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ON THE IMPACT OF THE COVID-19 PANDEMIC ON THE HOUSEHOLD'S CONSUMPTION AND LABOR SUPPLY: THEORY AND APPLICATION

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Abstract. The COVID-19 pandemic and the corresponding regulation measures carried out to curb it have had a strong negative impact on the whole economy, and household consumption has been seriously affected. A large part of the drop in consumption is due to the reduction of household income, which is mainly caused by the labor supply loss during the pandemic. To present the mechanism of the impact of the pandemic on consumption, this study constructs a novel theoretical model. Two hypotheses about the pandemic's impact on labor supply are proposed and empirically tested. Subsequently, a comparative static analysis is carried out to determine the numerical mechanism of the pandemic's impact on household consumption. In addition, the model is also empirically tested and further modified for application, enabling the studies of both a realistic simulation and a policy simulation. This study finds that the labor supply of households has been affected during the pandemic, and there is a mediating effect channel through the regulation stringency. The epidemic severity and regulation policies have a negative impact on household consumption, in turn, will raise the saving rate of households. The income effect of the two on consumption accounts for 32% and 44% of the total effect respectively.

Keywords: household, consumption, labor supply, COVID-19, theory and application.

JEL Classification: P36, H31, E21, E24, J22, K32, I18.

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1. Introduction

Since the emergence of COVID-19 in 2020, it has triggered an unprecedented global economic crisis. This crisis has affected countries all over the world, exerts a far-reaching impact, and is of high severity. In fact, about 90% of countries experienced a contraction in economic output in 2020, causing the world economy to decline by about 3% (World Bank, 2022a). Despite the passage of four years since the onset of the pandemic, its lasting economic consequences persist. The rapid spread of the Omicron variant further suggests that the pandemic will continue to disrupt economic activity in the foreseeable future (World Bank, 2022b). According to the World Bank's (2023) *Global Economic Prospects report*, global economic growth is projected to experience a significant slowdown, with an expected decline from 5.5% in 2021 to 4.1% in 2022 and further down to 3.2% in 2023. This deceleration can be attributed to the dissipation of pent-up demand and the gradual unwinding of fiscal and monetary support measures worldwide.

To curb the spread of COVID-19, countries around the world have taken unprecedented steps to implement a diverse range of non-pharmaceutical interventions (NPIs), which encompass isolating sick persons, conducting contact tracing, quarantining exposed persons, implementing school and workplace closures, and avoiding crowding. These measures have been widely deployed to mitigate the spread of the virus (Fong et al., 2020; Hale et al., 2023). These NPIs have exerted a comprehensive influence on all aspects of the economy, with different impacts on labor markets, production supply chains, financial markets, and GDP levels. The adverse impacts may differ based on the level of stringency in implementing the containment measures (Brodeur et al., 2021). Coibion et al. (2020a) conducted a comprehensive study utilizing multiple survey waves to assess the economic impact of the COVID-19 crisis. Their findings reveal that households in the United States endure notable job losses and simultaneously face a significant decrease in consumption as a result of the pandemic. The implementation of lockdown measures emerges as the predominant factor contributing to this predicament.

An unexpected occurrence that is unlikely to happen but can result in significant destruction and consequences is referred to as a "Black Swan" event, and the COVID-19 pandemic is a typical case (Wang & Liu, 2022; Weber, 2021). As a black swan event, COVID-19 has delivered a shock to all sectors of the economy. The first is the shock to the real economy. Liu et al. (2022) find that the impact of the COVID-19 pandemic has had significant effects on both manufacturing and consumption. However, the service sector appears to be particularly vulnerable to the shock caused by the pandemic. Investment behavior has also suffered a shock. Hysa et al. (2022) find that the COVID-19 pandemic has contributed to an increase in Foreign Direct Investment (FDI) outflows across European countries. Ahmad et al. (2021) find that the repercussions of the COVID-19 outbreak as a black swan event are apparent in the early stage of the pandemic. During this time, investors faced limited investment opportunities, with only a few sectors remaining unaffected by the pandemic in Western countries. The financial market is also disrupted. Wang and Liu (2022) find that the panic caused by the COVID-19 pandemic has had dual effects, leading to a depression in stock prices while simultaneously inflating volatility in daily returns.

