an susceptible, exposed, infectious, removed (SEIR) model to study the transmission dynamics, allowing *exogenous* variations of the fraction of the mask-wearing population. The model shows benefits from universal mask wearing, the stronger the earlier it is adopted.[1]

Should we just listen to the scientists? I argue that we should carefully listen to them. They work hard to try to help. But like most things that deal with incentives, we should be careful. Unlike hamsters, we humans deliberately decide for ourselves whether to wear a mask with conscious and subconscious trade-offs. While an infection curve from an SEIR model informs us that the potential collective benefits of *exogenously* imposed universal mask wearing are large, scientists can seldom guarantee that, individually, we would *endogenously* choose to put one on. A mask mandate that is incentive-incompatible would only result in low compliance. Almost no place on earth has enough enforcers to police people everywhere 24x7.[2]

1.1. *Some economics of mask-wearing*

Some economics plays a role in formulating policies concerning face mask. First, the interaction between the ways viruses transmit and the filtration efficiencies of masks create incentive problems.

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[1] Tian *et al.* (2020); Kai *et al.* (2020) also build computational models that quantify the impact of mask wearing on the contagiousness of the virus. People in their models do not choose whether to wear masks endogenously.

[2] Another argument for supplementing scientists' advice with economics is advocated by Viscusi (2020), who elaborates on the difficult trade-offs between health risks and economic costs. To monetize the value of health risk requires calculating the value of a statistical life. More aggressive policies such as lockdowns will take its economic toll while reopening raises health risk, but all such trade-offs involve the question of "how much." This paper, however, does not contribute to this line of argument.

Second, the inter-dependence of individuals' mask-wearing choices requires explicit consideration of strategic interactions and concept of equilibrium.

Virus transmission.   Coronaviruses come out of an infected person through attaching themselves with the person's droplets. If one is infected, when she talks, coughs, sneezes, or simply exhales, the droplets created can carry an amount of viruses enough to infect others. An infection can come from at least two transmission mechanisms: [1] the droplets with the viruses hanging in the air are inhaled by others; [2] the droplets fall on a surface, touched by others before completely evaporated, usually with hands that are in turn used to touch a face.

How does a mask work?   If worn properly, a mask can very effectively prevent the droplets with viruses from *leaving* the mask of the mask-wearer. It is because droplets are large in size easily trapped by a mask. The trapping in turn breaks down the above two transmission mechanisms. In contrast, if droplets have been hanging in the air, evaporation will shrink them. The resulting much lighter weight may allow some to float in the air for a considerably longer period of time. Masks are much less effective in blocking tiny particles. An unlucky mask-wearer may inhale the shrunk droplets containing the viruses to get infected. Some policymakers are aware of the fact that mask wearers protect others.[3]

Public good and free-riding.   Knowing how masks work, one would want others to wear masks. Not only does she get a better protection, she also does not need to bear the monetary and non-monetary costs of wearing a mask. But if everyone thinks so, no one would want to wear one. Mask-wearing is a classic public good. It is non-rivalrous in a sense that Peter's consumption, defined as the protection he gets from being around a mask-wearer, does not diminish the mask's protective effects on Mary who also happens to be around the mask-wearer. It is non-excludable in a sense that it is impossible for the mask-wearer to exclude Mary and Peter in public areas. I am not aware of anyone successfully charging others around her a price for the protection she gives to

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[3]Policymakers from both Canada and the U.S. seem to be aware. "Wearing a non-medical mask is an additional measure that you can take to protect others around you," Canada's Chief Public Health Officer Dr. Theresa Tam said on early April, reversing her advice against masks. She warned, however, that a non-medical mask does not necessarily protect the person wearing it. Tasker, John Paul (2020 April 6) "Canada's top doctor says non-medical masks can help stop the spread of COVID-19" *CBC News* Retrieved from https://www.cbc.ca/news/politics/non-medical-masks-covid-19-spread-1.5523321

others because she wears a mask.

The bottom-line. Basic science suggests that wearing a mask protects others more effectively than protecting the mask-wearer herself. A conundrum results: suppose there is no guarantee that we are sufficiently altruistic and we happen to know the basic science, why would we have incentives to wear a mask? Shall we better not listen to the scientists? How can we stop people from learning the science? Mask mandates seem almost an inevitable policy option. Is it really the case?

1.2. The approach

My approach is theoretical. Section 2 describes the simplest possible model I can think of concerning individuals' endogenous mask-wearing decisions that captures the interplay of the basic scientific and economic elements. It is deliberately made simple because my quest is to find out the minimal set of factors that explains mask-wearing. More complicated features may be added on only after knowing the minimal set.[4]

I rule out altruistic motives because they are hard to be quantified and measured precisely. Likewise, other behavioral explanations that may indeed drive people to wear masks during the pandemic are ruled out.[5]

A homogeneous group of self-interest and rational individuals know the basic science of why wearing a mask offers strong protection to others but only weak protection to themselves. Wearing one costs them the same.[6] They face uncertainty about their own private benefits of mask-wearing

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[4]In reality, scientific studies prove the existence of a variety of different factors, particularly environmental factors, that determine the contagiousness of a virus. No doubt, they are important factors. They are taken out because the theoretical model strives to be as simple as possible to pin down the drivers of incentives to wear masks.

[5]Some state people wear masks because they misunderstand how masks work. Some explain some cities where most wear mask even without a mask mandate due to the possibility that people were already used to wearing masks before the outbreak. Others say that social pressure from mask wearers can increase one's incentive to wear a mask. Signaling to others that one cares can also matter more during such difficult times, even if the person is non-altruistic. Although these explanations are not necessarily incorrect, they cannot help address the important policy question: As masks help "flatten the curve" only when most people wear one, do individuals acting in their self-interest have an incentive to do so? Otherwise, under what conditions does a mandatory mask wearing policy make sense? Would people comply? When should we expect few would comply, leading to huge enforcement costs?

[6]While fully acknowledging the presence of monetary and non-monetary costs, I lump all the costs of mask-wearing into a single parameter. In addition to the feelings of discomfort (especially for those with beards), searching and queuing for masks are costs. Other non-monetary costs include the steep learning curve of wearing a mask properly in a continuous fashion. Mistakes include wearing masks upside down, inside out, with the nose exposed, and with the tin left unbent and not fitting the shape of the face; touching the mask; lowering the mask to cough/sneeze (unfortunately, I witnessed many people doing so, probably because they do not want to make their masks dirty); talking on the phone

for two reasons: [1] asymptomatic: an infected person without symptoms can still infect others. Everyone knows that if she is already infected, the mask does not benefit them. But no one knows for sure if she is already infected; [2] an infection requires interactions with others; therefore, an individual's private benefits of mask-wearing depends on others' mask-wearing choices.

A key exogenous driver in the model is that to carry on a normal life, it is inevitable for one to randomly "bump" into a certain number of people during the game.[7] This exogenous parameter can be understood as a proxy of population density.[8] One caveat is that it is *not* a choice variable.[9] An infection can happen through "bumping" into an infected person.[10] The pair's mask-wearing choices determine the chance of an infection.

The model is static in a sense that it is best understood as a snapshot in time, say, a week. Within a week, everyone chooses whether to wear a mask, which is costly, or not to wear a mask. Intuitively, an individual's private benefits of mask-wearing is the reduction of her infection risk. The technical difficulty lies in figuring out *by how much*, for which section 3 addresses. The model allows me to pin down the factors that vary such benefits. While formalizing free-riding in mask-wearing, I find that it does not always prevail. Strategic complementarity, a stronger incentive for an individual to wear a mask when others choose a higher chance of doing so, is uncovered as a hidden incentive that sometimes prevail. In other words, mask-wearers mutually reinforce one

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with the mask lowered; forgetting to pull the mask all the way down to fully cover the chin; and inappropriate sizing, resulting in large gaps. The worst mistake is probably reusing a mask too many times (which I must admit I have done in the past when I did not have enough masks left at home). Other issues include using low-quality masks with compromised filters, learning the differences between the different types of filter (KF94, KF99, BFE, PFE, VFE, different levels of ASTM, EN14683, etc.), and learning how to detect the validity of masks' quality certification. Any stigma on mask-wearers can increase the psychological costs too.

[7]I regard "bumping into" others as inevitable in our daily life. The word "bump" here does not strictly refer to seeing and interacting with someone directly. It can mean taking an elevator, riding a bus or train, or entering an enclosed area (such as a public toilet) that others have used previously, thereby resulting in an infection. The science lies in the fact that virus transmission can be airborne, that is, a droplets containing the viruses stay in the air even after an infected person leaves the area. Scientific studies find that coughing, sneezing, and simply breathing and talking can spread the virus; however, their findings regarding flatulence are not conclusive. One way to understand why lockdown reduces the spread of viruses is that it abruptly cuts down the number of individuals inevitably bumping into one another.

[8]While this driver proxies population density, the two notions are not exactly the same.

[9]In reality, one always has some leeway to reduce the interactions with others, such as moving indoor activities to the outdoor. The more philosophical debate is whether one is willing to give up a normal social and economic life to minimize infection. If the parameter is not a choice variable, it is as if this paper is modeling a situation in which individuals in general do not give up their social and economic life for lower infection rates but to resort to other risk-reducing strategies, such as wearing masks, washing and sanitizing hands frequently, talk and do lunch with others with a glass in-between, and others. Such a modeling approach would be inappropriate if diminishing one's social and economic life is the only approach to tackle a virus.

[10]As such, it is similar but not identical to "essential contact" used in Toxvaerd (2021). In fact, "incidental contact" used in Toxvaerd (2021) is a more closely related term. What distinguish the two terms in Toxvaerd (2021) is whether an interaction is "essential for the creation of surplus or exchange," which is yes for "essential contact" and no for "incidental contact."

another.

I derive the model's symmetric Nash equilibria in section 4. The private benefits of wearing a mask to an individual and the corresponding social benefits are equilibrium outcomes once mask-wearing is made *endogenous*, not a purely *exogenous* scientific lever that can be varied in lab experiments or in SEIR simulations. The individual private benefits, not the social ones, in turn determine the equilibrium fraction of mask-wearing population. A more empirically-inclined reader can think of the equilibrium fraction as a y variable in and of itself. Asking "how much fewer infections can raising x% of fraction of mask-wearing population result?" is analogous to putting this y variable to the right-hand-side of the estimation equation. Data may show that being an x variable now, it correlates with yet another y variable, the infection rate. The model, however, casts doubt on a causal interpretation. All the fundamental factors that co-determine these endogenous outcomes are the confounding factors. The model tells us incorporating equilibrium means the question should be rephrased as "what factors raise the fraction of mask-wearing population by x% such that the infection rate can be reduced by y%?"

One theoretical result is that under a set of parameter values, multiple equilibria can occur: one in which everyone wears a mask and the other in which none wears a mask. It not only explains polar opposite mask-wearing behaviors among some crowded places, but it also suggests one policy role of mask mandates: equilibrium refinement for the collectively superior outcome.

In section 5, I make use of the simple model to evaluate both the arguments for and effects of a mask mandate. While validating that social and private individual benefits of mask-wearing always diverge, it is not a sufficient argument for mask mandates. Subtle theoretical qualifiers must be included before scientists call for a mask mandate using the argument that people do not internalize all the benefits of wearing a mask. Matching these theoretical qualifiers with observable measures are unlikely difficult. I identify the conditions under which a mask mandate is called for, unnecessary, socially-inefficient, and incentive-incompatible such as it is doomed to fail. Economics is thus essential to complement science in evaluating mask mandates.

Several extensions are discussed in section 6, including extending to dynamic models with endogenous mask-wearing decisions.

2. Model

N players are otherwise-identical except that some are infected asymptomatically (fraction α) while others are uninfected when the game begins. While no one knows her own type, the value of α is public knowledge. Each meets randomly with M others pair-wise. After all interactions with others, everyone realizes whether she is infected that would conclude the game. I assume that when one gets infected during the game, her virus load would not grow fast enough to further infect others. Wearing a mask costs a player $c > 0$. Each player chooses her probability of wearing mask $q \in [0, 1]$. During an interaction between an uninfected and an infected player, the uninfected player's infection risk depends on the pair's mask-wearing choices as in table 1.

Table 1: The probabilities of no infection

		Uninfected	
		Mask	None
Infected	Mask	i	j
	None	k	l

Assume $0 < l < k < j < i < 1$. It is the safest for the uninfected player when both wear masks because the infection risk is the lowest (i.e., i being the largest). It is the most dangerous for the uninfected player when none wears a mask because the infection risk is the highest (i.e., l being the smallest). A mask always offers some protection (i.e., $l < k$ and $j < i$) but the strength of protection depends on who wears it; stronger if it is worn by the infected person than the uninfected person (i.e., $k < j$).

Assume $i - j < k - l$. Wearing a mask reduces the infection risk by a lesser extent if the infected person is wearing a mask than not wearing one.

An N95 mask can more effectively filter droplets (higher quality) than a bandana in the sense that N95's (i, j, k, l) are higher than those of a bandana. But the two assumptions still hold true.

How long is the game? The game does not last long enough for a newly infected person to shed enough viruses asymptomatically to infect others. The corresponding biological concept is an amount of time shorter than the minimum of [1] the duration requires for a newly infected person to start the shedding of enough viruses to infect others, and [2] the duration for symptoms

to show up.[11]

After interacting with M other players, each player realizes if she is infected. Her payoff is normalized to 0 if she is infected and 1 if she remains healthy.

The solution concept is Nash equilibrium. A Nash equilibrium is an action profile $(q_1, q_2, ..., q_N)$, where the subscript indexes a player such that no one has an incentive to deviate given the others' actions. Although multiple equilibria can occur in the game, with some of them being asymmetric, I focus only on symmetric equilibria to simplify the analysis and allow the equations to look intuitive.[12]

3. Individual private benefits of mask-wearing

Suppose everyone else wears a mask with probability q. Denote by B a player's individual private benefits of wearing a mask, which equals the reduction of her infection risk (times 1, the payoff of remaining healthy). The form of B is $(1 - \alpha)\{\Pr(Healthy|Mask) - \Pr(Healthy|None)\}$ that can be expressed as:

$$B(q, \alpha, M, i, j, k, l) = (1 - \alpha)\{[(1 - \alpha) + \alpha(qi + (1 - q)k)]^M$$
$$- [(1 - \alpha) + \alpha(qj + (1 - q)l)]^M\}. \tag{1}$$

Equation (1) has the following intuition. When the game begins, she is healthy with probability $(1 - \alpha)$. The first term inside the curly bracket is $\Pr(Healthy|Mask)$, her probability of staying healthy after meeting M people when she puts on a mask. The first term inside the square bracket is the probability of meeting a healthy person; the second term is the probability of meeting an infected person without getting infected. An infected person wears a mask and no mask with probabilities q and $1 - q$, respectively; the corresponding probabilities of no infection is i and k, respectively. Increasing the number of people that she randomly "bumps" into lowering her probability of staying healthy, captured by "to the power M" due to statistical independence.

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[11]Generally, a quarantine period of 14 days is deemed long enough for most people to show symptoms. One can think of the game as lasting for less than 2 weeks.

[12]Cabral (1988) shows that in symmetric games with many players, one can understand an asymmetric pure-strategy equilibrium as an approximate outcome of the play of a specific symmetric mixed-strategy equilibrium. For instance, if the population size is large enough, then an individual expecting that only 1 in 3 people wears masks (thus, an asymmetric equilibrium) can also view everyone as having a one-third chance of wearing a mask. Therefore, the focus of symmetric equilibria instead of all equilibria does not appear to incur much loss while the clarity improves.

Similar construction goes for the second term inside the curly bracket, which is Pr(*Healthy|None*), the probability of staying healthy after meeting M people without a mask.

Figure 1: The shape of individual private benefits of mask-wearing B across q depends on M
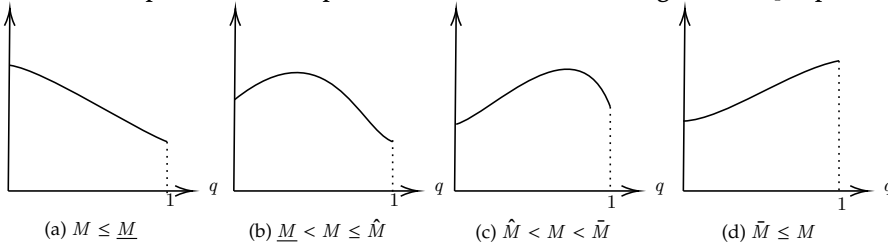

(a) $M \leq \underline{M}$ (b) $\underline{M} < M \leq \hat{M}$ (c) $\hat{M} < M < \bar{M}$ (d) $\bar{M} \leq M$

Figure 1 visualizes B when everyone else wears a mask with probability q. Appendix A gives the formal proofs of B's dependence on M. I double-check these shapes with simulations using different parameter values (Appendix B shows some). Figure 1's three thresholds are defined as:

$$\underline{M} \equiv \arg\sup_{M}\{M \in \mathbb{Z}^+ | \frac{\partial B(q, \alpha, M, i, j, k, l)}{\partial q} < 0\} \quad \forall q \in [0,1]$$

$$\bar{M} \equiv \arg\inf_{M}\{M \in \mathbb{Z}^+ | \frac{\partial B(q, \alpha, M, i, j, k, l)}{\partial q} > 0\} \quad \forall q \in [0,1]$$

$$\hat{M} \equiv \arg\sup_{M}\{M \in \mathbb{Z}^+ | B(0, \alpha, \hat{M}, i, j, k, l) > B(1, \alpha, \hat{M}, i, j, k, l)\}$$

The visualization formalizes the notion of free-riding in mask-wearing, a more-mentioned incentive problem that motivates mask mandates in some places. The visualization also uncovers a seldom-mentioned incentive: strategic complementarity among mask-wearers.

Free-riding: When $M \leq \hat{M}$, there exists a range of q within which B slopes downward in q. One's incentive to wear a mask *weakens* when everyone else chooses a higher probability to wear a mask. More formally, wearing masks are strategic substitutes among players. This problem is a more-mentioned incentive problem in the pandemic that motivates mask mandates in some places. It, however, does not always exist.

