The Effects of COVID-19 on the Labor Market

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***Abstract*—I developed a model combining the general DMP model and the Skeptical-Infected-Recovery model to analyze how the COVID-19 pandemic has influenced the labor market at the theoretical level. The model implies that both the decrease in infection rate by vaccination and the increase in recovery rate by improvement of health care services can cause turbulence in the labor market. Calibrating the model with data from the USA, I found that the trend of unemployment rate has experienced a slight increase right after the introduction of vaccination at the end of 2020. However, changes in recovery rate by improvement of health care services after infection cannot be accurately found in the current database. My research suggests that governments should propose policy packages to stimulate employment. Households and laborers should lower consumption to encounter the potential risks and costs that the vacancies have brought up to the labor market.**

***Index Terms*—COVID-19, SIR, unemployment, vaccination.**

I. Introduction

The outbreak of COVID-19 has caused an unprecedented crisis in the post-financial crisis era. It is undeniable that the achievement accomplished by the global community to recover the economy has been significant, but the sudden outbreak of the COVID-19 has caused damage to the previous recovery. Additionally, the negative impact caused by COVID-19 has generated more problems. The most striking problem is the negative impact on the labor market. Social restrictions have put the economies into the downturn. Therefore, laborers are forced to stop working. Based on the background given above, this paper analyzes how COVID-19 influenced the labor market and how the shock will affect the decisions of laborers in the market.

In this paragraph, I will discuss the impact caused by COVID-19 to the labor market. According to [1], until April 2020, when the pandemic spread all over the US without practical measures, the unemployment rate peaked at 14.7%. Though it fell to 8.4% in September 2020, it is still worthwhile to think through what factors have caused these changes. On the other hand, in China, the government has locked down the whole country, causing economic activities to halt and people staying at home because of the social restrictions. All industries stopped daily operation. Though online working emerged over time, the economy and the labor market have taken a severe hit because of COVID-19. Governments proposed stimulus packages such as coupons for stimulating the consumption. Staff was sent to the communities to ask if there were any unemployed people and they were given the opportunity to take part in the job fairs for the new jobs. Additionally, recent college graduates who have been seeking for jobs were unsure about how the labor market would be influenced. My research using models and that to explore this problem.

Another striking controversy is the trade-off between public health and the economy. The wide range of lockdowns have slowed down economic growth in many aspects. Chain reactions in the labor market occurred over time as well. Many companies turned to online working, which meant that these companies were able to protect their staff from being infected and still maintain their daily operations under this extreme condition. However, the transformation of working modes affected only a small range of enterprises, such as high-tech industries and other related businesses. For those high-repetitive and low-skilled workers, the lockdown stopped them from working regularly at the workplaces, and their jobs cannot be transferred online immediately since the intermediaries of their jobs are also mostly offline.

Based on the problems given above, this research was conducted to contribute to the current studies related to the pandemic and current labor market. This paper's incentives lie in two major papers. Firstly, the basic unemployment framework comes from [2]. In their research, they obtained an endogenous job creation and job destruction process and studied their properties. Building on Mortensen and Pissarides, my research uses their major framework as the basis to the unemployment during the pandemic. Another source is the basic Skeptical-Infected-Recovered Model (SIR) model, which comes from [3]. He lays out the basic SIR epidemiological model of contagion. Though the asymptomatic rate is not well-estimated, the results suggest finding the policies to achieve the optimal given transmission rate β and then form the paths of β to trade off the economic costs against the cost of lost lives.

Apart from these two major papers, this paper is also linked to a tradition in economics that studies the SIR model and its mutual effect with macroeconomic models. Reference [4] uses the SIR model to present the simulation of imposed severe mitigation for a few months, and what would happen if these mitigation measures are then gradually relaxed. The results show that the disease might simply restart the rapid progression and become highly infectious again within 18 months once mitigation efforts are relaxed, the approximate time for the virus to reach the peak infection is around 450 days.