Household consumption has also been seriously affected. Following the outbreak of the COVID-19 pandemic, there was a significant decline in household consumption and an unprecedented increase in propensity to save. In the United States, consumer spending in the second quarter of 2020 experienced a sharp decline, decreasing by 9.8% compared to the same period in 2019 (U.S. Bureau of Labor Statistics, 2022). The cumulative growth rate of China's total retail sales of consumer goods in February and March 2020 was – 20.5% and – 15.8% respectively, declining continuously for six months thereafter (National Bureau of Statistics of China, 2020). The saving rate of households has also risen. Excess savings in the euro area rose steadily from Q1 2020 to Q4 2022, reaching 11.3% of disposable income. In the United States, excess savings reached a peak of 13.2% in Q3 2021 before falling to 7.9% by Q4 2022 (Battistini et al., 2023).

Household consumption is an important part of the modern economy and the core driving force of economic growth, and its steady growth is of great significance to economic development. Public health emergencies like COVID-19 will cause a typical demand-suppressing economic crisis. Therefore, it is crucial to clarify the impact mechanism of the pandemic on household consumption to promote consumption and restore economic vitality.

The twisted consumption and saving patterns during the pandemic can be attributed to several transmission channels. Guglielminetti and Rondinelli (2021), together with Kim et al. (2020) have made detailed research, which can be summarized into four key points. First, the reduced income and the job losses directly lead to the reductions in consumption spending of households. Second, increased uncertainty leads households to precautionary savings. Third, lockdown policies and other regulation measures force households to cut consumption expenditures. Fourth, the fear of infection may curb households' propensity to consume.

The above views provide a reference for the analysis presented in this study. Nevertheless, it is still unable to quantitatively elucidate the precise mechanism of how the pandemic has influenced consumption. What is the mathematical mechanism of the pandemic's impact on household consumption? How does the household make the consumption decision when reacting to the pandemic? How many factors have exerted crucial influences on household consumption? Exploring and revealing the underlying mechanism that drives changes in consumption spending of households as well as the corresponding labor supply during the COVID-19 crisis is of great importance for mitigating its adverse impact and expediting economic recovery. Furthermore, it can serve as a valuable policy reference for addressing future public health emergencies.

To answer the questions shown above, we need to investigate the optimal consumption decision-making of households from the micro perspective. Therefore, this study constructs a mathematical model to reveal the mechanism of the COVID-19 pandemic's impact on household consumption. The model is a simple two-period static model, by constructing a representative household's utility function and budget constraint and making a utility maximization decision, the optimal consumption of the household can be obtained. In addition, this study proposes two hypotheses about the impact of the pandemic on household's labor supply and then empirically tests which one it should be. Subsequently, this study carries out a comparative static analysis to determine the numerical mechanism of the COVID-19 pandemic's impact on household consumption. Finally, this study empirically checks the effectiveness of model results using aggregate data from different countries.

This study mainly contributes to the literature in the following way. First, this study examines households' optimal consumption-savings decisions from the micro perspective and builds a novel model, which quantitatively reveals the mechanism of the impact of the pandemic on consumption. Second, this study tests the two hypotheses of the pandemic's impact on labor supply by using the mediation effect model and finds that the pandemic has a direct impact on the labor supply of households. Third, this study constructs an indicator of "real" working hours, which can reflect the true distortion of the pandemic to the labor supply.

The succeeding part of this study is structured as follows. After reviewing the related literature in Section 2, we set up the theoretical model and carry out a comparative static analysis in Section 3. Then, in Section 4, we introduce the data set and construct the novel indicator. In Section 5, we conduct the empirical analysis to test the model and in Section 6 we make a discussion to modify the model and conduct a realistic simulation. In Section 7, we apply the model to practice and discuss what kind of pandemic prevention policies the government should adopt in the future public health emergency. In Section 8, we present our concluding remarks.