Strategic complementarity: Surprisingly, mask-wearing can exhibit strategic complementarity among players too. When $M \geq \hat{M}$, there exists a range of q within which B slopes upward in q. One's incentive to wear a mask *strengthens* when everyone else chooses a higher probability to

wear a mask. I am not aware of anyone ever mentioning this incentive. Masks can matter more with a large enough M because infection risk becomes high. The intuition is that increasing the others' probability of wearing masks moderates the infection risk, incentivizing a person to also wear a mask to stay healthy. This hidden incentive replaces free-riding when M is large enough. Mask-wearers under this hidden incentive mutually reinforce one another.

4. Equilibrium

4.1. Equilibrium characterization

In equilibrium, every player wears a mask if $B > c$, and does not if otherwise. Everyone randomizes if $B = c$ as the following proposition states.[13] The following proposition formalizes the equilibrium.

Proposition 1 *Equilibrium action profiles include*

(a) $(1, 1, ..., 1)$ if $c \leq B(1, \alpha, M, i, j, k, l)$;

(b) $(0, 0, ..., 0)$ if $c \geq B(0, \alpha, M, i, j, k, l)$;

(c) $(q^*, q^*, ..., q^*)$ if $c = B(q^*, \alpha, M, i, j, k, l)$ for $q^* \in (0, 1)$.

The intuition for the everyone-wears-a-mask pure-strategy action profile in (a) to be a Nash equilibrium is that when everyone else is wearing a mask ($q = 1$), the individual private benefits of mask-wearing higher than its cost. Then when everyone is wearing one, no one can raise her payoff by deviating to any $q < 1$.

The intuition for the none-wears-a-mask pure-strategy action profile in (b) to be a Nash equilibrium is that when everyone else is wearing no mask ($q = 0$), the individual private benefits of mask-wearing lower than its cost. Then when none is wearing one, no one can raise her payoff by deviating to any $q > 0$.

The intuition for the mixed-strategy action profile in (b) to be a Nash equilibrium is when the cost of wearing a mask happens to cut through the B curve at $q^* \in (0, 1)$, that particular point which the specific q^* characterizes is such that $B = c$, meaning that everyone randomizes at exactly that probability with no one having any incentive to deviate to another q.

The overall intuition is that whenever the cost of wearing a mask is sufficiently low, it is in

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[13]To prove it, given everyone else's mask-wearing probabilities, no deviation can increase anyone's payoff.

the interest of everyone to wear a mask, and vice versa. How low the cost has to go below which universal mask wearing would be voluntarily adopted by the population depends on the other fundamental factors: [1] α: the fraction of people expected to have been infected without showing symptoms yet; [2] (i, j, k, l): the filtration efficiencies of the masks; and [3] M: the number of people one inevitably "bumps" into periodically to carry on a normal life. From equation (1) and the simulations shown in figure 3, the threshold varies non-linearly with these parameters.

4.1.1. Policy implications

Despite strategic concerns that may trigger a call for mask mandates, the model suggests a simple and effective policy instrument to encourage more to wear masks: reduce the cost of doing so c.

One can understand U.S. Centers for Disease Control and Prevention's reversal from advising against wearing masks to recommending cloth face coverings on April 4, 2020 as a clever attempt to push down c as much as possible while simultaneously getting around the Food and Drug Administration (FDA) regulations on medical and non-medical-grade masks.[14] Certainly, cloth face coverings filter tiny particles less effectively than regular masks. One can view the policy as a quality-versus-compliance trade-off: lower quality "masks" (such as a bandana) yields higher compliance rate due to its low cost: more fashionable, ready-accessible from home, re-usable, etc. Leung *et al.* (2020) show that even a low-quality, not particularly well-fitted mask is effective in trapping droplets from the wearer. The quality-versus-compliance trade-off is a calculation that the model can shed some light on through simulations, as I show in figure 3 and explained in Appendix B.

An interesting decentralized episode happened in Czech Republic: Petr Ludwig, a key opinion leader, made a video on March 14, 2020 to discuss the rationale of wearing masks that went viral.[15] The video might have been instrumental in reducing Czechs' psychological costs of wearing a mask. If there is a general perception that wearing a mask signifies weakness, the

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[14]Source: Matzko, Paul. (2020 Apr 1) "To help solve the surgical mask shortage, get the FDA out of the way." *New York Daily News* Retrieved from https://www.nydailynews.com/opinion/ny-oped-surgical-masks-fda-20200401-vlwe72h76bb53hibyf5ddu6mou-story.html
FDA publishes "Face Masks, Including Surgical Masks, and Respirators for COVID-19," (the latest update as of Nov 24, 2020) that list its regulations of face masks. Source: https://www.fda.gov/medical-devices/coronavirus-covid-19-and-medical-devices/face-masks-including-surgical-masks-and-respirators-covid-19 FDA did not issue Emergency Use Authorizations (EUAs) of masks under the Federal Food, Drug, and Cosmetic Act until as late as August 5, 2020. Source: The authorization letter from the chief scientist of FDA at https://www.fda.gov/media/140894/download
[15]Abaluck *et al.* (2020) mention this interesting episode as well.

psychological costs of wearing a mask can be substantial. Petr Ludwig might have greatly reduced such costs in Czech Republic.

A much trickier policy some politicians have advocated is to enact anti-price-gouging law on masks. Cabral & Xu (2020) report that "from mid January to mid March 2020, 3M masks were priced 2.72 times higher than Amazon sold them in 2019." A 2020 March report by the U.S. Public Interest Research Group criticizes Amazon's inability to stop mask price from rising, reporting that "thousands of Americans have signed an online petition asking Amazon's CEO Jeff Bezos to set hard price protections that prevent gouging before it happens."[16] Senator Edward J. Markey urged the Federal Trade Commission in an open letter dated Mar 10, 2020 to protect consumers by imposing anti-price-gouging policies on medical supplies, including masks, hand sanitizer, and disinfecting wipes.[17] On April 2, 2020, the Department of Justice had a press release entitled "Department of Justice and Department of Health and Human Services Partner to Distribute More Than Half a Million Medical Supplies Confiscated from Price Gougers."[18] It writes: "If you are amassing critical medical equipment for the purpose of selling it at exorbitant prices, you can expect a knock at your door," said the then Attorney General William P. Barr. "The Department of Justice's COVID-19 Hoarding and Price Gouging Task Force is working tirelessly around the clock with all our law enforcement partners to ensure that bad actors cannot illicitly profit from the COVID-19 pandemic facing our nation." How large is the actual price of a mask as a fraction of c, the overall cost of wearing a mask, is an empirical question, possibly varying substantially across places too. No study has yet given an estimate, rendering it difficult to judge whether preventing the prices of masks from going up can effectively bring down c. My model also does not have the necessary dynamic structure to assess whether anti-price-gouging laws on masks are good or bad policies. High prices are in theory important in attracting firms to produce more masks but whether, by how much, and how fast they do are empirical questions. While iPhone assembler FoxConn and automaker SGMW might have switched to producing masks due to politics but not market incentives, quite a few new firms sprung up to produce masks in Hong Kong, a place

---

[16]Source: Garber, Adam (2020 Mar 11) "Coronavirus worry triggers most surgical mask, sanitizer prices to spike at least 50% on Amazon." The U.S. Public Interest Research Group. Retrieved from https://uspirg.org/news/usp/coronavirus-worry-triggers-most-surgical-mask-sanitizer-prices-spike-least-50-amazon

[17]Senator Markye's open letter is accessible from: https://www.markey.senate.gov/imo/media/doc/Letter%20--%20FTC%20on%20Coronavirus%203-10-20.pdf

[18]Source: The official website of Department of Justice. https://www.justice.gov/opa/pr/department-justice-and-department-health-and-human-services-partner-distribute-more-half

where one politician advocated anti-price-gouging laws on masks that went unnoticed, driving the prices of masks down eventually.[19]

4.1.2. Empirical implications

The expected reproductive number is one equilibrium outcome of interest. At the beginning of the game with α fraction of the players already infected, M, c, and the mask's filtration efficiencies pin down the equilibrium $q^* = f(\alpha, i, j, k, l, M, c)$ according to Proposition 1. Among those $(1-\alpha)$ healthy players, each has the following probability of staying healthy:

$$
\begin{aligned}
\Pr(\textit{Healthy}) = & q^* \Pr(\textit{Healthy}|\textit{Mask}) - (1 - q^*) \Pr(\textit{Healthy}|\textit{None}) \\
= & q^* ((1 - \alpha) + \alpha(q^* i + (1 - q^*) k))^M \\
& + (1 - q^*)((1 - \alpha) + \alpha(q^* j + (1 - q^*) l))^M.
\end{aligned}
\tag{2}
$$

Thus, the expected number of healthy individuals getting infected during the game is $(1-\alpha)[1 - \Pr(\textit{Healthy})]$. Dividing this number by the number of already infected individuals yields the *economic* reproductive number in epidemiology:[20]

$$
\begin{aligned}
R_0(q^*) = & \frac{1 - \alpha}{\alpha} \Big[1 - \big[q^* ((1 - \alpha) + \alpha(q^* i + (1 - q^*) k))^M \\
& + (1 - q^*)((1 - \alpha) + \alpha(q^* j + (1 - q^*) l))^M \big] \Big].
\end{aligned}
\tag{5}
$$

In words, the model implies both the infection rate R_0 and the mask-wearing behaviors of the players q are equilibrium outcomes determined by parameters $(\alpha, i, j, k, l, M, c)$.

When researchers attempt to empirically assess whether mask-wearing significantly reduces infection rate, they may have in mind collecting data across time and space regarding the infection

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[19]Source: "More plants join mask production to fight coronavirus." Xinhua (Feb 11, 2020) http://www.xinhuanet.com/english/2020-02/11/c_138774547.htm

[20]The scientific benchmark, however, does not take mask-wearing as an endogenous choice of an individual. Therefore, no equilibrium concept exists in the computation. The *scientific* reproductive number in epidemiology is

$$
R_0(1) = \frac{1 - \alpha}{\alpha} \Big[1 - \big[(1 - \alpha) + \alpha i \big]^M \Big],
\tag{3}
$$

if somehow everyone wears a mask and

$$
R_0(0) = \frac{1 - \alpha}{\alpha} \Big[1 - \big[(1 - \alpha) + \alpha l \big]^M \Big],
\tag{4}
$$

if no one wears a mask. Clearly, $R_0(q^*) \in [R_0(0), R_0(1)]$.

rates and fraction of mask-wearers.[21] They may then estimate the following equation:

$$\text{Infection rate}_t = \alpha + \beta \text{Fraction of mask-wearers}_t + \Gamma \textbf{Controls}_t + \text{Error}_t, \qquad (6)$$

where t can be either cross-sectional, time-series, or both. The model suggests that the estimation yields a biased estimate of β if $(\alpha, i, j, k, l, M, c)$ are not controlled for because they are the confounding factors. If these parameters have already been controlled for in estimation, there is no theoretical reason to expect that β is significantly negative.[22] No matter how strong is a significantly negative relationship between infection rate and fraction of mask-wearers in an empirical study, the estimate must be interpreted with caution; it may not be of any use for guiding policies of mask mandates.

4.2. Polar opposite mask-wearing behaviors among crowded places:

Combining Proposition 1(a) and 1(b) allows us to see the potential multiple equilbria: both action profiles $(0, 0, ..., 0)$ and $(1, 1, ..., 1)$ are equilibria when $B(0, \alpha, M, i, j, k, l) \leq c \leq B(1, \alpha, M, i, j, k, l)$. Figure 3 shows that it is possible for $B(0, \alpha, M, i, j, k, l) < B(1, \alpha, M, i, j, k, l)$ when $M > \hat{M}$.

Corollary 1 *For* $M > \hat{M}$, *if* $B(0, \alpha, M, i, j, k, l) \leq c \leq B(1, \alpha, M, i, j, k, l)$, *then both action profiles* $(0, 0, ..., 0)$ *and* $(1, 1, ..., 1)$ *are equilibria.*

What does a large enough M mean? If one takes the view that people in a crowded place cannot avoid "bumping" into many people in order to carry on a normal life, then the model shows that everyone-wears-a-mask and none-wears-a-mask can both be equilibria in a crowded place. The model thus offers an economic explanation for the difference between Hong Kong (where everyone wears masks (Cowling *et al.*, 2020)) and other equally crowded places such as Manhattan (where only a few wear masks in the beginning of the pandemic) *without* assuming ad hoc differences.

---

[21]Examining the infection rates of 42 countries differ in terms of the norms of mask wearing, Abaluck *et al.* (2020) recommend universal mask wearing.

[22]Think of the parameters as a vector of confounding factors Z that simultaneously determine x (Fraction of mask-wearers) and y (Infection rate). Then, x should not be correlated with y after Z is controlled for.

4.2.1. Policy implications

In crowded places where meeting many people is inevitable to carry on a normal life, when the cost of wearing a mask falls between the private benefits of everyone and none wearing a mask, both no-one-wears-masks and everyone-wears-masks are equilibria. The policy implication is that a mask mandate in such an area where it happens to have none wearing a mask can be regarded as an equilibrium refinement. It "refines" the equilibrium away from the no-one-wears-masks equilibrium to the everyone-wears-masks equilibrium without any incentive incompatibility.

The model thus allows policy-makers to identify the range of parameters within which a mask mandate can indeed be regarded as such an equilibrium refinement. On the flip side, the model also informs policy-makers when a mask mandate is *not* such an equilibrium refinement. Precisely, it is when M, which proxies population density, is not high enough. And the cost of wearing-mask c appears unlikely to be between $B(0, \alpha, M, i, j, k, l)$ (individual private mask-wearing benefits when none wears a mask) and $B(1, \alpha, M, i, j, k, l)$ (individual private mask-wearing benefits when everyone wears a mask). Under these conditions, mask mandates would be incentive-incompatible for people to comply.

So far, I have not considered a mask mandate as a public policy that punishes non-wearers. Suppose with $s\%$ chance a non-wearer would get caught and be fined f, it can be reflected in the model by an upward shift of B for everyone by sf. It is trivial to see that with a big enough chance of being caught and a large enough fine, B can get shifted up enough to make a mask mandate works. Not only is such a shift mechanically, and therefore uninteresting, but there are also numerous factors that constraint f and s from rising. Manpower can be inadequate to enforce. It can also be politically infeasible to put non-wearers in jail. Perhaps infeasible punishment and inadequate manpower have motivated the use of social forms of enforcement and punishment. When discussing his mask mandate executive order, Governor Larry Hogan elevated "wearing masks" to a new moral high ground by arguing that not doing so infringes others' rights:

> "Some people have said that covering their face infringes on their rights. This isn't just about your rights or protecting yourself. It's about protecting your neighbors, and the best science that we have shows that people might not know that they're carriers of the virus and through no fault of their own, they could infect other people. Spreading this

disease infringes on your neighbor's rights."[23]

4.2.2. *Empirical implications*

When would a comparison between a place with everyone wearing a mask and another with none wearing a mask be an apple-to-apple comparison?[24] Corollary 1 suggests that if we are certain that the pair of places are otherwise identical except that one "refines" its equilibrium to no-one-wears-masks while the other "refines" its equilibrium to everyone-wears-masks, then the comparison truly reflects the extent to which universal mask wearing reduces infection rate as compared to none wearing a mask. A rule of thumb is that both places must be densely populated enough with an intermediate cost of wearing a mask faced by the individuals. Comparing Los Angeles and New York City appears to be more appropriate than Miami and New York City.

Corollary 1 may guide econometricians to develop the appropriate propensity scores to match pairs of places in order to assess the usefulness of mask mandates as a policy tool to reduce infection rate.

Another empirical implication calls for reverting back to the golden standard of empirical works: randomization. In a work-in-progress, a group led by Yale researchers conducted randomized trials in Bangladesh around the end of 2020 where free masks are given through door-to-door visits and at markets and mosques.[25] Some receive cloth masks while others receive surgical masks. The randomized trials allow them to draw a casual relationship between mask-wearing and infection rate.

4.3. *Randomization*

Proposition 1(c) states players may randomize, which explains those areas where only a fraction of the population wear masks. Figure 1 shows one such mixed-strategy equilibrium exists in the following situations.

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[23]Miller, Stetson (2020 Apr 18) "Coronavirus Latest: Executive Order Requiring Face Coverings In All Maryland Businesses, Public Transit Goes Into Effect" *CBS Baltimore* Retrieved from https://baltimore.cbslocal.com/2020/04/18/coronavirus-latest-face-coverings-executive-order-maryland

[24]One study that is unlikely an apples-to-apples comparison is Cheng *et al.* (2020). Comparing Hong Kong to other crowded cities from the last day of 2019 till early April of 2020, they report a negative relation between mask-wearing and infection rates.

[25]The work-in-progress is entitled "Face Masks to Reduce COVID-19 in Bangladesh." More unpublished details are given in https://clinicaltrials.gov/ct2/show/record/NCT04630054

(i) For $M \leq \hat{M}$, it is when $B(1, \alpha, M, i, j, k, l) < c < B(0, \alpha, M, i, j, k, l)$;

(ii) For $M > \hat{M}$, it is when $B(0, \alpha, M, i, j, k, l) < c < B(1, \alpha, M, i, j, k, l)$;

(iii) For $\underline{M} < M < \bar{M}$, it is when $c = max_q B(q, \alpha, M, i, j, k, l)$.

Two such mixed-strategy equilibria exist in the following situations.

(iv) For $\underline{M} < M \leq \hat{M}$, it is when $B(0, \alpha, M, i, j, k, l) < c < max_q B(q, \alpha, M, i, j, k, l)$;

(v) For $\hat{M} < M < \bar{M}$, it is when $B(1, \alpha, M, i, j, k, l) < c < max_q B(q, \alpha, M, i, j, k, l)$.

Echenique & Edlin (2004) prove that strict strategic complementarity(B increases in q) makes mixed-strategy equilibrium unstable, applying to (ii) and the one with smaller probabilities in (iv) and (v).