To find out what other researches have formed the theoretical framework, I looked through other macroeconomic researches related to the COVID-19 pandemic. [5] analyzes the effects of an epidemic in three standard macroeconomic models. They find that the neoclassical economic model does not rationalize the positive

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co-movement of consumption and investment observed in recessions during the epidemic, while the introduction of monopolistic competition mends this problem even when prices are completely flexible. The main finding is that the sticky prices can lead to a larger recession, but do not fundamentally alter the predictions of the monopolistic competition model. Their extended model implies that people's decisions to cut back on consumption and work reduce the severity of the epidemic; however, these decisions might exacerbate the size of the recession. In the benchmark model, the best simple containment policy increases the severity of the recession, but saves roughly half a million lives in the U.S. This research has directly shown the tradeoffs that the US government would confront and this research has inspired my research to the right direction.

Reference [6] use the reformulated version of [7] framework and embed the unemployment theory in [8], [9]. They used the model to analyze the sources of unemployment fluctuations. The main results show that the demand shocks are the main driver of unemployment fluctuations at business cycle frequencies.

Reference [10] establish the scale and direction of information flows during multiple distinct phases of the development of the pandemic. The first result shows that the majority of domestically-traded Chinese stocks present evidence of significant information flows at a far earlier stage than internationally-traded comparatives, suggesting that domestic investors recognised the dangers associated with COVID-19 far in advance of the rest of the world. The corresponding result explains that the severity of domestically-reported Chinese news was not appropriately recognised by international investors. The second result presents that while evidence of safe-haven and flight-to-safety behaviour is evident throughout traditional energy and precious metal markets, cryptocurrencies became informationally-synchronised with Chinese equity markets, indicating their use as an investor safe-haven. This is a particularly concerning outcome for international policy-makers and regulatory authorities due to the fragility of these developing markets.

The remainder of the paper is structured as follows. Section II discusses the equations of each sector in the overall framework. Section III summarizes the data and calibration. Section IV presents the sensitivity tests based on the benchmark model. The paper is closed with final conclusions.

II. Model

This section discusses how the pandemic, as a shock, influenced the labor market under the condition of search match friction. The whole framework includes: Workers-In-Pandemic models that combine simplified DMP framework and SIR models. Another part is basic equations of the labor market. Other related parties are: firm, government, asset market and aggregation.

Assume that time is continuous and infinite, e.g. $t \in [0,+\infty]$. Labors are heterogeneous.

A. Workers-in-Pandemic Model

1) SIR model

The SIR Model in this framework is simplified as follows: the initial infected cases are represented as z_0. Initial skeptical cases are represented as s. Here we assume that the rest of the laborers are all skeptical. As for the key parameters, f_0 is infectious rate, f_1 is recovery rate and f_2 refers to case fatality rate.

Assume that there are three states for the benchmark of the SIR Model. They are infected cases, recovered cases, and death cases. Though the skeptical cases must be taken into consideration, they are initially simplified as the sum of population at the beginning of pandemic. Recovered cases are represented by $z_0 f_1$ and death cases are represented by $z_0 f_2$.

In this case, the change in infected cases is given by:

$$\dot{z} = z_0' - (sf_0 - z_0 f_2 - z_0 f_1)$$

z' is the infected cases of next period.

In the model, the death cases will not appear in the next period.

The change of skeptical cases is given by:

$$\dot{s} = s' - (s - f_0 s + z_0 f_1)$$

where the s' is the skeptical cases of the next period.

As for the labor market transition, I set up the following matrix:

$$\begin{vmatrix} -f_0 & f_0 \\ f_1 & -f_1 - f_2 \end{vmatrix}$$

According to the states of workers and SIR models, there should be 6 states in total in the Workers-In-Pandemic Model. Once the death cases appear, the employed or unemployed death cases are not laborers in the market anymore. Therefore, based on the first matrix, the new four states in the new model set can be recognized correspondingly.