5. Mask mandates?

5.1. The conventional arguments revisited

Does the model imply that endogenizing individuals' mask-wearing choices invalidates the policy arguments for mask mandates? If so, what is a valid argument for mask mandates?[26]

Recall that due to the public good nature of mask-wearing that invites free-riders, individual rationality does not necessarily lead to collective rationality. Figure 1 shows that free-riding sometimes but not always happen and strategic complementarity among players in mask-wearing is a hidden incentive. It means free-riding is sometimes a valid argument for mask mandates but not all the time.

Proposition 1 states that everyone-wears-a-mask is an equilibrium under certain conditions even without a mask mandate. Under those conditions, the notion that wearing-mask is a public good that calls for mask mandates is an invalid argument.

---

[26]Whether there is a mask mandate and the enforcement effort vary across places and over time. Feng *et al.* (2020) survey the recommendations and policies across different places concerning the use of face masks. The U.S. Center for Disease Control and Prevention and the Singaporean government did not recommend mask wearing in public until early April. Abaluck *et al.* (2020) carefully sort out the countries in their sample that changed their mask policies, including Switzerland, Austria, Czech, Australia, Romania, Thailand, Bulgaria, and Singapore. Hong Kong's chief executive commanded the public officials not to wear masks in February 2020, for which most ignored. She retracted her command the next day. The French government restricted the use of masks to medical professionals at the beginning of the pandemic. Oxford systematically collects up-to-date policy measures to tackle the virus and publishes its Stringency Index (Hale *et al.*, 2020). Their dataset does not explicitly collect the various mask policies used around the world. I have yet to locate a comprehensive database on mask mandates and mask-related policies that are consistently measured and comparable across places and time.

5.2. One valid argument based on the model

I show that under certain conditions a mask mandate is still called for after incorporating individuals' endogenous mask-wearing choices. The conditions are rather subtle. To begin with, note that the actual enforcement renders it inappropriate just to compare the equilibrium outcome of the social planner's problem with the decentralized model's outcome.[27]

Second, note that universal mask wearing yields higher social surplus when c is lower than individual social benefits. I denote individual social benefits by B^*, which is computed as follows:

$$B^*(\alpha, M, i, l) = (1 - \alpha)\{[(1 - \alpha) + \alpha i]^M - [(1 - \alpha) + \alpha l]^M\}, \tag{7}$$

where the first square bracket is the probability for a healthy player to stay healthy after meeting M people under universal mask wearing with a mask, while the second square bracket is the probability for a healthy player to stay healthy after meeting M people without a mask when no one else masks one too. At the beginning of the game, only $(1 - \alpha)$ fraction of the players are uninfected; therefore, the first term scales back the individual social benefits.

Recall that I assume $0 < l < k < j < i < 1$, which implies

$$B^*(\alpha, M, i, l) > B(q, \alpha, M, i, j, k, l) \text{ for all } q \in [0, 1]. \tag{8}$$

In words, it means that an individual player's private benefits of wearing a mask is always below her social benefits of wearing a mask. Putting it differently, an individual's choice of wearing a mask brings certain benefits to the society but only a fraction of which that individual would internalize. Despite the presence of strategic complementarity of mask-wearing among players under certain conditions, this social-versus-private divergence always exists.[28] Its magnitude depends on the

---

[27]I can write out the social planner's problem as:

$$max_q N\left\{(1 - \alpha)\left[(1 - \alpha) + \alpha(q^2 i + q(1 - q)(j + k) + (1 - q)^2 l)\right]^M - cq\right\}.$$

It is easy to find a range of parameters such that the socially optimal q falls between 0 and 1. Alas, even if social optimum calls for, say, everyone to wear a mask only 65% of the time, the enforcement can only be all or nothing, rendering these special cases uninteresting.

[28]Abaluck *et al.* (2020) recommend universal mask wearing partly based on their expressed concern about the divergence of the private and social benefits of mask wearing. They advocate the emphasis on the social benefits of mask wearing so as to motivate more people to wear masks. My model theoretically confirms their divergence prediction.

parameters, for which the simulations in figure 3 gives us a glimpse. However, the mere divergence between individual social and private benefits is *insufficient* to call for a mask mandate.

Figure 2: Categorizing scenarios (a) and (b) that rank social and private benefits differently
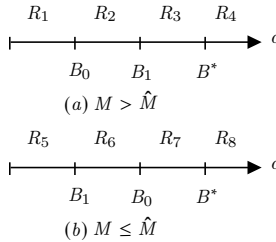

$$R_1 \quad R_2 \quad R_3 \quad R_4$$

$$c$$

$$B_0 \quad B_1 \quad B^*$$

$$(a) \; M > \hat{M}$$

$$R_5 \quad R_6 \quad R_7 \quad R_8$$

$$c$$

$$B_1 \quad B_0 \quad B^*$$

$$(b) \; M \le \hat{M}$$

Figure 2 categorizes two scenarios: (a) for sufficiently large M and (b) for smaller M. The categorization allows me to rank the individual social benefits of mask-wearing, as well as the individual private benefits of mask-wearing when everyone else and none wears a mask (for brevity I denote them by $B_1 = B(1, \alpha, M, i, j, k, l)$ and $B_0 = B(0, \alpha, M, i, j, k, l)$, respectively).

As stated above, the social incentives are stronger than the private ones. I further divide scenarios (a) and (b) into 8 cases depending on the cost of mask-wearing, c. Among these 8 cases, only case R_2 calls for mask mandates, precisely the case described in Corollary 1.

Both cases R_1 and R_5 yield unique equilibrium in which everyone wears a mask, rendering a mask mandate unnecessary. Both cases R_4 and R_8 feature extremely high mask-wearing cost, rendering it socially inefficient to wear a mask even if doing so reduces infection rate. Therefore, a mask mandate should not be called for.

Cases R_3, R_6 and R_7 appear the usual suspects of policy interventions in which it is socially beneficial for everyone to wear a mask, yet decentralized individuals lack the private incentives to do so. The reason why a mask mandate should not be called for is not because it is socially inefficient to do so, but because even if there is a mask mandate, it is incentive-incompatible and therefore destined to yield low compliance.

Only in Case R_2 can a mask mandate be incentive-compatible for individual players to comply. Of course, Corollary 1 suggests that everyone-wears-a-mask might have already been the equilibrium.

When would a mask mandate work? At the risk of repeating section 4.2.1, at the minimum the policy-makers should have a sense of whether parameters $(M, c, \alpha, i, j, k, l)$ fall within the

parameter space for both no-one-wears-masks and everyone-wears-masks to be equilibria, as summarized in Corollary 1. If it is likely the case, a mask mandate helps "refine the equilibrium" away from the no-one-wears-masks to everyone-wears-masks. Otherwise, a mask mandate is not called for because it is either socially inefficient (cases R_4 and R_8), incentive-incompatible (cases R_3, R_6 and R_7), or unnecessary (cases R_1 and R_5; and when everyone-wears-a-mask is already equilibrium in case R_2). This is the case despite the fact that individuals always fail to fully internalize the social benefits of their choices of wearing a mask.

6. Concluding remarks

Science alone cannot pin down a virus's contagiousness/infection rate when people endogenously choose whether to wear masks. They are both equilibrium outcomes co-determined by a bunch of other more fundamental variables, which takes into consideration people's inter-dependence and strategic interactions. Placing these outcomes under the equilibrium lens renders empirical statements such as "raising $x\%$ of fraction of mask-wearing population reduces the infection rate by $y\%$" confusing because $x\%$ fraction more people endogenously choose to wear masks in response to some changes in those more fundamental variables, which ought to simultaneously change a virus's contagiousness/infection rate too. Empirically, those more fundamental variables can be regarded as confounding factors that determine both the fraction of mask-wearers and virus's contagiousness/infection rate. The model thus calls for cautiousness in interpreting a significantly negative relationship between mask-wearing and infection rate. Evaluating mask mandates using masks' scientific properties alone may give wrongheaded policy recommendations.

My model, as simple as it is, offers three uses: [1] Calculate the *economic* reproductive number incorporating equilibrium decisions, thus different from those calculated in epidemiology. [2] Simulate, like figure 3, to help evaluate whether mask mandates would work, predict compliance, and calculate quality-versus-compliance trade-off. [3] Enrich a dynamic SEIR model. The structure of the model is deliberately made simple enough such that it is not difficult to be incorporated into dynamic SEIR models featuring endogenous mask-wearing decisions.[29]

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[29]One way how it can be done is as follows: Repeat the game indefinitely. Calibrate $\beta/(\beta + \alpha)$ as the probability for an infected person to show symptoms within a period; they either drop out of the game forever or come back after a certain recovery period. The remaining $\alpha/(\beta + \alpha)$ fraction plays one round together with $(1-\alpha)$ healthy persons. In each round, people make mask-wearing decisions depending on their updated beliefs of the fraction of infected remaining

The model relates closely to the model of Toxvaerd (2021). It features a binary decision among a pair of individuals to decide whether to expose to each other. The two individuals can be altruistic or non-altruistic depending on a parameter. When contacts are "incidental," only infection externalities are present; when contacts are "essential," both infection and socioeconomic externalities are present. Toxvaerd (2021) finds that compared to the social optimum, too much exposure happens in the former while too little exposure happens in the latter. My model features more than two individuals but do not distinguish interactions among them into "incidental" versus "essential." While a fixed number of interactions are assumed (i.e., parameter M), each player has a binary choice of whether to wear a mask or not, which is similar to the exposure decision in Toxvaerd (2021). I assume players are non-altruistic instead.

My model may be extended in three theoretical directions: [1] Exogenously heterogeneous individuals. [2] Interactions with other policies, such as lockdowns or vaccines. [3] Endogenizing heterogeneity across individuals, such as vaccines going to certain groups before others, in turn creating endogenous heterogeneity across individuals.

In terms of public policy, a future extension is to make use of the model to study the allocation of masks (and possibly other types of personal protective equipment [PPE]) across regions with varying supplies of masks and PPE. This modification can be achieved by modeling more than one region facing issues of individual endogenous mask-wearing decisions. As an example, although Manila is extremely crowded, the Philippines has other less crowded regions. The infection rates across regions probably differ. Suppose that masks and other PPE are of limited supply. How should the government allocate them to achieve the most positive effects for the country? How would the socially optimal allocation depend on changing infection rates, crowdedness, and mask quality? Can this within-country allocation problem be applied across countries with different infection rates and other factors?

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in the game. Simulation in such a infinite game can show infection trends. More interestingly, one can show how two otherwise similar places picking different equilibrium would end up having rather different infection curves.

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Figure 3: Simulations with 4 α and 3 mask quality levels: (B of $q = 0$(gray), $q = 1/2$(dotted), $q = 1$(black), B^* (dashed)
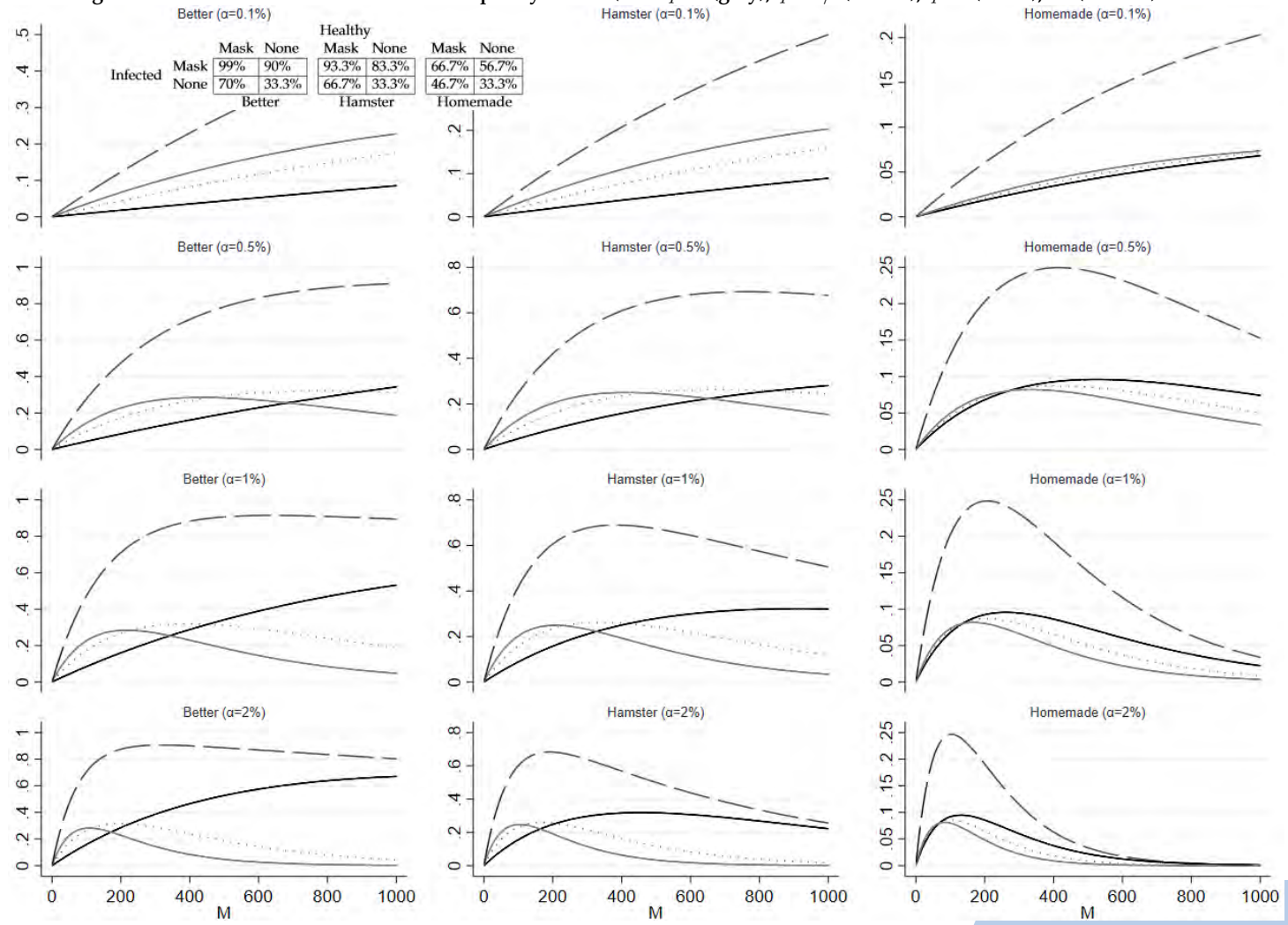
A. Proving figure 1 with two lemmas

Lemma 1 *With a small α, B first increases in M and then decreases in M.*

Proof B first increases and then decreases in M because a mask does not matter if the infection risk is either extremely high or low. When $M = 0$ (zero infection risk) and $M = \infty$ (destined to get infected), $B = 0$.

In (1), $(1-\alpha)$ is a scalar. Define $A \equiv [(1-\alpha) + \alpha(qi + (1-q)k)]$ and $D \equiv [(1-\alpha) + \alpha(qj + (1-q)l)]$. Increasing M by 1 changes the curly bracket in (1) by $\{A^{M+1} - D^{M+1}\} - \{A^M - D^M\}$, which is positive iff

$$(\frac{D}{A})^M > \frac{1-A}{1-D}. \tag{9}$$

As $0 < D < A < 1$, $\frac{D}{A} < 1$, which implies LHS of (9) decreases in M monotonically. RHS of (9), $\frac{1-A}{1-D}$ is a constant less than 1. If $(\frac{D}{A})^M > \frac{1-A}{1-D}$ when M is small, further increasing M eventually upset this inequality, implying increasing M further decreases $\{A^M - D^M\}$.

If $\alpha < \frac{1}{2}$, then $D > \frac{1}{2}$. If $D > \frac{1}{2}$, then $[(A-D) + 2D] > 1$ and $\{A^2 - D^2\} > \{A - D\}$, which ensures $\{A^M - D^M\}$ first increases before decrease in M. $\qquad\square$

Lemma 2 *There exists a range of $(\underline{M}, \bar{M})$ such that*
(a) B decreases with q $\quad \forall \; M < \underline{M}$;
(b) B increases with q $\quad \forall \; M > \bar{M}$;
(c) B first increases then decreases with q $\quad \forall \; M \in [\underline{M}, \bar{M}]$.

Proof Start with

$$\frac{\partial B(q, \alpha, M, i, j, k, l)}{\partial q} = (1-\alpha)M\alpha\{(i-k)[(1-\alpha) + \alpha(qi + (1-q)k)]^{M-1} \\ - (j-l)[(1-\alpha) + \alpha(qj + (1-q)l)]^{M-1}\}.$$

For $M = 1$, $\frac{\partial B(q,\alpha,1,i,j,k,l)}{\partial q} = (1-\alpha)\alpha[(i-k) - (j-l)]$, which is negative due to the assumptions for the probabilities. For $M > 1$, $\frac{\partial B(q,\alpha,M,i,j,k,l)}{\partial q}$ is positive only if the curly bracket in (1) is positive, i.e.,

$$\frac{i-k}{j-l} > \left[\frac{(1-\alpha) + \alpha(qj + (1-q)l)}{(1-\alpha) + \alpha(qi + (1-q)k)}\right]^{M-1}. \tag{10}$$

The assumptions of the probabilities give: [1] LHS of (10) is smaller than 1 (i.e., $\frac{i-k}{j-l} < 1$); [2] RHS of (10) is a fraction smaller than 1 to the power $M - 1$, which monotonically decreases in M. When M exceeds a certain threshold $\bar{M}$, the RHS of (10) becomes smaller than LHS of (10). When M is smaller than a certain threshold $\underline{M}$, RHS must be larger than LHS (true when $M = 1$). Thus, (a) and (b).