2) Labor market

Below are the conditions and equations to set up the basic mechanisms in the context of this paper:

- **Job Finding and Filling Rates**

$$f_t = \frac{M(u_t, v_t)}{u_t} = M(1, \theta_t)$$

$$q_t = \frac{M(u_t, v_t)}{v_t} = M(\theta_t^{-1}, 1)$$

- **Labor Market Tightness**

$$f = \theta^{(1-\eta)}\chi$$

$$q = \theta^{(-\eta)}\chi$$

$$u = \frac{\sigma}{\sigma + f}$$

$$v = \theta u$$

$$\dot{u}_t = \sigma(1 - u_t) - f_t u_t$$

Our model uses two states to represent employed or unemployed workers. Employed and unemployed workers have different conditions in income, state-constraint boundary conditions, and HJB equations.

The income of the worker is given by:

$$y = [w, (I, 1)h]$$

$$W(a_0, s_0) = max_{\{c_t\}_t \geq 0} \mathbb{E} \int_0^\infty e^{-\rho t} u(c_t) \mathrm{d}t$$

$$y_t(a_t, s_t) = \begin{cases} \omega(a_t), & \text{if } s_t = e \\ h, & \text{if } s_t = u \end{cases}$$

where the y_t refers to the notation of income.

$$\dot{a} = y(a_t, s_t) + (r_t - \delta)a_t - c_t$$

$$a_t \geq \underline{a}$$

$s_t \in e, u$ is a Poisson Process with intensities presented by f_t, λ

- **Employed Workers**

As for the employed workers, I present the HJB equation and state-constraint boundary condition:

$$\rho W(a,e,t) = max_c\{u(c) + \partial a W(a,e,t)[\omega(a,t) + (r_t + \delta)a - c] + \rho[W(a,u,t) - W(a,e,t) + \partial t W(a,e,t)]\}$$

$$\partial a W(a,e,t) \geq u'(\omega(\underline{a},t) + (r_t - \delta)\underline{a})$$

- **Unemployed Workers**

However, unemployed workers, had to save to prepare for the loss of jobs. Therefore, the equations for unemployed workers are:

$$\rho W(a,u,t) = max_c\{u(c) + \partial a W(a,u,t)[h + (r_t + \delta)a - c] + \rho[W(a,e,t) - W(a,u,t) + \partial t W(a,u,t)]\}$$

$$\partial a W(a,u,t) \geq u'(h + (r_t - \delta)\underline{a})$$

B. Firm

The profit of the firm is given by:

$$profit = k^\alpha - rk - w$$

C. Government

In the model, the government sets up the nominal interest rate following a modified Taylor rule:

$\Phi R \in [0,1)$ refers to the degree of interest-rate smoothing. $\gamma_\Pi > 0$ and $\gamma_y \geq 0$ are the responses to inflation from target Π and steady-state output y. R refers to the steady-state nominal interest rate and it is determined by the equilibrium of this economy. The budget constraint is as follows,

$$b_t = b_{t-1}\frac{R_{t-1}}{\prod_t} + g_t - (c_t\tau_{c,t} + w_t l_t \tau_{l,t} + r_{k,t}u_t k_{t-1}\tau_{k,t} - \delta k^b_{t-1}\tau_{k,t} + \Omega_t)$$

D. Asset Market

The interest rate r is given by:

$$r = \alpha k^{(\alpha-1)}$$

where K is the aggregated capital depends on the unemployment according to

$$K = (1-u)k$$

E. Aggregation

The aggregate demand is given by:

$$y_t = c_t + i_t + g_t + \frac{\phi_p}{2}(\prod_t - \prod)^2 y_t + \frac{\phi_w}{2}(\frac{w_t}{w_{t-1}} - 1)^2 y_t$$

The capital-labor ratio was chosen from Fernandez (2011) as follows,

$$k_{t-1} = \int_0^1 k_{it} d_t$$

The aggregate supply is:

$$y_t = A_t(u_t k_{t-1})^\alpha l_t^{1-\alpha}$$

Under this condition, the market clearing is:

$$y_t = c_t + i_t + g_t + \frac{\phi_p}{2}(\prod_t - \prod)^2 y_t + \frac{\phi_w}{2}(\frac{w_t}{w_{t-1}} - 1)^2 y_t = A_t(u_t k_{t-1})^\alpha l_t^{1-\alpha}$$

III. Data and Calibration

In this section, benchmark parameter values and corresponding results of the calibration are presented.