When M increases from $\underline{M}$ to $\bar{M}$, $B(q, \alpha, M, i, j, k, l)$ transitions from everywhere decreasing in q to everywhere increasing in q. This is the case when $(\frac{(1-\alpha)+\alpha j}{(1-\alpha)+\alpha i})^{M-1} > \frac{i-k}{j-l} > (\frac{(1-\alpha)+\alpha l}{(1-\alpha)+\alpha k})^{M-1}$. The first inequality means $\frac{\partial B(q,\alpha,M,i,j,k,l)}{\partial q}$ evaluated at $q = 1$ is negative. The second inequality means $\frac{\partial B(q,\alpha,M,i,j,k,l)}{\partial q}$ evaluated at $q = 0$ is positive. Thus, (c). $\qquad\square$

B. Simulations

I use the hamsters' infection rates found in Chan *et al.* (2020) for the simulation. As no infection rate is available for both hamsters "wearing" masks, I make one up (6.7%, thus 93.3% is the probability of staying healthy). I also make up a worse set of infection rates to proxy homemade cloth face coverings, such as that recommended by the U.S. Surgeon General on April 4, 2020, and another better set. The tables in the figure shows the numbers.

I simulate the individual private benefits B of the different probabilities of everyone else wearing a mask in Figure 3 under four infection levels. I also simulate the social benefits B^*.

The simulations yield the following observations:

1. B increases and then decreases, and it tends to 0 when M becomes large. One cannot guarantee that increasing M will encourage more people to wear masks because B does not increase monotonically with M.

2. B decreases in q under small M and increases in q under large M.

3. B is positive when $M > 0$, even for low-quality homemade masks (If c is low enough, at any positive M, the scenario with everyone wearing a mask is equilibrium.)

4. α affects B non-monotonically. Therefore, one cannot claim that if the infection risk increases because more people are already infected, then more people will wear masks. It is only sometimes the case. At a certain infection level, the risk is too high for a mask to make a meaningful difference.

5. The range $(\underline{M}, \bar{M})$ appears to shrink when α increases.

6. $B^* > MB(1, \alpha, M, i, j, k, l)$.

7. The divergence between social and private benefits varies in size and can be substantial.

Monetary and fiscal complementarity in the Covid-19 pandemic[1]

Jagjit S. Chadha,[2] Luisa Corrado,[3] Jack Meaning[4] and Tobias Schuler[5]

In response to the coronavirus (Covid-19) pandemic, there has been a complementary approach to monetary and fiscal policy in the United States with the Federal Reserve System purchasing extraordinary quantities of securities and the government running a deficit of some 17% of projected GDP. The Federal Reserve pushed the discount rate close to zero and stabilised financial markets with emergency liquidity provided through a new open-ended long-term asset purchase programme. To capture the interventions, we develop a model in which the central bank uses reserves to buy much of the huge issuance of government bonds and this offsets the impact of shutdowns and lockdowns in the real economy. We show that these actions reduced lending costs and amplified the impact of supportive fiscal policies. We then run a counterfactual analysis which suggests that if the Federal Reserve had not intervened to such a degree, the economy may have experienced a significantly deeper contraction as a result from the Covid-19 pandemic.

Non-technical summary

The 2020 pandemic had the features of a perfect storm: a supply (shutdown) and demand shock (lockdown), which halted the functioning of the global economy for several months. We examine the critical role of monetary policy in offsetting these shocks and in particular in providing support for the fiscal policy interventions. We examine and calibrate the responses of the Federal Reserve in the United States, but the results can be generally interpreted as reflecting the supportive policies adopted by major central banks.

In response to the coronavirus (Covid-19) pandemic, there has been a complementary approach to monetary and fiscal policy in the United States with the Federal Reserve System purchasing extraordinary quantities of securities and the government running a deficit of some 17% of projected GDP. The Federal Reserve pushed the discount rate close to zero and stabilised financial markets with emergency liquidity, which had been a key instrument innovation during the financial crisis. In March 2020 the Federal Reserve initially implemented emergency refinancing by cutting its discount rate close to zero and by setting a USD 700 billion limit for asset purchases.

We are able to match stylised facts in the United States by implementing a shock to the velocity of money and to labour supply. To capture the interventions, we develop a model in which the central bank uses reserves to buy much of the huge issuance of government bonds and this offsets the impact of shutdowns and lockdowns in the real economy. We show that these actions reduced lending costs and amplified the impact of supportive fiscal policies.

We demonstate how a combined fiscal-monetary response helped avoid turning the Covid-19 crisis into an economic recession of even greater magnitude and severity in a counterfactual analysis. Our calibrated model shows that if the Federal Reserve had not intervened, output would have fallen by more than 10% more on impact and in the following quarter. Real wages would be down by more than 15% more and unemployment up by more than 20%. Wages would be 20% lower than with QE. As a result inflation would have fallen even further. Hence, we find that prompt, combined fiscal-monetary interventions mitigated the impact of the pandemic shocks and helped to establish a more rapid recovery to pre-crisis levels of activity.

1 Introduction

The economic consequences of the Covid-19 pandemic have been dramatic. In the United States, real GDP fell by more than 10% in the first six months of 2020 when compared with the final quarter of 2019 (Figure 1). The unemployment rate soared in April when restrictions on movements were first introduced rising by 11.2 percentage points when compared to February 2020 and almost hitting 15%. The initial impact softened somewhat. Unemployment stood at 8.4% in August 2020 and subsequently fell to 6% in March 2021. The rate of inflation, measured by the personal consumption expenditure price index, fell from 1.8% in February to 0.5% in April and May 2020, but picked up to 1% in July 2020 and was 1.6% in March 2021. We contend that a complementary monetary and fiscal strategy limited the impact of Covid-19 on the US economy.

Figure 1: US macro variables
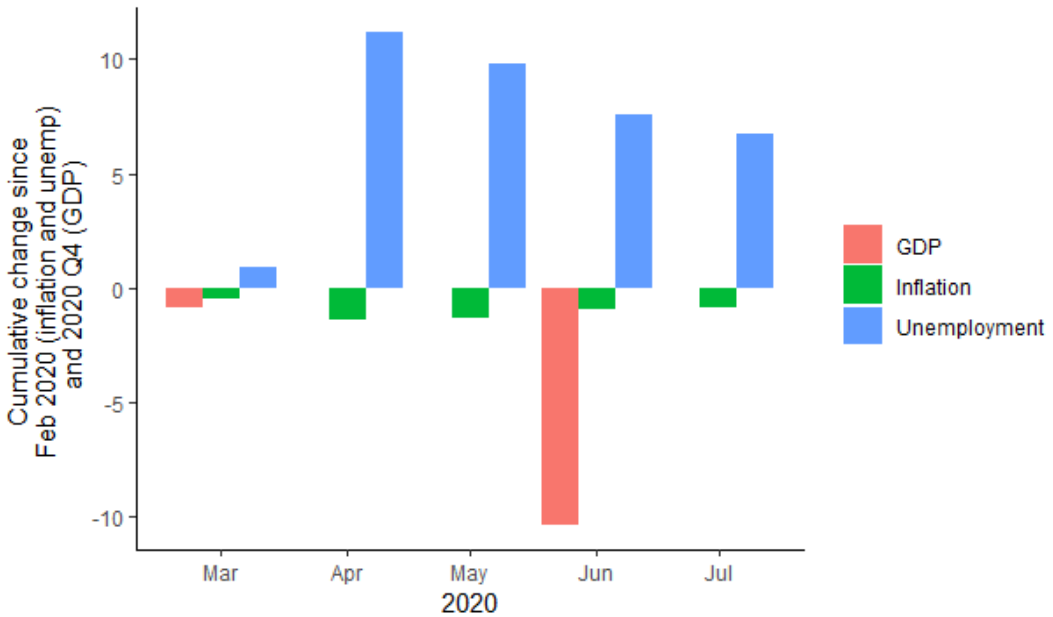
Source: Federal Reserve Bank of St Louis (FRED).

To capture the salient features of the crisis, we augment the macroeconomic model with the banking system of Chadha, Corrado, Meaning and Schuler (2020) to understand the impact of the lockdown (as a negative velocity shock), the shutdown (as a negative labour supply shock) and the fiscal response (as a positive support to aggregate demand financed by the issuance of government bonds) in conjunction with the supportive monetary policy response of the Federal

Reserve System, which we show amplified the stabilising force of discretionary fiscal policy (see Bartsch et al, 2020). In this model, the central bank uses reserves to buy government bonds with reserves to offset the shutdown and lockdown shocks in the real economy. We show that the provision of reserves stabilised the value of collateral and amplified the impact of supportive fiscal policies. The responses of monetary aggregates to the pandemic shocks, and the role they have played under the influence of monetary and fiscal policies - in the subsequent economic path provide a key feature for the calibration and aid our understanding of the economic and policy mechanisms at work during the pandemic. Our calibrated model suggests that the fall in output in the first stage of the pandemic might have been as much as twice as large, with a significant deflation, loss of employment and falls in asset prices, if such extensive fiscal and monetary policies had not been implemented (Bullard, 2020).

1.1 Monetary-fiscal interactions in response to the Covid-19 crisis

To limit the economic impact of lockdown and shutdown, the Federal Government, as many governments around the world, ran unprecedented peacetime fiscal deficits. A key feature of government debt management has been massive purchase of government securities by the Federal Reserve. The purchases began in March 2020 after market liquidity became impaired, and an initial motivation was to restore market function.

In the United States, an avalanche of debt issuance in March and April overwhelmed the capacity of primary dealers in government securities. Foreign investors also sold USD 498 billion of Treasury notes and bonds in those two months, compared with average monthly sales of USD 6 billion over the year to February 2020.[1] The Federal Open Market Committee (FOMC) promptly announced that it would purchase US Treasury securities "in the amounts needed to support smooth market functioning and effective transmission of monetary policy to broader financial conditions and the economy."[2] We interpret this steps as the Federal Reserve providing a complementary monetary policy response to support the fiscal policy response for the impact of Covid-19.

Accordingly in the United States, the Federal Reserve bought USD 1.4 trillion (gross) of Treasury coupon securities by the end of April 2020.[3] The purchase rate decreased during April and May, and by the beginning of 2021 was about USD 80 billion a month, plus USD 40 billion

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[1] See U.S. Treasury (2020).

[2] Federal Reserve (2020a).

[3] In response to the Covid-19 pandemic, the Federal Reserve resumed purchasing extraordinary quantities of securities, which had been a key instrument innovation during the financial crisis of 2008-09. In March 2020 the Federal Reserve initially implemented emergency refinancing by cutting its discount rate close to zero and by setting a USD 700 billion limit for asset purchases. After stabilising the market with emergency liquidity the Federal Reserve announced a new stream of open-ended long-term asset purchasing program in amounts judged sufficient to support the smooth functioning of markets in response to the pandemic shocks.

of mortgage-backed securities, in all about 7% of GDP (Figure 2).

Figure 2: Fed purchases and Treasury auction sales

Fed purchases (-) and US Treasury auction sales (+) of Treasury coupon securities ($), and the 10-year Treasury yield (rhs).
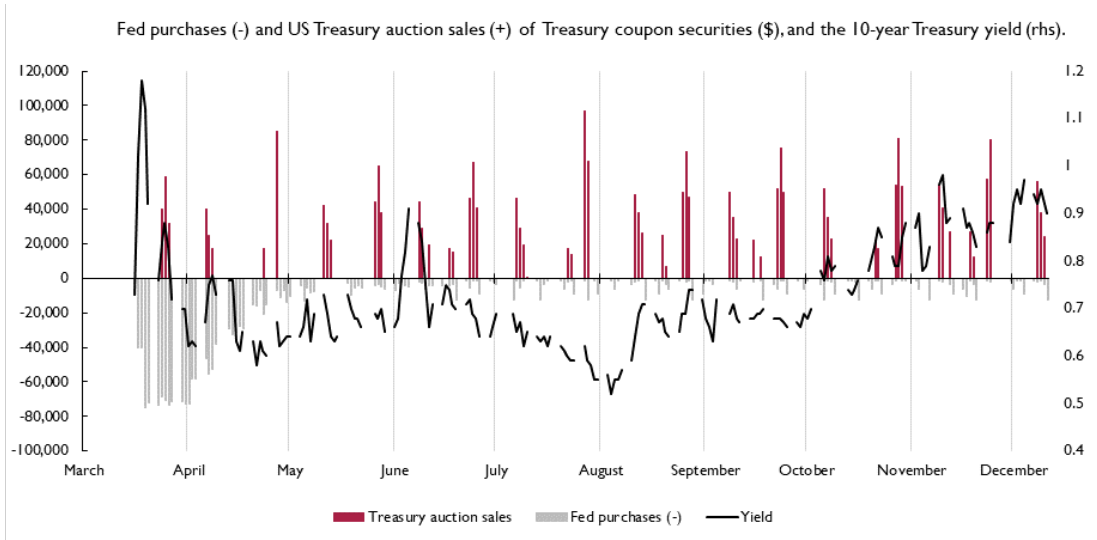
Source: Allen (2021)

The Federal Reserve has undertaken to maintain this purchase rate "until substantial further progress has been made toward the [Federal Open Market] Committee's maximum employment and price stability goals".[45]

Long-term bond yields fell after the March 2020 announcement and continued to fall until August, after which they reversed much of the earlier fall (Figure 2). The reversal was probably a reaction to the Federal Reserve's revised statement on 27 August of its longer-run inflation

[4]Federal Reserve (2020b).

[5]The expansion of narrow money directly accounted for by the Federal Reserve's QE purchases can be thought of as a "supply-driven" increase in reserves, with the quantity determined by the Federal Reserve. However, there has also been an endogenous increase in narrow money that has been more "demand-driven". As part of its response to the pandemic, the Federal Reserve also announced other policy moves, such as a lending program for businesses and facilities aimed to help markets for commercial paper, corporate debt and municipal bonds. Some of these schemes, such as the Primary Dealer Credit Facility, the Money Market Mutual Fund Liquidity Facility and the Commercial Paper Funding Facility are new iterations of programmes that were utilised in the global financial crisis of 2008-09. Others, such as the Paycheck Protection Program Liquidity Facility, are novel developments. The take up of these facilities has been an order of magnitude smaller than the expansion of reserves created by the Fed's asset purchases. Drawings on the Primary Dealer Credit Facility, the Money Market Mutual Fund Liquidity Facility, the Commercial Paper Funding Facility II and other corporate credit facilities at the Federal Reserve have totalled around USD 87 billion over the same period. Drawings on the Paycheck Protection Program Liquidity Facility increased reserves by a further USD 49 billion. It is perhaps not surprising that banks have not had a great need to draw on these funds to get liquidity when the assets purchase programme has meant that their balance sheets are already flush with liquid reserves and has dramatically increased the supply of deposits they can draw on for funding.

goals, in which the policy objective was an aim for inflation "that averages 2 per cent over time", and that it would compensate for periods of persistently below target inflation by aiming for moderately above-target inflation for a period. It might also have reflected somewhat the slower pace of purchases by the Federal Reserve.[6]

The patterns of government financing are given in Table 1. There were no substantive net sales of government coupon securities to the market; the Federal Government relied largely or exclusively on short-term financing. The ratio of short-term interest-bearing public debt (Treasury bills and deposits at the central bank) to GDP is in the range of 40 to 50%, compared with 5% in the United States at the end of 2006, before the global financial crisis.

Table 1: Central government financing, March-November 2020, United States

	Total government borrowing	Sales of coupon securities to market (net)	Financed by (1) Treasury bill sales to market (net)	Central bank purchases of Treasury securities (net)	Ratio of short-term interest-bearing debt (Treasury bills + deposits at central bank) to GDP (%)
United States (USD billion)	3,936	-700 (2)	+2,300 (2)	+2,100 (2)	40

Sources: United States: Government Accountability Office (2020), Federal Reserve System table H4-1. We thank Bill Allen and Richhild Moessner for this data.
Notes:
(1) Some financing items have been omitted, but they are not material in aggregate.
(2) Approximate. Approximations are necessary because some of the data are weekly and some monthly.
(3) Gilts only.
(4) After end of current quantitative easing (QE) programme.

1.2   The lockdown as a shock to velocity of money

The significant increase in the stock of money[7] coupled with the substantial fall in GDP has meant that the velocity of money has fallen dramatically (Figure 4).

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[6]Federal Reserve (2020c).

[7]The pandemic led to some extraordinary movements in monetary aggregates (Figure 3). US broad money (M2) increased by USD 3 trillion from the end of February to the final week of August 2020.This was a 20% increase and the largest six-month increase in broad money since at least the 1970s. This increase is reflected in the data on commercial bank deposits which increased 16% over the same period, or by USD 2.1 trillion. The monetary base has also expanded enormously, predominantly through an expansion in reserve balances held at the Fed. At their peak in May 2020, reserves reached USD 3.3 trillion, or USD 1.6 trillion more than they had been at the end of February, ; an increase of 100%. They have subsequently fallen back slightly to USD 2.8 trillion, but that still represents an increase of more than 70% relative to their pre-pandemic levels. The expansion of

Figure 3: US money aggregates
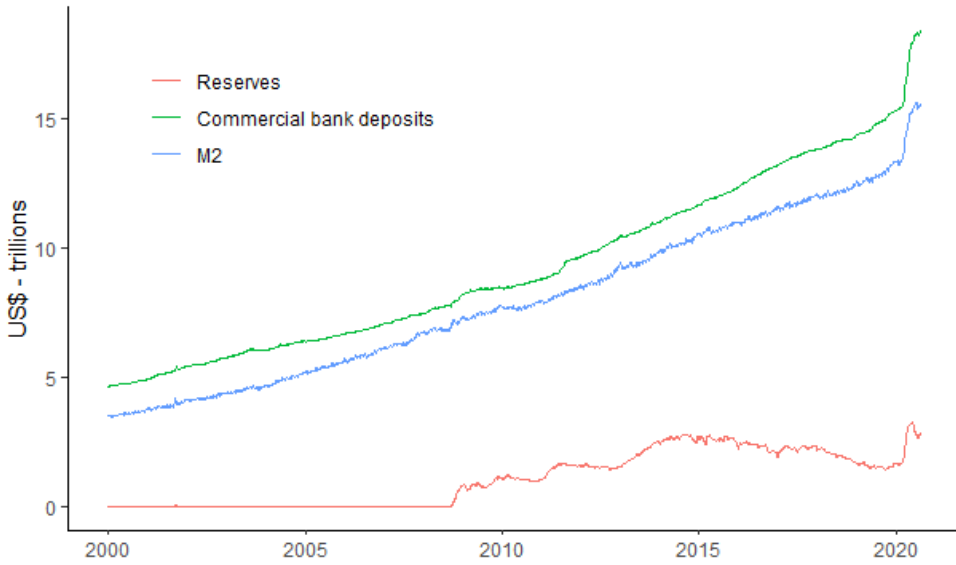
Source: Federal Reserve Bank of St Louis (FRED).

Figure 4: Velocity of US money (M2)
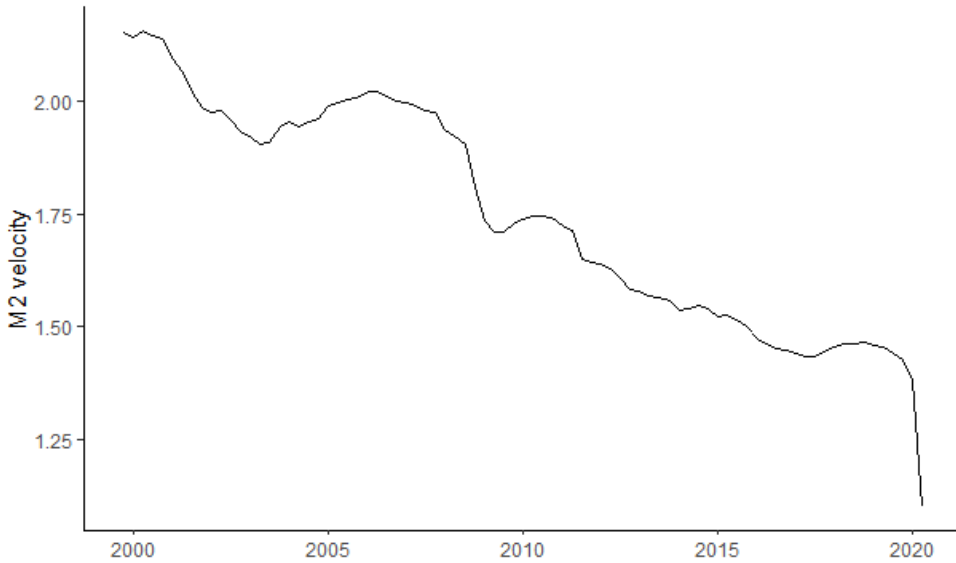
Source: FRED

Between the end of 2019 and the end of the second quarter of 2020, the ratio of M2 to nominal GDP fell more than 30 basis points, from 1.43 to just 1.10 (Table 2). This was a significantly larger and quicker fall in velocity than during the global financial crisis of 2008-09 and was likely to deepen and persist as long as the Federal Reserve continued to expand the monetary base and economic output remained weak.

Table 2: Changes in macro and monetary aggregates: February 2020 - August 2020

	Change (USD billion)	Change (%)
Real GDP		-10
PCE inflation		-0.5
Reserves	1,180	72
M2	3,030	20
Bank deposits	2,145	16

Note: Real GDP is the change between 2019 Q4 and 2020 Q2. Personal Consumption Expenditure (PCE) inflation change is in percentage points.

An important driver of the fall in velocity was the choices of households, which cut spending sharply. Note that there are likely to have been elements of both planned and forced savings and, that although the aggregate income of all households has fallen, a substantial majority of employees have been working and earning income (Bell and Blanchflower, 2020). Total household income did not fall by nearly as much as spending, largely because those who are still employed, working from home or elsewhere cut back on their purchases. Savings jumped as a result, with the personal saving rate increasing to 13.1% in March 2020, from 7.7% in January. And savings increased further over the rest of the spring, in April and early May. While authorities have forced many establishments to close, leaving workers jobless, and issued stay-at home orders ("lockdowns"), consumers also decreased their demand for many services, most likely for precautionary reasons. Furthermore, newly jobless workers reduced their consumption of all goods and services. We summarise the main stylised facts around monetary and macroeconomic variables in the first part of the crisis in Table 2.

narrow money has been driven by the Federal Reserve's policy response to the pandemic. On 15 March 2020, after an emergency meeting, the Federal Reserve announced it would purchase USD 700 billion of assets, split between Treasury securities (USD 500 billion) and mortgage-backed securities (USD 200 billion), and that these purchases would be funded by the creation of new reserves, as with other rounds of QE. On 23 March, amid a period of market dysfunction, the guidance around these purchases was changed. The Federal Reserve began to buy securities in "the amounts needed" to support smooth market functioning and the transmission of monetary policy.

1.3 Demand and supply joined at the hip

The pandemic entails both a primitive supply shock and a demand shock, and consequently, a fiscal impulse to support aggregate demand. A demand shock is a reduction in consumers' ability or willingness to purchase goods and services at given prices. People avoiding restaurants for fear of contagion or due to stay-at-home orders is an example of a demand shock. In addition, as service sector workers lose jobs and income, they reduce purchases of goods such as cars and domestic appliances, which can also be seen as a sectoral demand shock. A supply shock, on the other hand, is anything that reduces the economy's ability to produce goods and services, at given prices. Shutdown measures prevent workers from doing their jobs and can be interpreted as a supply shock. As stressed in a recent paper (Brinca, Duarte, and Faria-e-Castro, 2020), while most sectors in the United States experienced negative supply shocks, some sectors experienced small positive demand shocks. For example, some retailer benefited when people stopped going to restaurants and started buying more groceries to cook at home.[8] The paper's results suggest that labour supply shocks accounted for most of the fall in hours worked in March and April 2020, but demand shocks were also important.[9]

A further aspect of the crisis was that fiscal policy provided prompt and profound support for the economy and the central bank, rather than responding to the injection of demand by seeking to tighten monetary and financial conditions, created space for the fiscal authority by easing funding costs. This was achieved by reducing the net supply of bonds that had to be absorbed by the private sector and by directly affecting the yield curve by lowering the federal funds rate and making supportive statements about the future stance of policy (see Barwell, Chadha and Grady, 2020).

This paper is organised as follows. Section 2 discusses relevant literature. Section 3 describes the model and outlines our approach to modelling monetary and fiscal responses to the Covid-19 pandemic shocks. Section 4 gives the calibration of the quantitative model, Section 5 outlines the impulse response functions with and without extraordinary monetary interventions in the presence of lockdown, shutdown and fiscal responses. We also show the aggregate path of the economy in a counterfactual analysis with and without the monetary interventions. Section 6 concludes.

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[8]The information technology sector also benefited, probably owing to increased interest in telecommuting.

[9]For instance, Shapiro (2020) analyses the dramatic fall in inflation following the onset of the Covid-19 pandemic. Breaking down the underlying price data according to spending category reveals that a majority of the drop in core personal consumption expenditures inflation came from a large decline in consumer demand. This demand effect far outweighed upward price pressure from Covid-19-related supply constraints.

2 Related literature

The macroeconomic effects of the Covid-19 shocks are analysed in a number of papers. Eichenbaum, Rebelo and Trabandt (2020) find that people's decision to limit consumption and work effort reduces the severity of the pandemic, as measured in total deaths, but exacerbated the size of the recession caused by the pandemic. Fornaro and Wolf (2020) examine the long-run effect of the supply disruption caused by the Covid-19 shocks: they show that the spread of the coronavirus might cause a demand-driven slump, give rise to a supply-demand doom loop, and open the door to long-run stagnation traps induced by pessimistic animal spirits. Baqaee and Farhi (2020) look instead at the short-run business cycle effects of the pandemic shocks and argue that the effects of negative sectoral supply shocks are stronger than those of shocks to the sectoral composition of demand.

Guerrieri et al. (2020) focus specifically on supply shocks, motivated by the shutdowns, and study the induced effects on demand. They argue that the economic shocks associated with the Covid-19 pandemic – shutdowns, layoffs, and firm exits – can amplify the initial effect, thereby aggravating the recession. They find that an optimal policy, closing down contact-intensive sectors and providing full insurance payments to affected workers can achieve the first-best allocation, despite the lower per-dollar potency of fiscal policy. Bigio, Zhang and Zilberman (2020) show that the Covid-19 shocks have lead to a reduction in the demand and supply of sectors that produce goods that need social interaction for their production or consumption and analyse the role played by fiscal lump-sump and credit transfers. Auerbach, Gorodnichenko and Murphy (2020) argue that the effectiveness of such fiscal policies also depend on the level of inequality and on the joint distribution of capital operating costs and firm revenues. In general, inequality has negative effects on output, while also diminishing the effect of a demand-side fiscal stimulus. Significantly, the economic impact of Covid-19 has also been extremely unequal across sectors: del Rio-Chanona et al. (2020) correctly predicted that some sectors would be hit by demand shocks (transport, for instance), some by supply shocks (manufacturing and mining, for instance), and some by both (entertainment, restaurants, and tourism), while some others would be relatively immune (in particular, high-wage occupations).

There were also additional policy proposals in response to the Covid-19 shocks, a large number which were collected in Baldwin and Weder di Mauro (2020). As stressed by Bartsch et al. (2020), neither monetary policy nor fiscal policy by itself can protect the economy from extreme output contractions, job losses and financial turmoil. One emerging conclusion is that a successful stimulus in a pandemic requires fiscal and monetary authorities to create space for each other. As debt rises, monetary stimulus creates fiscal space by setting favorable borrowing terms for the Treasury. However, for this space to be effective, the central bank must also provide reliable monetary support for government debt – primarily to protect debt markets from sudden increases

in sovereign risk. With interest rates close to a minimum, the Treasury creates space for monetary stimulus (through QE and other unconventional measures) by providing emergency support to the central bank's budget, so that monetary authorities do not face the risk of losing control over the level of prices, even in the event of large economic losses.

Hofmann et al. (2020) analyse fiscal-monetary interactions when interest rates are very low. The model features conventional monetary policy conducted through the short-term interest rate, central bank balance sheet policies conducted through asset purchases, fiscal policy in the form of a primary deficit rule and government debt accumulation. They further find that systematic balance sheet policies considerably enhance macroeconomic stability in a low interest rate environment as they help the central bank to partly overcome the zero lower bound constraint and preserve fiscal space, thereby rendering countercyclical fiscal policy more effective.

In our paper we push the debate forward and analyse the macroeconomic impact of both shutdowns (supply shocks) and lockdowns (demand shocks) and consider a supportive monetary and fiscal mix in a low interest rate environment that can limit the disruption to output. We show that nonconventional monetary tools may offset the effect of the zero lower bound and provide space for monetary policy to support fiscal stimulus so that much of the output loss is mitigated.

3 The model

We now set out a simple framework for analysing extraordinary central bank and fiscal interventions during the Pandemic. We employ the model by Chadha, Corrado, Meaning and Schuler (2020).[10] The central bank controls the stock of fiat money and banks create intra-private sector claims by the means of loans, L and deposits, D.

We first take a more detailed look at the private sector balance sheet, shown in Table 3. The private sector has three forms of assets: deposits, D, held at banks, some fraction of bonds, γB, issued by government and a fraction of total capital.[11] The liabilities are loans, $D-r$, provided by banks and taxes. Capital lies on the assets side of household balance sheets because households own firms. The fiscal authority issues government bonds, B, which are recorded on its balance sheet as a liability in the form of outstanding public debt, and collects taxes, t. The commercial banks' balance sheet liabilities are deposits, D. Some fraction of liabilities, r, is held as reserves and the rest, $D-r$, is available to be lent to the private sector. The central bank holds assets in the form of some fraction of government bonds, $(1-\gamma)B$, and a fraction of capital, $(1-\gamma_k)K$,

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[10]For further details, see also Chadha et al. (2020)

[11]In this example we assume that the private sector is represented by households, so firms are included here.

with liabilities determined by central bank money, which are bank reserves.[12] The net assets of commercial banks and of the central bank are both zero.

The private sector has net assets given by $D + \gamma B + \gamma_k K - (D - r + \sum_{i=0}^{\infty} \beta^i t_i)$ and so because $r = (1 - \gamma)B + \gamma_k K$ and $\sum_{i=0}^{\infty} \beta^i t_i = B$, we can see that the net private sector assets are also zero.

Table 3: Balance Sheets

Private Sector		Fiscal Authority	
Assets	Liabilities	Assets	Liabilities
Deposits D	Loans $(D - r)$	Tax $\sum_{i=0}^{\infty} \beta^i t_i$	Bonds B
Bonds γB	Tax $\sum_{i=0}^{\infty} \beta^i t_i$		
Capital $\gamma_k K$			

Commercial Banks		Central Bank	
Assets	Liabilities	Assets	Liabilities
Reserves r	Deposits D	Bonds $(1 - \gamma)B$	Reserves r
Loans $(D - r)$		Capital $(1 - \gamma_k)K$	

From this flow of funds we can see the mechanism by which extraordinary policies operate in the Pandemic. The central bank can implement QE which involves the expansion of its balance sheet through the issuance of bank reserves that are backed by increased holdings of either bonds or capital. The bank reserves are lodged with commercial banks against which the private sector, which has sold the bonds or capital to the central bank, has a deposit claim.

When the fiscal authority issues government bonds to finance its deficit this acts as cushion to the fall in GDP. Through bond purchases in the context of QE, the amount of government bonds held by the private sector can be steered, giving fiscal policy further space for stabilisation policies.

We outline our model based on Chadha, Corrado, Meaning and Schuler (2020) which is an extended version of Goodfriend and McCallum (2007). This primarily consists of a Calvo-Yun monopolistically competitive production economy with sticky prices and four main blocks: households, which can work either in the goods-production sector for firms or for banks monitoring loan quality for banks, who meet consumer deposit demand with reserves and a loan production function. As standard there is a monetary authority and a fiscal authority. [13]

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[12]If we operate in an open economy, central bank assets would also include foreign exchange reserves r^f.

[13]The Fiscal authority chooses the level of its deficit. We can fix the level of government debt as a constant

3.1 Households

Households are faced with a utility function in real consumption, c_t, and leisure:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t [\phi_t \log(c_t) + (1 - \phi_t) \log(1 - n_t^s - m_t^s)] \tag{1}$$

They supply labour to the goods production sector, n_t^s, or to financial intermediaries in the form of monitoring work, m_t^s. In our model ϕ_t denotes the labour supply (shutdown) shock. They are also subject to the budget constraint:

$$q_t(1 - \delta)K_t + \frac{\gamma B_t}{P_t^A} + \frac{D_{t-1}}{P_t^A} + w_t(n_t^s + m_t^s) + c_t^A \left(\frac{P_t}{P_t^A} \right)^{1-\theta} + \Pi_t \tag{2}$$
$$-w_t(n_t + m_t) - \frac{D_t}{P_t^A} - t_t - q_t K_{t+1} - \frac{\gamma B_{t+1}}{P_t^A(1 + R_{t+1}^B)} - c_t = 0$$

where q_t is the price of capital, K_t is the quantity of capital, P_t is the price of goods produced by households, P_t^A is the consumption goods price index, n_t is the labour demanded by households as producer, m_t, is the labour demanded by households' banking operations, w_t is the real wage, D_t is the nominal holding of deposits, t_t is the real lump-sum tax payment, R_t^B is the nominal interest rate on government bonds purchased in $t + 1$, B_{t+1}. We also assume that any profit from the banking sector, Π_t, goes to the household sector. The Lagrange multiplier of this constraint is denoted as λ_t and θ is the elasticity of household demand.

In addition, households have a "deposit-in-advance" constraint which requires them to hold deposits with a bank in order to implement their consumption plans, where v_t is the velocity of broad money,

$$c_t = v_t D_t / P_t^A. \tag{3}$$

In our model v_t denotes the velocity shock. An important driver of the fall in velocity during the Covid-19 pandemic has been the choice made by consumers, who cut spending sharply during lockdown.

3.2 Firms

The production sector, characterized by monopolistic competition and Calvo pricing, employs a Cobb-Douglas function with capital, K_t, and labour, n_t, subject to productivity shocks. Firms

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but also shock the level should the government choose to run a deficit. The model is outlined in more detail in Annex B.

decide the amount of production they wish to supply and the demand for labour by equalizing sales to net production:

$$K_t^\eta (A1_t n_t)^{1-\eta} - c_t^A (P_t/P_t^A)^{-\theta} = 0, \tag{4}$$

where η denotes the capital share in the firm production function, $A1_t$ is a productivity shock in the goods production sector whose mean increases over time at a rate ϱ and θ denotes the elasticity of aggregate demand, c_t^A. The Lagrange multiplier of this constraint is denoted as, ξ_t. By clearing the household and production sectors,[14] we can define the equilibrium in the labour market and in the goods market. Specifically, the demand for monitoring work:

$$m_t = \left(\frac{\phi_t}{\lambda_t c_t} - 1 \right) \frac{1-\alpha}{w_t} c_t \tag{5}$$

depends negatively on wages, w_t, and positively on consumption, c_t, where $1-\alpha$ is the share of monitoring in the loan-production function. These two sectors also provide the standard relationship for the risk-free interest rate and the bond rate.

3.3 Banks

The role of banks in our economy is to meet the deposit demand of liquidity constrained consumers confronted with the deposit-in-advance constraint. These deposits are created in two ways: (i) they can be created by the central bank in the form of narrow money (reserves) which is lent to or lodged with commercial banks, or (ii) commercial banks can create deposits themselves by producing loans which generate an equivalent deposit on the liabilities side of the bank's balance sheet. Thus

$$L_t + r_t = D_t \tag{6}$$

and broad money is determined in part by the central bank, but also mostly by the banking system. $\frac{D}{r}$ therefore represents the money multiplier and, as the only source of narrow money in our model is reserves, $\frac{1}{MM} = \frac{r}{D}$, also equals the reserve ratio.[15]

3.3.1 Loans

We abstract from cash and assume that narrow money consists solely of reserves, which in normal times the central bank supplies to commercial banks perfectly elastically in response to

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[14]For details on the model set-up, derivation and notation see the technical appendix, which is available on request.