A. Benchmark Parameter Values

Some of the parameters are set based on the standard values. In the stationary problem, z = 1, the relative risk aversion is set as $\gamma = 1$ and assume that agents can only save, resulting in a = 0. Let the elasticity of matching with respect to unemployment be $\eta = 0.72$, and impose the Hosios condition, $\beta = \eta$. In the standard DMP with linear utility, this condition guarantees efficiency. In our setting it does not, because of the over-accumulation of capital induced by precautionary saving.

The rest of the parameters are calibrated to match various moments of the data. The choice of bargaining solution only affects the vacancy cost. Table I presents the benchmark parameter values.

TABLE I: Benchmark Parameter Values

	Parameter	Value
Monthly Separation Rate	σ	0.1038
Relative Risk Aversion	γ	1
Matching Elasticity to Unemployed	η	0.72
Discount Rate	ρ	0.01
Matching Efficiency	χ	1.7935
Worker Bargaining Power	β	0.72
Home Production	h	0.75
Capital Share	α	0.3
Depreciation Rate	δ	0.021
Infectious Rate	f_0	1/5.2
Recovery Rate	f_1	1/18
Case Fatality Rate	f_2	0.0239
Initial Infected	e	0.01

According to [11], the recovery rate of COVID-19 is f_1=1/18 reflecting an estimated duration of illness of 18 days. Likewise, those who are exposed to the disease become infected for an estimated incubation period of the disease for 5.2 days, which is represented by f =1/5.2. Finally, the global case fatality rate is set to f_2=0.0239 as defined in [12].

In terms of the forming process of each group of people in the SIR model, here are three major equations that I simplified based on the original models from [4].

The first equation shows that the initial skeptical cases are

given as the overall population minus the initial infected.

$$s=1-e$$

To avoid the errors with the natural logarithm, the initial infected people are given the notation by z_0.

$$z_0=e$$

Here, the initial death cases are given the value of 0.

$$d_1=0$$

Therefore, the final assumption of the model is that, at the beginning of the outbreak, there are no death cases and only a small group of people are infected, while all of the remaining population are regarded as the skeptical cases in the model.

Fig. 1 presents the responses of employed and unemployed laborers in key variables along with the increase of assets. With the given changes in either infectious rate or recovery rate, the responses present no significant changes. The analyses have focused on the steady state values of those key parameters.

B. Benchmark Steady State

TABLE II: STEADY STATE VALUE

	Parameters	Values
Aggregate Capital	K	24.1801
Capital Per Worker	k	24.5668
Equity Price	p	-21.9436
Dividend	d	-0.2393
Interest Rate	r	0.0319
Unemployment Rate	u	0.0158
Vacancies	v	1.5482
Job Finding Rate	f	6.4782
Job Filling Rate	q	0.0660
Tightness	θ	99.1189
Annualized Return on Capital	r_k	0.0427

C. Benchmark Results

Fig. 1 demonstrates how unemployed laborers consume more than the employed workers. Although they both share the increasing trend, the consumption of the unemployed laborers gradually turns higher than that of the employed laborers. This could be because the pandemic has influenced the consuming and saving behaviors of the employed and unemployed workers differently. As the pandemic began, the unemployed would worry more since they don't have any income, and they would also suffer more than usual in the job-finding process since the pandemic has made the time of finding the job longer. Therefore, they would consume more to maintain their lives, especially since the costs of finding a job has increased over the pandemic. This difference could be also explained in the saving behavior, the unemployed save less because they might have consumed more in maintaining their lives and finding their new job. Also, the employed tend to save more in the pandemic since some of them are still at work that is conducted online and they still can earn their living and, therefore. save more. The pandemic has widened the saving and consumption gaps between the employed and the unemployed.