[15]Under a 100% reserve system, the broad money supply, and thus consumption within our model, would be restricted by the creation of narrow money by the central bank. But here $D_t = r_t$ and the subsequent problem of reserve demand simplifies to depend purely on demand for consumption at the given policy rate.

their demand. In order to obtain any excess reserves commercial banks face a cost, which is the central bank's policy rate, paid via open market operations conducted at a discount window.[16]

Commercial banks can create deposits by making loans, which generate an equivalent deposit on the liability side of the bank balance sheet, but also incur a cost. Banks produce these loans by applying a production technology to collateral posted by households in the form of bonds, b_t, or capital, $q_t K_t$. This process is captured by a Cobb-Douglas production function for loans where collateral is combined with monitoring work, m:

$$L_t/P_t^A = F(\gamma b_{t+1} + A3_t k q_t K_{t+1})^\alpha (A2_t m_t)^{1-\alpha} \quad 0 < \alpha < 1, \tag{7}$$

$A2_t$ denotes a shock to monitoring work, $A3_t$ is a shock on capital as collateral and $b_{t+1} = B_{t+1}/P_t^A(1+R_{t+1}^B)$. The parameter k denotes the inferiority of capital as collateral in the banking production function,[17]while α is the share of collateral in loan production. Increasing monitoring effort is achieved by increasing the number of people employed in the banking sector and conse-quently reducing employment in the goods production sector. One channel that policy can affect is to limit the increase in the costs of loan provision as workers move from goods production to loan monitoring.

Commercial banks seek to maximize total returns within the period subject to the returns from loans, L_t, which are lent out at the collateralized interest rate of R_t^L, the interest on reserves, $R_t r_t$, and the payment of interest on deposits, R_t^D:

$$\max \Pi_t = R_t^L L_t - R_t^D D_t + R_t r_t - w_t m_t, \tag{8}$$

with m_t refering to monitoring work employed.

3.4 Conventional and unconventional monetary policy

The central bank policy rate, R_t, is the market clearing rate for reserves and is set by a feedback rule responding to inflation, π_t, and output, y_t, with parameters, ϕ_π and ϕ_y, respectively. Policy rates are smoothed so that $1 > \rho > 0$. The policy rule is active until the central bank interest rate on reserves reaches the zero lower bound (assumed to coincide with the effective lower bound in this model setup). We incorporate active QE policy by assuming that the central bank adopted the following countercyclical feedback rule with the size of reserves, r_t, as the policy variable, with $\bar{r}$ being the steady state reserves, ψ_y and ψ_π being the weights of output and inflation in

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[16]See Freeman and Haslag (1996).

[17]Capital is considered inferior as there are increased costs to the bank of verifying its physical quality and condition as well as its market price. It is also less liquid should it be needed in the event of default.

the policy function.

$$
\begin{cases}
R_t = R_{t-1}^{\rho} \left(\frac{y_t}{y}\right)^{(1-\rho)\phi_y} \left(\frac{\pi_t}{\pi}\right)^{(1-\rho)\phi_\pi} & \text{for } R_t > 0 \\
r_t = \bar{r}(r_{t-1})^{\rho_r} \left(\frac{y_t}{y}\right)^{-\psi_y(1-\rho_r)} \left(\frac{\pi_t}{\pi}\right)^{-\psi_\pi(1-\rho_r)} & \text{for } R_t = 0
\end{cases}
\tag{9}
$$

We model open market operations in which an asset, primarily bonds, is bought from the private sector in exchange for newly created money.[18] The central bank now holds more bonds on its balance sheet. The private agent from whom the bonds have been purchased receives a newly created deposit in its account with its commercial bank, while that commercial bank's own account with the central bank is credited with an equal increase of freshly created reserves.[19] We assume that the central bank does not react to the loss in collateral value in real time.[20] To incorporate this mechanism into our model we assume the central bank must match its only liability, reserves, by holding just one class of assets, government bonds, B_t.

3.5 Fiscal spending and debt absorption

For the fiscal authority we assume two different regimes: normal times and discretionary fiscal spending. In normal times, in this model, the fiscal authority follows a balanced budget rule, i.e. the total supply of government bonds is fixed. This is reflected in the following government rule:

$$
g_t - t_t = \frac{B_t}{P_t^A (1 + R_t^B)} - \frac{B_{t-1}}{P_t^A}
\tag{10}
$$

where g_t is government spending. Under discretionary fiscal spending, such as during a large external shock like the pandemic, the stock of debt increases. Discretionary fiscal spending enters through an exogenous increase in government debt, $a6_t$, i.e. in log linear form

$$
\widehat{B}_t = a6_t.
\tag{11}
$$

While during the global financial crisis the provision of liquidity followed bank demand and

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[18] The mechanism outlined here abstracts from sterilized open market operations in which the purchases of assets are funded by the sale of other assets on the central bank's balance sheet rather than the creation of new reserves and instead acts through "credit easing" channels as defined by Bernanke (2009).

[19] We abstract from the possibility of banks themselves holding bonds and acting as the central bank's counterpart in an open market operation. While this would be closer to how traditional open market operations have been carried out, it is not consistent with recent large-scale asset purchases carried out by central banks that avoided buying assets directly from banks. In the context of our model, the distinction between the two frameworks is of little importance.

[20] Wu and Xia (2015), among others, calculate shadow rates from long-term yields of government bonds during phases of QE where the policy rate was at the zero lower bound. In principle, a QE rule could link the size of monetary intervention to the desired shadow rate. As the model setup incorporates only short-term bonds, we apply the reserves rule.

concerns about subdued inflation and the the economic recovery, the motivation for QE also included the goal of stabilising market function. In the environment during the pandemic this would include also potential repercussions of the large issuance of government debt during the Covid-19 pandemic.[21] We incorporate this accommodative stance by further assuming a rule that keeps the reserve to deposit ratio constant in response to a discretionary fiscal expansion:[22]

$$\Delta r_t = \Delta D_t(a6_t) \tag{12}$$

The result of adopting this rule is that it creates fiscal space by buying up a substantial share of the new issuance of bonds. An expansionary fiscal shock would increase GDP and, all else being equal, that would tend to induce the central bank to lower reserves and become more restrictive as in equation (9). Through additional QE, the central bank absorbs a significant share of the additional bonds issued, B_t, in order to stabilise bond prices and interest rates. The accumulation of reserves and higher bond prices supports the provision of loans. Thus, by matching the increase in deposits, D_t, from fiscal policy with an increase in reserves, r_t, the central bank can augment the positive shock from discretionary fiscal spending.

When the central bank buys bonds in an open market operation, it increases the fraction of the total bond supply which it holds and decrease that held by the private sector. We can therefore define total bond holdings as the sum of private sector and central bank bond holdings,

$$b_t = b_t^{CB} + b_t^{P}, \tag{13}$$

where $b_t^{CB} = B_t^{CB}/P_t^A(1 + R_t^B)$ and $b_t^P = B_t^P/P_t^A(1 + R_t^B)$. As central bank bond holdings must equal reserves, we can substitute and re-arrange this equation to give the log linear relationship

$$b_t^p \hat{b}_t^p = b_t \hat{b}_t - r_t \hat{r}_t \tag{14}$$

It is this newly defined variable b^p which determines the amount of collateral households have available and thus b^p which features in our equations for loan supply and the marginal value of collateralised lending as well as the consolidated government budget constraint.[23]

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[21]See Federal Reserve (2020a), which refers to a need "to support smooth market functioning".

[22]The adopted rule keeps monetary policy neutral in that it does not counteract the output and inflation increase induced by discretionary fiscal spending, but provides adequate reserves to the banking system to allow for the discretionary fiscal spending to take its full effect.

[23]As we are dealing with a consolidated government budget constraint, the net effect of interest payments on bonds held by the central bank is zero.

3.6 Interest rates spreads

The inclusion of this banking sector gives rise to a number of interest rates and financial spreads. The benchmark theoretical interest rate R^T is the standard intertemporal nominal pricing kernel, priced from expected real consumption growth and inflation. Basically it boils down to a one-period Fisher equation:

$$R_t^T = E_t(\lambda_t - \lambda_{t+1}) + E_t\pi_{t+1}. \tag{15}$$

To find the excess of the loan rate, R^L, over funding costs, R, as the real marginal cost of loan production, we divide the factor price, $\frac{w_t}{P_t^A}$, by the marginal product of labour which equates to the marginal product of loans per unit of labour $(1-\alpha)\frac{L_t}{m_t}$ where loans are defined by the following relationship $L_t = D_t(1 - rr_t) = \frac{c_t P_t^A}{v_t}(1 - rr_t)$:

$$EFP_t = \frac{w_t v_t m_t}{(1-\alpha)(1-rr_t)c_t}.$$

Therefore, in log-linear form the interest rate on loans, R_t^L, is greater than the policy rate by the extent of the external finance premium.

$$R_t^L - R_t = \underbrace{[v_t + w_t + m_t + rr_t - c_t]}_{EFP_t}. \tag{16}$$

The external finance premium, EFP_t, is the real marginal cost of loan management, and it is increasing in velocity, v_t, real wages, w_t, monitoring work in the banking sector, m_t, and the reserve ratio, rr_t, and decreasing in consumption, c_t. As $rr_t = \frac{1}{MM_t}$ the EFP is also decreasing in the money multiplier, meaning that in this model, banks switch to narrow money taking more of the burden of meeting deposit demand, when the EFP is higher.

The yield on government bonds is derived by maximizing households' utility with respect to bond holdings, $R_t^T - R_t^B = \left[\frac{\phi}{c_t \lambda_t} - 1\right]\Omega_t$. In its log-linear form, it is the risk-free rate, R_t^T, minus the liquidity service on bonds, which can be interpreted as a liquidity premium (LP):

$$R^B R_t^B = R^T R_t^T - \underbrace{\left[\left(\frac{\phi}{c\lambda} - 1\right)\Omega\Omega_t - \frac{\phi_t \Omega}{c\lambda}(c_t + \lambda_t)\right]}_{LP_t}, \tag{17}$$

where $(c_t + \lambda_t)$ measures the household marginal utility relative to households' shadow value of funds, while Ω_t is the marginal value of the collateral. It is in fact these key margins - the real marginal cost of loan management and the liquidity service yield - that determine the behaviour of spreads. In the above expression, ϕ denotes the consumption weight in the utility function and λ_t is the shadow value of consumption, c_t. The interest rate on deposits is the policy rate,

R_t, minus a term in the reserve/deposit ratio:

$$R_t^D = R_t - \frac{rr}{1 - rr} rr_t. \tag{18}$$

As these spreads influence the asset allocation of banks they also have an impact on the resulting path of consumption. When we come to the analysis of the model we will discuss these premia as a way of understanding our results.

4 Calibration

Table 4 describes the model variables, Table 5 reports the values for the parameters and Table 6 the steady-state values of relevant variables.[24]

Following Goodfriend and McCallum (2007), we choose the consumption weight in utility, ϕ, to yield one-third of available time in either goods or banking services production. We also set the relative share of capital and labour in goods production, η, at 0.36. We choose 11 for the elasticity of substitution of differentiated goods, θ. The discount factor, β, is set at 0.99, which is close to the canonical quarterly value, while the mark-up coefficient in the Phillips curve, κ, is set at 0.1. The depreciation rate, δ, is set at 0.025, while the trend growth rate, ϱ, is set at 0.005, which corresponds to 2% per year. The steady-state value of bond holding level relative to GDP, b, is set at 0.56 as of the third quarter of 2005. The steady state of private sector bond holdings relative to GDP is set at 0.50, consistent with holdings of US Treasury securities as at the end of 2006.[25]

The deep parameters linked to money and banking are defined as follows. Velocity at its steady state-level is set at 0.276, which is close to the average ratio of US GDP to M3 given by 0.31. The fractional reserve requirement, rr, is set at 0.1. This is consistent with the reserve ratio set by the Federal Reserve on all liabilities above the low reserve tranche and approximately equal to the average Tier 1 capital ratio in the United States since the mid 2000s.

This allows us to manipulate three key deep parameters which may influence the rest of the steady-state variables. Interestingly, these are three financial variables and are thus of particular relevance for our debate on policies. α is the Cobb-Douglas weight of collateral in loan production. This is the degree to which banks base their lending on collateral as opposed to monitoring work or information based-lending. The benchmark calibration of 0.65 is within a range throughout the literature of 0.6 to 0.89 (Zhang, 2011), so this is what we follow. k is the degree to which capital is less efficient as collateral than bonds, as it entails higher costs to the bank in order

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[24]The equations for the steady-state values are listed in the technical appendix, which is available on request.

[25]The steady state of the transfer level, the Lagrangian for the production constraint and base money depend on the above parameters. The steady state of the marginal cost is $mc = \frac{\theta-1}{\theta}$.

Table 4: List of Variables

Variable	Description
c	Real consumption
n	Labour input
m	Labour input for loan monitoring, or "Banking employment"
w	Real wage
q	Price of capital goods
P	Price level
π	Inflation
mc	Marginal cost
r	Reserves
rr	Reserves/Deposit ratio
D	Deposits
L	Loans
P^A	Aggregate prices
b	Real bond holding
b^p	Real private sector bond holdings
Ω	Marginal value of collateral
EFP	Uncollateralised external finance premium (R^T - R^{IB})
LSY^B	Liquidity service on bonds
LSY^{KB}	Liquidity service on capital ($kLSY^B$)
R^T	Benchmark risk free rate
R^B	Interest rate for bond
R	Policy rate
R^L	Loan rate
R^D	Deposit rate
λ	Lagrangian for the budget constraint (shadow value of consumption)
ξ	Lagrangian for the production constraint
T	Real transfer (%)

Table 5: Parameterization

Parameter	Description	Value
β	Discount factor	0.99
κ	Coefficient in Phillips curve	0.1
α	Collateral share of loan production	0.65
ϕ	Consumption weight in utility	0.4
η	Capital share of firm production	0.36
δ	Depreciation rate of capital	0.025
ϱ	Trend growth rate of shocks	0.015
ρ	Interest rate smoothing	0.8
ϕ_π	Coefficient on Inflation in Policy	1.5
ϕ_y	Coefficient on Output in Policy	0.5
F	Production coefficient of loan	9.14
k	Inferiority coefficient of capital as collateral	0.2
θ	Elasticity of substitution of differentiated goods	11

Table 6: Steady-state parameters

Steady-state	Description	Value
m	Banking employment	0.0063
n	Labour input	0.3195
R^T	Risk free rate	0.015
R^{IB}	Interbank rate	0.0021
R^L	Loan rate	0.0066
R^B	Bond rate	0.0052
b/c	Bond to Consumption ratio	0.56
b^p/c	Private sector bond holdings/Consumption	0.50
$\gamma\ (b^p/b)$	Fraction of bonds held By private sector	0.893
c	Consumption	0.8409
T/c	Transfers/Consumption	0.126
w	Real wage	1.9494
λ	Shadow value of consumption	0.457
ν	Velocity	0.31
Ω	Marginal value of collateral	0.237
K	Capital	9.19
K^P	Private sector capital holdings	9.19
rr	Reserve ratio	0.1
r/c	Reserves/Consumption	0.36

to check its physical condition and market price. It is also less liquid should default occur and the collateral be called upon to repay the value of the loan. We set this parameter at 0.2, which is validated by data on the Term Securities Lending Facility, which found that less liquid assets were swapped for bonds in a ratio of 0.21 to 1. F, can be thought of as total factor productivity in loan production, or a measure of the efficiency with which banks use the factors of production to produce loans.[26] We set this to ensure the rest of our steady-state values meet three criteria as closely as possible:

- a 1% per year average short-term real "risk-free rate" which is the benchmark in the finance literature;

- a 2% average collateralised EFP, which is in line with the average post-war spread of the prime rate over the federal funds rate in the United States;

- a share of total US employment in depository credit intermediation in August 2005 of 1.6%, as reported by the Bureau of Labor Statistics.

The value this yields is $F = 9.14$. With these parameter values we see that the steady state of labour input, n, is 0.31, which is close to one-third as required. The ratio of time working in the banking service sector, $\frac{m}{m+n}$, which is 1.9% under the benchmark calibration, is not far from the 1.6% share required. As the steady-states are computed at zero inflation we can interpret all the rates as real rates. The risk-free rate, R^T, is 6% per year. The interbank rate, R, is 0.84% per year, which is close to the 1% per year average short-term real rate. The government bond rate, R^B, is 2.1% per year. Finally, the collateralised EFP is 2% per year, which is in line with the average spread of the prime rate over the federal funds rate in the United States. The model is solved using the method of King and Watson (1998) who also provide routines to derive the impulse responses of the endogenous variables to different shocks, to obtain asymptotic variance and covariances of the variables and to simulate the data. For the impulse response analysis and simulation exercise, we consider the real and financial shocks set out in Table 7, which reports the volatility and persistence parameters. These are standard parameters in the literature.

5 Impulse response functions

We first show the combined pandemic shock by aggregating the impact of shutdown, lockdown and fiscal policies and then decompose it into the individual contributions. We calibrate the

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[26]Some authors have also described it as a measure of credit conditions within the economy. The rationale for this seems plausible as banks will require more collateral when credit conditions are tight and will employ more monitoring work to provide the same amount of loans to the economy.

Table 7: Parametrization of Exogenous Shocks

Shock name	Standard deviation	Persistence
Productivity	0.35%	0.95
Monitoring	1.00%	0.95
Collateral	0.35%	0.9
Mark-up	0.11%	0.74
Bond Holdings	1.00%	0.9

Covid-19 shocks so that the demand shock dominates to some degree (see Shapiro, 2020). Table 8 reports the calibration of the composite shock.

Table 8: Calibration of COVID-19 shocks

|	Volatility σ	Size of shock in σ	Persistence ρ
Velocity of money	0.01	-25%	0.95
Labor supply disutility	0.03	5%	0.25
Policy rate	0.0082	-1%	0.3
Fiscal	0.03	11%	0.95

Note: Calibrated values according to long-run averages. Size of the shock calibrated to match movements of US variables during H1 2020.

5.1 Combined Covid-19 shocks with fiscal shock and QE

Figure 5 shows the combined effect of the lockdown shock and the shutdown shock calibrated to the impact of the Covid-19 pandemic shocks in the United States. We compare the case, where the Federal Reserve deploys QE to respond to these shocks (dashed line) with the counterfactual that involves no deployment of asset purchases to respond to macroeconomic shocks (solid line). The combined shock in the case of no QE intervention has a strong effect on real output and goods employment which drop by more than 20% and 30%, respectively. Asset prices plummet by almost 25%. While the fiscal stimulus mitigates some of the fall, without monetary accommodation, the expansion of government debt, visible through a 10% increase in private sector bond holdings, leads to a large increase in the bond rate. While the EFP reaches 1% on impact, it drops temporarily due to intervention, and stabilises at 1% in the long run. The policy rate reaction, which mimics the rate cut by the Federal Reserve, completely mitigates this initial increase in the EFP. As loans increase while collateral is falling, given strongly reduced

asset prices, monitoring work jumps by 20%. Real reserves rise mostly with the increase in real deposits.

Figure 5: Combined Covid-19 shock with fiscal and monetary response
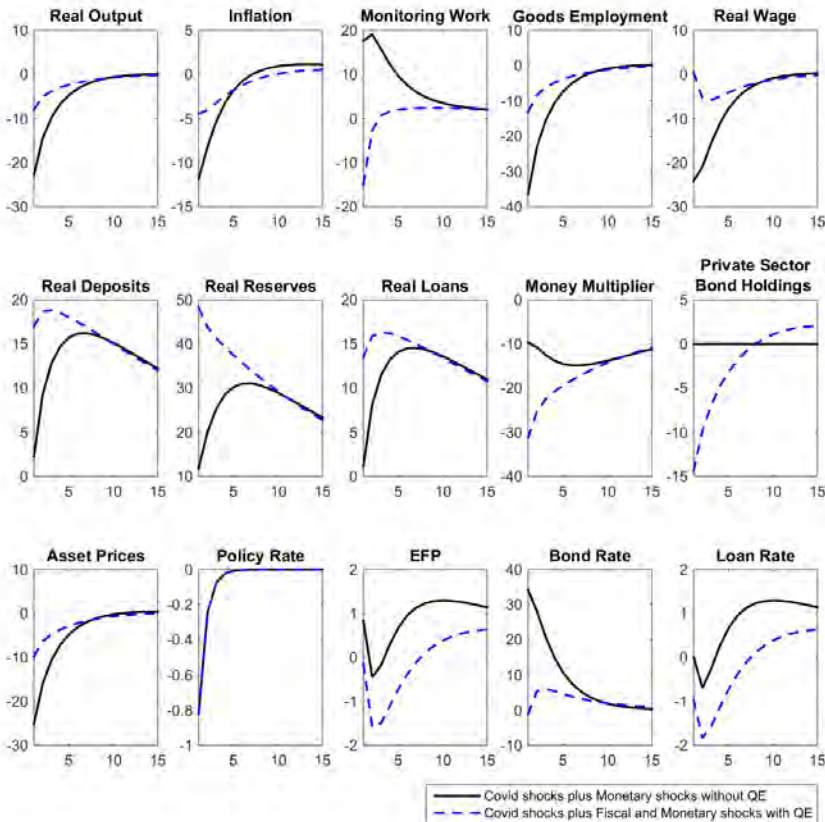
Note: All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage point deviations from the implied steady state value. EFP means external finance premium. QE means quantitative easing.

In the case of intervention by the Federal Reserve through large-scale asset purchases (QE), reserves increase on impact by 45%. This has a direct effect on the fall in asset prices which is limited to 10% on impact and to 5% in the following quarter. QE intervention more than absorbs the increase in bonds through the fiscal intervention such that private sector bond holdings fall by more than 10%. This intervention has many benign effects on the economy. The bond rate

increase is now limited, as is the increase of the EFP, and as a consequence the loan rate drops and then stabilises around a neutral rate. These effects allow loans to expand with positive effects on activity and inflation. Goods employment and real wages are to a large extent stabilised. Through the stabilization of wages, the effect on inflation is also mitigated to an average drop of 1.5% in the first year after the shocks.

The results show that if the Federal Reserve had not intervened, output would have fallen by more than 10% more on impact and in the following quarter. Real wages may have fallen by more than 15% more and unemployment may have increased by more than 20%. Wages would be 20% lower than with QE. As a result, inflation would fall by substantially more, and the recovery would probably have taken up to twice as long.

## 5.2 Breaking down the Covid-19 crisis into individual shocks

Disentangling the overall Covid-19 shock, we plot the individual simulations for (i) the velocity (or lockdown) shock (Figure 6) and (ii) the labor supply (or shutdown) shock (Figure 7). We show a pure fiscal shock with and without the accommodating monetary policy stance (Figure 8).

Figure 6 displays the response of economic variables to the "lockdown shock" in isolation. We have implemented this as a shock to the velocity of money which generates an increase in deposits, but a fall in output and inflation at the same time. This reflects the observation that households were not able to consume goods and services in aggregate to the same extent as a result of government restrictions and personal choices on social distancing and, accordingly, they accumulated additional deposits in their bank accounts. The main channel of this shock is an increase in deposits, while real output and inflation decrease as aggregate demand falls. Asset prices fall due to the sharp fall in output. We note that a policy reaction through QE helps stabilise asset prices via an increase in reserves, which attenuates the deleterious effect on output and inflation.

Figure 7 shows the "shutdown shock" in isolation. This is a shock to goods sector employment as factories are shut due to restrictions and/or cannot produce due to supply chain disruptions, and thus employees are not able to work. The main effect is a decrease in real output with asset prices falling due to the collapse in activity. By contrast, the effect on inflation is positive. However, given the fall in output, asset prices, deposits and loans contract. We show that prompt intervention by the central bank in increasing reserves can dampen the impact of this shock.

Finally, Figure 8 shows the response of the economy to a fiscal intervention. By engaging in QE, the central bank can keep the government bond rates at a lower level than otherwise. In a more standard setting, monetary policy may limit the efficacy of the fiscal intervention by tightening monetary and financial conditions, but here we introduce a loosening or accommodation

Figure 6: Covid-19 lockdown shock with QE response
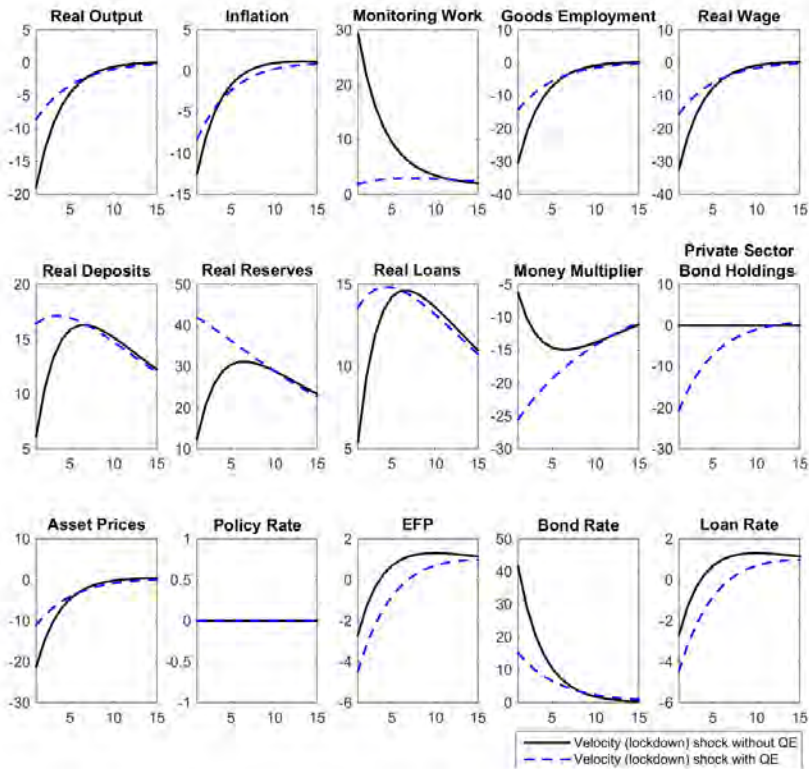
Note: All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage point deviations from the implied steady state value. EFP means external finance premium. QE means quantitative easing.

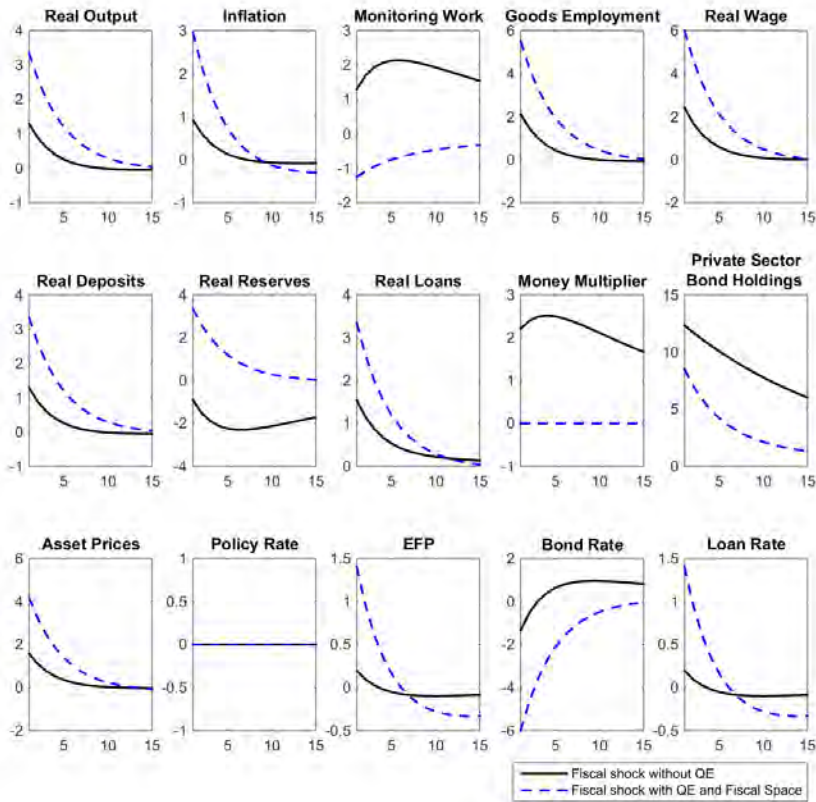Figure 7: Covid-19 shutdown shock with QE response
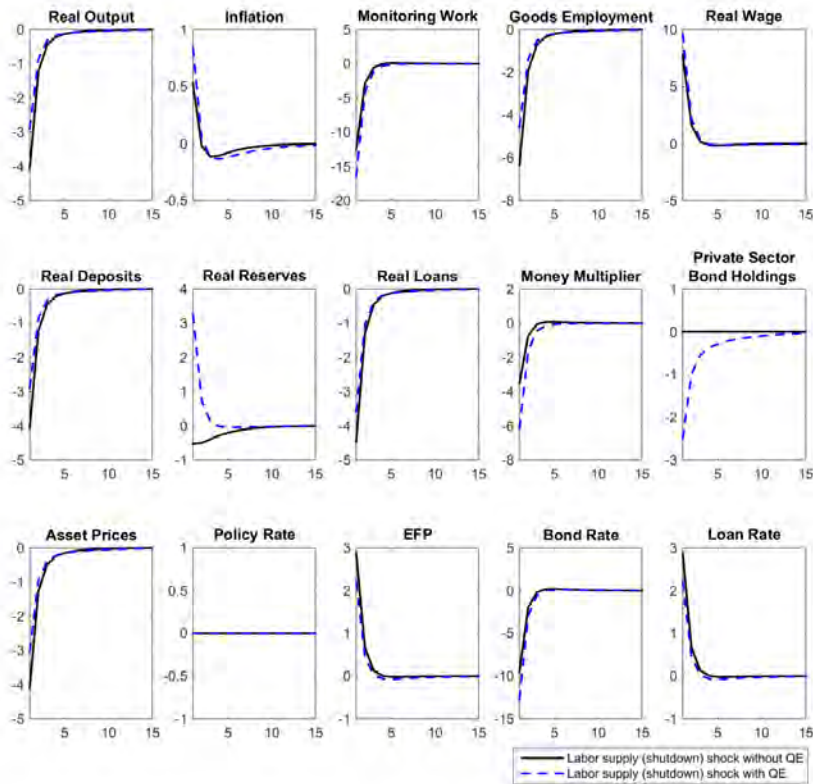
Note: All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage point deviations from the implied steady state value. EFP means external finance premium. QE means quantitative easing.

Figure 8: Fiscal shock with QE response

Note: All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage point deviations from the implied steady state value. EFP means external finance premium. QE means quantitative easing.

of the fiscal impulse that amplifies the effectiveness of the fiscal stabilisation. In this set-up, the central bank accommodates the increase in government debt through an expansion of reserves rather than tightening the monetary policy stance. This acts to increase reserves alongside broad money and creates fiscal space that in turn supports activity, goods employment, wages and inflation. As asset prices increase this reduces the need for costly monitoring work in the financial sector, allowing lending to proceed with a relatively elastic supply schedule.

6   Conclusions

The 2020 pandemic had the features of a perfect storm: a supply (shutdown) and demand shock (lockdown), which halted the functioning of the global economy for several months. We examine the critical role of monetary policy in offsetting these shocks and in particular in providing support for the fiscal policy interventions. We examine and calibrate the responses of the Federal Reserve in the United States, but the results can be generally interpreted as reflecting the supportive policies adopted by major central banks. We are able to match stylised facts in the United States by implementing a shock to the velocity of money and to labour supply. We show that a combined fiscal-monetary response may have helped avoid turning the Covid-19 crisis into an economic recession of even greater magnitude and severity. Our calibrated model shows that if the Federal Reserve had not intervened, output would have fallen by more than 10% more on impact and in the following quarter. Real wages would be down by more than 15% more and unemployment up by more than 20%. Wages would be 20% lower than with QE. As a result inflation would have fallen even further. Hence, we find that prompt, combined fiscal-monetary interventions mitigated the impact of the pandemic shocks and helped to establish a more rapid recovery to pre-crisis levels of activity.

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A   Model

A.1   Initial maximisation problems

Utility Function

$$U = E_0 \sum_{t=0}^{\infty} \beta_t \left[\phi_t \log(c_t) + (1 - \phi_t) \log(1 - m_t^s - n_t^s) \right] \tag{19}$$

where c_t is real consumption, m_t^s is the supply of labour to the banking sector and n_t^s is the supply of labour to the goods production sector.

Household budget constraint (HBC)

$$q_t(1 - \delta)K_t + \frac{\gamma_{t-1}}{P_t^A}B_{t-1}(1 + R_{t-1}^B) + \frac{D_{t-1}}{P_t^A} + w_t(n_t^s + m_t^s) + c_t^A \left(\frac{P_t}{P_t^A} \right)^{1-\theta} \tag{20}$$
$$-q_tK_{t+1} - \frac{\gamma_t}{P_t^A}B_t - \frac{D_t}{P_t^A} - w_t(n_t + m_t) - c_t - tax_t$$

Households must fund their consumption through wages earned on working and sales of their own production good, in which they have a degree of market power, designated by θ. They also receive income from net sales of financial assets (which consist of bonds and deposits) and net sales of physical assets (capital). Although the aggregated level of capital is fixed within the model, individual households can buy or sell between each other, affecting the price of capital q_t. As a producer, the household also pays wages on the hours of work it employs. tax_t refers to a real lump sum tax transfer. We assume government spending on anything other than financing debt (g_t) is zero, as in Goodfriend and McCallum (2007).

As $\frac{\gamma_t}{P_t^A} = \frac{1}{P_t^A(1+R^B)}$ the real value of bonds can be written as $\frac{B_t}{P_t^A(1+R_t^B)}$ and thus HBC becomes;

$$q_t(1 - \delta)K_t + \frac{B_{t-1}}{P_t^A} + \frac{D_{t-1}}{P_t^A} + w_t(n_t^s + m_t^s) + c_t^A \left(\frac{P_t}{P_t^A} \right)^{1-\theta} \tag{21}$$
$$-q_tK_{t+1} - \frac{B_t}{P_t^A(1 + R_t^B)} - \frac{D_t}{P_t^A} - w_t(n_t + m_t) - c_t - tax_t$$

Sales equals net production constraint[27]

---

[27]Households consume c_t which is a basket of different goods produced by intermediate producers (indexed by i $\in$ [0,1]). An optimal demand of intermediate goods $y(i)$ is derived by maximizing the bundle given the expenditure

$$max_{y(i)} \left[\int_0^1 y_t(i)^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}$$

$$K_t^\eta (A1_t n_t)^{1-\eta} - c_t^A \left(\frac{P_t}{P_t^A} \right)^{-\theta} = 0 \tag{23}$$

Government budget constraint

$$g_t - tax_t = \frac{\gamma_t}{P_t^A} B_t^P - \frac{\gamma_{t-1}}{P_t^A} B_{t-1}(1 + R_{t-1}^B) - \frac{r_t}{P_t^A}(R_t^{IB}) \tag{24}$$

$$g_t - tax_t = \frac{B_t}{P_t^A(1 + R_t^B)} - \frac{B_{t-1}}{P_t^A} - \frac{r_t}{P_t^A}(R_t^{IB})$$

The government runs a surplus or deficit so that it can finance its interest payments owed on reserves held by commercial banks in the current period and the redemption of one period bonds issued in the previous period (plus the rate of interest due on them) which have come to maturity. It funds this by issuing new debt in the current period.

Deposit in advance constraint

$$c_t = v_t \frac{D_t}{P_t^A} \tag{25}$$

Loans

$$L_t = D_t(1 - rr_t) \tag{26}$$

Reserve/Deposit Ratio

$$rr_t = \frac{r_t}{D_t} \tag{27}$$

Loan production function

$$\frac{L_t}{P_t^A} = F \left(\frac{B_t}{P_t^A(1 + R_t^B)} + A3_t kq_t K_{t+1} \right)^\alpha (A2_t m_t)^{1-\alpha} \tag{28}$$

subject to

$$\int_0^1 P_t(i) y_t(i) di = Z_t$$

This yields the set of demand functions. The relative demand for intermediate good i is therefore

$$y_t(i) = \left(\frac{P_t(i)}{P_t^A} \right)^{-\theta} y_t^A, \tag{22}$$

with θ being the elasticity of substitution between goods. With $\theta \to \infty$ there is perfect competition.