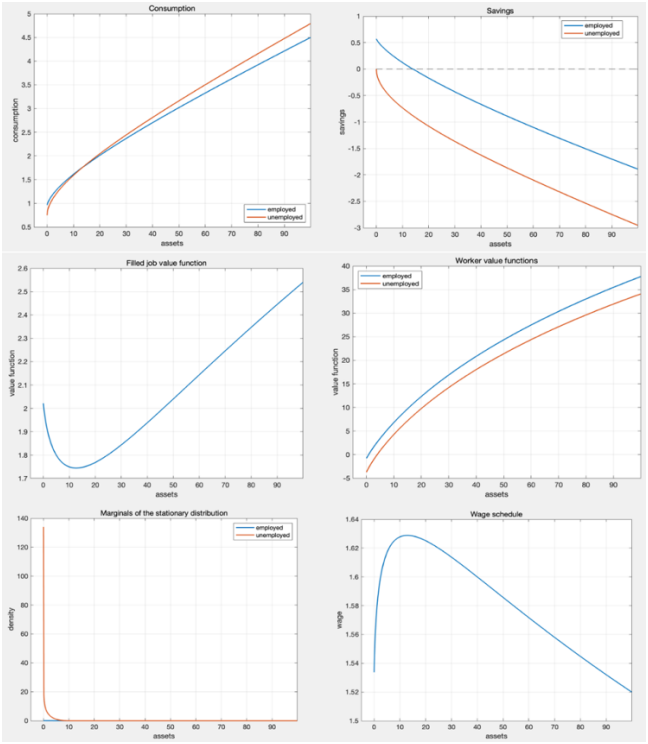

Fig. 1. Responses with Benchmark Parameter Values.

In the equations, the job matching process is presented by the filled job value function and the worked value functions. The filled job value experiences a decrease at first and then steeply increases. The findings suggest that both employed and unemployed workers will experience the growth of their value continuously. The wage schedule increases sharply and then decreases continuously.

The asset distribution of the unemployed experiences a sharp decrease at the beginning and then stays the same as that of the employed.

The benchmark results have presented general responses of key variables and interpretations of steady states when COVID-19 hit the labor market and the economy.

IV. SENSITIVITY TESTS

In this section, I conduct the sensitivity tests by changing the infection rate, recovery rate, relative risk aversion, and matching efficiency and the worker bargaining power that are closely related to the labor market. The results of these tests will prove how the pandemic and changes in the labor market influence the overall performance of the economy.

A. Infection Rate

To make things less uncertain, the COVID-19 infection is recognized as a first-time infection. The decrease of infection rate can be interpreted as the introduction of vaccination. Therefore, the process is a pre-infection process since the vaccinations are for those who haven't been infected; those who have been infected will be discussed in the next section. Therefore, the only change here is the decrease of infectious rate f_0 from 1/5.2 to 1/14, which means that the estimated incubation period of the COVID-19 after the introduction of the vaccination will be 2 weeks.

- **Steady State-Infection Rate**

TABLE III: STEADY STATE VALUE

	Parameters	Values
Aggregate Capital	K	23.5900
Capital Per Worker	k	24.0023
Equity Price	p	-11.5037
Dividend	d	-0.1314
Interest Rate	r	0.0324
Unemployment Rate	u	0.0175
Vacancies	v	1.1734
Job Finding Rate	f	5.8204
Job Filling Rate	q	0.0869
Tightness	θ	67.6106
Annualized Return on Capital	r_k	0.0447

- **Comparisons with Benchmark Results**

This section illustrates those who haven't been infected and the first introduction of vaccination for the public.

Table III shows that if, the estimated incubation period of COVID-19 becomes longer because of the introduction of the vaccination, changes happen in the steady state values of some key parameters.

Aggregate capital and capital per worker have experienced a slight decrease while the equity price and the dividend have increased over time. After the short-term period when the vaccination was first introduced, the decrease of the infection rate can prevent more people from being infected, allowing more laborers for the labor market. However, the economy shrinks because of the lockdown and social restrictions, which stopped some traditional industries from working as normal. Workers in traditional industries, which account for a big proportion of the labor force, cannot work online and it is also hard for them to gain new skills immediately.

Therefore, the direct result is the increase of unemployment rate in the short-term period after the introduction of the vaccinations. The decrease of the job finding and filling rates also reflects that more people have lost their jobs and it is harder for them to find a new job. Also, the decrease of the vacancies could prove that more laborers are available and they are seeking jobs while the economy cannot recover that fast for more vacancies and positions. The interest rate in this theoretical framework is equal to the capital rate, which has experienced a slight increase that, could be interpreted as more laborers will be found in the future and the output will increase with the growing needs of the capital.

- **Data Matching and Explanations**

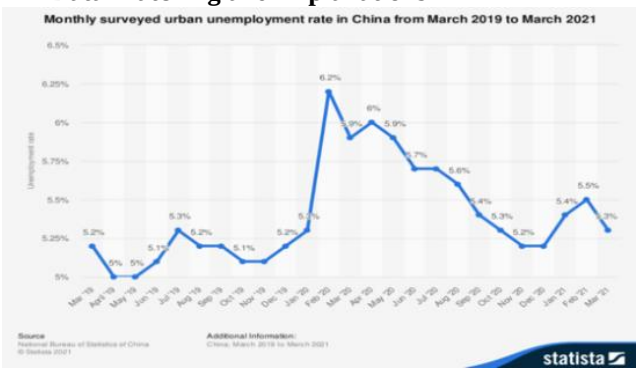

Fig. 2. Unemployment Rate of China.

Here, Fig. 2 shows the unemployment rate in China to prove the analysis given in the sensitivity test for infection rate.

According to the press, the introduction of the vaccination in China happened at the beginning of December in 2020. Based on the analysis given above, the introduction of vaccination would cause the short-term increase of unemployment rate and then in vacancies and other key parameter values. The change in the unemployment rate is the most direct way to prove that the analysis is reasonable. After the March of 2021, the unemployment rate decreased, which proves the conclusion that the introduction of vaccination would cause the immediate increase of the unemployment rate for a short-term period.

Reference [13] has shown that higher unemployment is associated with higher vaccination rates in the USA. This result has also shown that the changes in infection rate merely caused by introduction of vaccination would have an immediate influence on the unemployment rate.

B. Recovery Rate

For recovery rate, I only changed the value of duration of the COVID-19 illness from 18 days to 10 days, which changes the recovery rate f_1 from 1/18 to 1/10 The change is based on the introduction of better healthcare services from the health department of a typical government such as China or USA. Incubation period of the disease is maintained to 5.2 days, which reflects that the better healthcare services have shortened the time for recovery from more than ten times of the illness duration to less than two times of the time period. To make things specific, this is the pro-infection process, and this is why the incubation period of the disease is still maintained. Moreover, the change is only for those cases that are still alive; dead cases are not taken into consideration. 10 days seems to be the optimal choice for this alternative process.

- **Steady State-Recovery Rate**

TABLE IV: STEADY STATE VALUE

	Parameters	Values
Aggregate Capital	K	23.8645
Capital Per Worker	k	24.2590
Equity Price	p	-16.9707
Dividend	d	-0.1898
Interest Rate	r	0.0322
Unemployment Rate	u	0.0166
Vacancies	v	1.3836
Job Finding Rate	f	6.2029
Job Filling Rate	q	0.0738
Tightness	θ	84.8749
Annualized Return on Capital	r_k	0.0438

- **Comparisons with Benchmark Results**

The changes caused by the increase of the recovery rate experience the same trends as those of the decrease of infection rate in Table IV.