Substitute LPF into CIA

$$c_t = v_t \frac{F\left(\frac{B_t}{P_t^A(1+R_t^B)} + A3_t kq_t K_{t+1}\right)^\alpha (A2_t m_t)^{1-\alpha}}{1 - rr_t} \tag{29}$$

Bank's Problem

$$\max \Pi_t = R_t^L L_t - R_t^D D_t + R_t r_t - w_t m_t, \tag{30}$$

Real price of bonds

$$\frac{\gamma_t}{P_t^A} = \frac{1}{P_t^A(1+R^B)} \tag{31}$$

A.2 First order conditions

Here we use our initital equations to form the Lagrangian function in which λ is the Lagrangian coefficient of the household's budget constraint, ξ is the Lagrangian coefficient of the sales equals net production constraint and the deposit in advance (DIA) constraint is substituted in. From this we derive the following first order conditions:

Derivative wrt m_t^s and n_t^s

$$-\frac{(1 - \phi_t)}{1 - n_t^s - m_t^s} + w_t \lambda_t = 0 \tag{32}$$

Derivative wrt m_t (Supply)

$$\frac{\phi_t}{c_t} \frac{\partial c_t}{\partial m_t} - \lambda_t w_t - \lambda_t \frac{\partial c_t}{\partial m_t} = 0$$

Through our substituted DIA constraint we find

$$\frac{\partial c_t}{\partial m_t} = \frac{1-\alpha}{m_t} c_t$$

Thus

$$w_t = \left(\frac{\phi_t}{\lambda_t c_t} - 1\right) \frac{1-\alpha}{m_t} c_t \tag{33}$$

Derivative wrt n_t

$$\xi_t A1_t(1 - \eta)\left(\frac{K_t}{n_t A1_t}\right)^\eta - \lambda_t w_t = 0$$

Thus

$$w_t = \frac{\xi_t}{\lambda_t} A1_t(1 - \eta)\left(\frac{K_t}{n_t A1_t}\right)^\eta \tag{34}$$

Derivative wrt to K_{t+1}

$$\frac{\phi_t}{c_t}\frac{\partial c_t}{\partial K_{t+1}} + E_t\lambda_{t+1}q_{t+1}(1-\delta)\beta - q_t\lambda_t - \lambda_t\frac{\partial c_t}{\partial K_{t+1}} + E_t\xi_{t+1}\beta\eta K_t^{\eta-1}(A1_t n_t)^{1-\eta}$$

Through our substituted DIA constraint

$$\frac{\partial c_t}{\partial K_{t+1}} = \frac{c_t\alpha A3_t kq_t}{\frac{B_t}{P_t^A(1+R_t^B)} + A3_t kq_t K_{t+1}}$$

If we set Ω_t to

$$\Omega_t = \frac{c_t\alpha}{\frac{B_t}{P_t^A(1+R_t^B)} + A3_t kq_t K_{t+1}}$$

Then

$$\frac{\partial c_t}{\partial K_{t+1}} = \Omega_t A3_t kq_t$$

So our derivative wrt to K_{t+1} becomes

$$\left(\frac{\phi_t}{\lambda_t c_t} - 1\right)\Omega_t A3_t kq_t + E_t\frac{\lambda_{t+1}}{\lambda_t}q_{t+1}(1-\delta)\beta - q_t + E_t\beta\eta\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\xi_{t+1}}{\lambda_{t+1}}\left(\frac{A1_t n_t}{K_t}\right)^{1-\eta}\right] \quad (35)$$

Derivative wrt to P_t

$$\lambda_t(1-\theta)c_t^A\left(P_t^A\right)^{-(1-\theta)}(P_t)^{-\theta} + \xi_t\theta c_t^A\left(P_t^A\right)(P_t)^{-\theta-1} = 0$$

Rearranging gives

$$\frac{\xi_t}{\lambda_t} = \frac{\theta-1}{\theta}\frac{P_t}{P_t^A} \quad (36)$$

Derivative wrt B_t^P

$$\frac{\phi_t}{c_t}\frac{\partial c_t}{\partial B_t^P} + \lambda_{t+1}(1+R_t^B)\frac{B_t}{P_{t+1}^A(1+R_t^B)} - \lambda_t\frac{B_t}{P_t^A(1+R_t^B)} - \lambda_t\frac{\partial c_t}{\partial B_t}$$

$$\frac{\partial c_t}{\partial B_t} = \Omega_t\frac{B_t}{P_t^A(1+R_t^B)}$$

So our derivative wrt B_t can be written

$$\left(\frac{\phi_t}{\lambda_t c_t} - 1\right)\Omega_t\frac{B_t}{(1+R_t^B)} + \frac{\lambda_{t+1}}{\lambda_t}\frac{P_t^A}{P_{t+1}^A}\frac{B_t}{(1+R_t^B)}(1+R_t^B) = \frac{t}{(1+R_t^B)}$$

or

$$\left[\left(\frac{\phi_t}{\lambda_t c_t} - 1\right)\Omega_t - 1 + \frac{\lambda_{t+1}}{\lambda_t}\frac{P_t^A}{P_{t+1}^A}(1+R_t^B)\right] = 0 \quad (37)$$

Derivative wrt m_t (Demand)

$$\frac{\partial \Pi_t}{\partial m_t} = R_t^L - R_t - w_t / \frac{\partial L_t/P_t}{\partial m_t} = 0$$

Given

$$\frac{\partial L_t/P_t}{\partial m_t} = m_t^{-1}(1 - \alpha)L_t/P_t$$

by the Deposit in Advance Constraint we have

$$R_t^L - R_t = \frac{vw_t m_t}{(1 - \alpha)(1 - rr_t)c_t}.$$

A.3   Interest rates

Riskless Rate

To derive this rate we assume the existence of a perfectly riskless asset which offers the purchaser no benefits in terms of use as collateral. If we differentiate our household's problem with respect to consumption we get

$$\frac{\partial U}{\partial c_t} = \frac{\phi_t}{c_t} - \lambda_t = \left(\frac{\phi_t}{\lambda_t c_t} - 1 \right) = 0$$

Putting this back into equation (37) we find

$$1 + R_t^T = \frac{\lambda_t}{\lambda_{t+1}} \frac{P_{t+1}^A}{P_t^A} \tag{38}$$

Bond Rate

Using equation (37) we can find that

$$1 + R_t^B = 1 - \left(\frac{\phi_t}{\lambda_t c_t} - 1 \right) \Omega_t \frac{\lambda_t}{\lambda_t + 1} \frac{P_{t+1}^A}{P_t^A}$$

and that

$$\frac{(1 + R_t^B)}{(1 + R_t^T)} = 1 - \left(\frac{\phi_t}{\lambda_t c_t} - 1 \right) \Omega_t$$

We can interpret $\left(\frac{\phi_t}{\lambda_t c_t} - 1 \right) \Omega_t$ as a premium yield paid on bonds for the liquidity service they provide, or liquidity premium. We denote this LP_t and can write it as:

$$R_t^T - R_t^B = LP_t \tag{39}$$

This premium depends on the marginal value of collateral.

The liquidity service on capital (physical assets) can be written:

$$LSK = kLP$$

where k denotes the extent to which capital is inferior to bonds as a form of collateral. Together the liquidity service on bonds and the liquidity service on capital make up the overall liquidity service of collateral and thus the return on collateralised loans. This means:

$$R_t^L - R_t^B = LSK = \left(\frac{\phi_t}{\lambda_t c_t} - 1 \right) k\Omega_t \tag{40}$$

Interbank/Policy rate

In our full model the interbank rate is set by the policy-maker via a policy rule in response to changes in output and inflation. However it is worth looking at how this rate also relates to the other interest rates in the model.

$$R_t^T - R_t = \frac{v_t m_t w_t}{(1 - \alpha)(1 - rr_t)c_t} \tag{41}$$

Marginal product of loans per unit of labour equals marginal cost. Thus, the difference between policy and riskless rates is the real marginal cost of loan management. This gives the collateralised external finance premium (EFP).

Loan rate

Multiply by the factor share of monitoring in loan production $(1 - \alpha)$ to give the collateralised EFP.

$$R_t^L - R_t = \frac{v_t m_t w_t}{(1 - rr_t)c_t} \tag{42}$$

Deposit rate

$$R_t^D = R_t(1 - rr_t) \tag{43}$$

A.4   Steady-states

Now we must identify each of our variables in the steady state. We assume no inflation so $P = P^A = 1$. We also assume a trend growth rate of our productivity and monitoring shocks of $(1 + \gamma)$ so $A1 = A2 = (1 + \gamma)$ and thus λ shrinks at the rate γ and $\frac{\lambda_{t+1}}{\lambda_t} = \frac{1}{1+\gamma}$. K is constant and $q = 1$ in the steady state. We set or reserve deposit ratio to 0.1 in the steady state.

This means we require one identifying equation per variable.

Lagrangian

$$\lambda = \frac{1-\phi}{w(1-n-m)} \tag{44}$$

Monitoring work

$$m = \left(\frac{\phi}{\lambda c} - 1\right) \frac{1-\alpha}{w} c \tag{45}$$

Wages

$$w = \frac{\theta - 1}{\theta}(1 - \eta) \left(\frac{K}{n}\right)^{\eta} \tag{46}$$

Employment in the real sector

$$\left(\frac{\phi}{\lambda c} - 1\right)\Omega kq + \frac{1}{1+\gamma}q(1-\delta)\beta - q + E_t\beta\eta\left[\frac{1}{1+\gamma}\frac{\xi}{\lambda}\left(\frac{n}{K}\right)^{1-\eta}\right] = 0$$

or

$$\left(\frac{\phi}{\lambda c} - 1\right)\Omega kq - 1 + \frac{\beta}{1+\gamma}\left[(1-\delta) + \eta\frac{\theta-1}{\theta}\left(\frac{n}{K}\right)^{1-\eta}\right] = 0 \tag{47}$$

Capital

$$c = K^{\eta}n^{1-\eta} - \delta K \tag{48}$$

Consumption

$$c = \frac{vF}{1-rr}(b + kqK)^{\alpha}(m)^{1-\alpha} \tag{49}$$

Deposits

$$D = \frac{c}{v} \tag{50}$$

Reserves

$$r = rrD = \frac{c}{v}rr \tag{51}$$

Total bond holdings

$$B = 0.35c \tag{52}$$

Loans

$$L = D(1 - rr) \tag{53}$$

Omega

$$\Omega = \frac{c\alpha}{b^p + kqK} \tag{54}$$

Price of bonds

$$P^B = \frac{1}{(1+R^B)} \tag{55}$$

Real value of bonds

$$b = \frac{B}{1+R^B} \tag{56}$$

Liquidity shortfall

$$\tau = R^L - R^{IB} \tag{57}$$

Government budget constraint

$$T = b - b(1+R^B) - r(R^{IB}) \tag{58}$$

Liquidity premium

$$LP = \left(\frac{\phi}{\lambda c} - 1\right)\Omega \tag{59}$$

EFP

$$EFP = \frac{vmw}{(1-\alpha)(1-rr)c} \tag{60}$$

Collateralised EFP

$$CEFP = \frac{vmw}{(1-rr)c} \tag{61}$$

Riskless rate

$$R^T = \gamma \tag{62}$$

Bond rate

$$R^B = R^T - LP \tag{63}$$

Policy rate

$$R = R^T - EFP \tag{64}$$

Lending rate

$$R^L = R + CEFP \tag{65}$$

Deposit rate

$$R^D = R(1 - rr) \tag{66}$$

From these equations and our exogenously determined parameters α, β, γ, δ, η, θ, ϕ, k, and v we have a fully determined model and can derive the steady state values for each of our variables (see Table 6). From this we can also carry out steady state analysis of our system via comparative statics.

A.5 The Log-linearised model

The following system of 25 equations defines our benchmark model which contains 27 variables, four lags and eight exogenous shock terms. These equations, plus an identifying equation for each lagged term, are solved using the King and Watson (1998) algorithm.

Supply of labour

$$\frac{n}{(1-n-m)}\widehat{n}_t + \frac{m}{(1-n-m)}\widehat{m}_t - \widehat{\lambda}_t - \widehat{w}_t = 0 \tag{67}$$

Demand for labour

$$\widehat{m}_t + \widehat{w}_t + \frac{(1-\alpha)c}{mw}\left(\widehat{c}_t + \frac{\phi_t}{\lambda}\widehat{\lambda}_t\right) = 0 \tag{68}$$

DIA constraint

$$\widehat{c}_t + \widehat{p}_t = \widehat{D}_t + \widehat{v}_t \tag{69}$$

Supply of banking services:

$$\begin{aligned}
\widehat{c}_t &= \widehat{v}_t c + \widehat{rr}_t c + (1-\alpha)(a2_t + \widehat{m}_t) + \\
&\quad \alpha\left[\frac{b}{b+(1+\gamma)kK}(\widehat{b}_t) + \frac{kK(1+\gamma)}{b+(1+\gamma)kK}(a3_t + \widehat{q}_t)\right]
\end{aligned} \tag{70}$$

Aggregate supply:

$$\widehat{c}_t = (1-\eta)(1+\frac{\delta K}{c})(a1_t + \widehat{n}_t) - \frac{\delta K}{c}\widehat{q}_t \tag{71}$$

Marginal cost:

$$\widehat{mc}_t = \widehat{n}_t + \widehat{w}_t - \widehat{c}_t \tag{72}$$

Mark-up

$$\widehat{mc}_t = \widehat{\widehat{\xi}}_t - \widehat{\lambda}_t \tag{73}$$

Inflation:

$$\widehat{\pi}_t = \widehat{p}_t - \widehat{p}_{t-1} \tag{74}$$

Calvo pricing:

$$\widehat{\pi}_t = \kappa\widehat{mc}_t + \beta E_t\widehat{\pi}_{t+1} + a5_t \tag{75}$$

Marginal value of collateralised lending:

$$\Omega_t = \frac{kK}{b+kK}(\hat{c}_t - \hat{q}_t - a3_t) - \frac{b}{b+kK}b \tag{76}$$

Asset Pricing:[28]

$$\widehat{q}_t \left[1 - k\Omega \left(\frac{\phi_t}{c\lambda} - 1\right)\right] = \left[\frac{\beta(1-\delta)}{1+\gamma} + \frac{\beta\eta mc}{1+\gamma} \left(\frac{n}{K}\right)^{1-\eta}\right] \left(E_t\widehat{\lambda}_{t+1} - \widehat{\lambda}_t\right) \tag{77}$$
$$+ \frac{\beta(1-\delta)}{1+\gamma} E_t\widehat{q}_{t+1} + \frac{k\Omega\phi_t}{c\lambda} \left(-\widehat{c}_t - \widehat{\lambda}_t\right)$$
$$+ k\Omega(\frac{\phi_t}{c\lambda} - 1)\left(\widehat{\Omega}_t + a3_t\right)$$
$$+ \left(\frac{\beta\eta mc}{1+\gamma}(\frac{n}{K})^{1-\eta}\right) E_t\left[\widehat{mc}_{t+1} + (1-\eta)\left(\widehat{n}_{t+1} + a1_{t+1}\right)\right]$$

Government budget constraint:

$$TT_t = b^P \left[b_t^P - b_{t-1}^P - R^B \left(b_{t-1}^P + R_{t-1}^B\right)\right] - rR^{IB}(r_t + R_t^{IB}) \tag{78}$$

Bond holding:

$$\widehat{B}_t = a6_t \tag{79}$$

Riskless interest rate:

$$\widehat{R}_t^T = \widehat{\lambda}_t + E_t\widehat{\pi}_{t+1} - E_t\widehat{\lambda}_{t+1} \tag{80}$$

Liquidity service on bonds:

$$R^T\widehat{R}_t^T - R^B\widehat{R}_t^B = \left(\frac{\phi_t}{c\lambda} - 1\right)\Omega\widehat{\Omega}_t - \frac{\phi\Omega}{c\lambda}(\widehat{c}_t + \widehat{\lambda}_t) \tag{81}$$

External finance premium:

$$\widehat{EFP}_t = \widehat{v}_t + \widehat{w}_t + \widehat{m}_t - \widehat{c}_t + \widehat{rr}_t \tag{82}$$

Other interest rates:

$$\widehat{R}_t = \widehat{R}_t^T - \widehat{EFP}_t \tag{83}$$

$$\widehat{R}_t^L = \widehat{R}_t + \widehat{EFP}_t \tag{84}$$

$$\widehat{R}_t^D = \widehat{R}_t - \widehat{rr}_t \frac{rr}{(1-rr)} \tag{85}$$

Policy feedback rule:

$$\widehat{R}_t = (1-\rho)\left(\phi_\pi\widehat{\pi}_t + \phi_y\widehat{y}_t\right) + \rho\widehat{R}_{t-1} + a4_t \text{ for } R_t > 0 \tag{86}$$

Reserves:

$$\widehat{r}_t = \rho_r\widehat{r}_{t-1} + (-\psi_y)(1-\rho_r)\widehat{y}_t + (-\psi_\pi)(1-\rho_r)\widehat{\pi}_t \text{ for } R_t = 0 \tag{87}$$

[28]Note that in steady-state $\frac{\xi}{\lambda} = mc$ and $\frac{\lambda_{t+1}}{\lambda_t} = \frac{1}{1+\gamma}$.

Velocity:

$$\widehat{v}_t = a7_t \tag{88}$$

Loans:

$$\widehat{L}_t = \frac{1}{1-rr}\widehat{D}_t - \frac{rr}{1-rr}\widehat{r}_t \tag{89}$$

Reserve deposit ratio:

$$\widehat{rr}_t = \widehat{r}_t - \widehat{D}_t \tag{90}$$