The only significant difference is that the increase of the recovery rate caused less of an increase in unemployment rate, which means that the recovery of the labor is slower in this case. This conclusion reflects that the improvement in health care services might generate a longer time for the labor market to become healthy. As for the data matching, there's no evidence to clear the irrelevant factors in reality to

guarantee that the changes in recovery rate can influence the unemployment rate directly.

C. Relative Risk Aversion

The relative risk aversion presents the laborers' willingness to confront the risks in the market. In this test, I assume that the laborers are less willing to face the risks with the value of relative risk aversion changed from 1 to 0.5. Another test for relative risk aversion is that the value will become larger from 1 to 4, which means that laborers put more of their attention to the asset market, meaning that they are more likely to face more risks with the pandemic.

- **Steady State-Relative Risk Aversion (0.5)**

TABLE V: STEADY STATE VALUE

	Parameters	Values
Aggregate Capital	K	24.2203
Capital Per Worker	k	24.5466
Equity Price	p	-29.7847
Dividend	d	-0.3256
Interest Rate	r	0.0319
Unemployment Rate	u	0.0131
Vacancies	v	2.5429
Job Finding Rate	f	7.8488
Job Filling Rate	q	0.0403
Tightness	θ	196.7753
Annualized Return on Capital	r_k	0.0428

In the Table V, with the changes of value in relative risk aversion, when laborers are less willing to face risks in the market, mean assets sharply decrease and the unemployment rate decreases with the increase in vacancies, which demonstrates that the laborers are more likely to focus on finding the job, as shown by the increase of the job finding rate. However, as more people tend to find jobs when the risk aversion turns lower, the job filling rate will decrease and the tightness would sharply increase. This is the sudden change for the sharp increase in tightness, and the labor market turns harder to react immediately, which is why the job filling rate would slightly decrease. When the economy recovers, more jobs will be provided, leading to a decrease i the unemployment rate. I found no sharp changes in the aggregated capital and capital per worker, clear changes of values of those parameters related to the labor market. This finding demonstrates that laborers would choose either finding jobs or facing more risks in purchasing the assets to maintain their wealth in the market.

- **Steady State-Relative Risk Aversion (4)**

TABLE VI: STEADY STATE VALUE

	Parameters	Values
Aggregate Capital	K	24.1449
Capital Per Worker	k	24.5589
Equity Price	p	-17.6686
Dividend	d	-0.1928
Interest Rate	r	0.0319
Unemployment Rate	u	0.0170
Vacancies	v	1.2777
Job Finding Rate	f	6.0149
Job Filling Rate	q	0.0799
Tightness	θ	72.0298
Annualized Return on Capital	r_k	0.0427

In Table VI, we can see that when the relative risk aversion is turned higher, meaning laborers are focusing on purchasing more assets in the market, the unemployment rate increases, vacancies decrease, the job finding rate decreases, and job filling rate increases. Mean assets turn higher. All of the changes at the steady states are opposite to those when the relative risk aversion is lower than 1. This could also prove that laborers would either choose to purchase more assets to maintain their wealth or to spend more time and money to seek jobs when the pandemic hits the economy. The findings show that the pandemic changes the attitude of people towards the purchasing behavior of assets and the job-finding.

V. CONCLUSION

I develop a Workers-In-Pandemic model based on the search match model in DMP Models from [2] and the SIR model from [3]. The Worker-In-Pandemic model examined how the shock of a pandemic influenced the laborers in seeking jobs based on the search and match model.

The major conclusion generated from the changes of infection rate and recovery rate is that changes in infection rate can encourage more laborers to go back to the labor market, also this process is faster in the given time period within the model settings. This conclusion is proven by the larger decrease in the aggregate capital, capital per worker and vacancies. The larger increase in the unemployment rate also proves this. Finally, the unemployment rate data from the USA can prove that the changes of infection rate have caused the short-term decrease of the unemployment rate.

A final conclusion from the sensitivity test is that laborers choose to spend time and money on either finding jobs or facing more risks in purchasing the assets to maintain their wealth in the market.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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