2. Literature review

The COVID-19 pandemic has hit all aspects of the economy, and analyzing the impact of the pandemic on household consumption needs to be considered from every aspect. The following section summarizes the related literature on the important areas where the pandemic has influenced household consumption.

2.1. Disrupted consumer behavior: The direct factor of consumption change

The COVID-19 pandemic, together with the NPIs, has significantly impacted consumer behaviors, which can be attributed to two major factors: preventive measures (regulation measures) and self-protective mentalities (fear of infection) (Sheth, 2020; Wang et al., 2022).

The regulation measures such as lockdowns have changed consumer behavior strongly. During the COVID-19 pandemic, the tendency to self-isolate emerged as an important determinant of disruption in consumer behavior. Based on this finding, it appears that the changed consumer behaviors are primarily driven by their anticipation of being placed under quarantine (Laato et al., 2020). The implementation of NPIs, such as lockdown measures, has demonstrably influenced transaction and spending outcomes making consumers reduce the frequency they go out shopping (Rose et al., 2023).

Fear of infection has been found to be closely associated with disrupted consumer behavior during the COVID-19 pandemic. These concerns have affected both traditional and online shopping patterns. Notably, those who exhibit a high level of fear of infection, especially during shopping activities, are more likely to reduce consumption and increase savings (Eger et al., 2021; Immordino et al., 2022). Another important question is to consider how much of the decline in consumption is due to the containment measures, and how much is due to the fear of infection? According to the estimations made by Goolsbee and Syverson (2021), most of the decline can be attributed to individuals' voluntary choices to withdraw from participating in economic activities, rather than a result of policy restrictions imposed on such activities.

2.2. Declining household income: The determinant of consumption change

In the theoretical framework of Keynesian economics, income is regarded as the determinant of consumption. The consumption function, proposed by Keynes (1936), represents the functional relationship between consumption and income, which suggests that consumption increases with income. While subjective and objective factors (e.g., psychological feature and fiscal policy) may also influence consumption, they remain relatively stable in the short term, the consumption is thus determined by income.

As mentioned previously, the COVID-19 pandemic has caused a strong and broad negative effect on household income. Pinkovetskaia (2022) studied the impact of the COVID-19 pandemic on household income levels using the data of 43 countries. The research shows that about half of households have experienced an income drop as a direct result of the pandemic. Almeida et al. (2021) find that in the absence of fiscal policy support, the COVID-19 pandemic would lead to a 9.3% decline in disposable income per capita in the European Union.

Bundervoet et al. (2022) analyzed representative data from 31 developing countries. Their findings showed that, on average, 36% of respondents stopped working immediately after the outbreak of the COVID-19 pandemic, and 65% of households reported a drop in income. Furthermore, the pandemic-induced income shock can have a substantial impact on households' expectations regarding spending, debt, and labor market activity (Hanspal et al., 2020).

Regarding the reasons for the decline in household income, the economic consequences of the pandemic and the measures implemented to contain it account for it. The adverse effects of the pandemic and the subsequent public response have been substantial, with more than 40% of adults in the United States reporting job losses, reduced work hours, or pay cuts for themselves or their family members. The containment measures implemented to mitigate the spread of COVID-19 have directly impacted the ability of individuals to work, thereby affecting their earnings (Acs & Karpman, 2020; Kuypers et al., 2022).

2.3. Twisted labor market: The main factor affecting household income

As a classical theory, Keynesian economics argues that a given level of income is contingent upon a corresponding level of employment. Higher employment typically leads to increased production of goods and services, which in turn raises the overall income levels in the economy. Conversely, a decrease in employment results in lower production and, consequently, reduced income (Keynes, 1937). Thus, the major factor affecting household income is the labor market (for most households).

The COVID-19 pandemic has resulted in a widespread contraction of the labor market across almost all industries (Forsythe et al., 2020). The pandemic had a serious impact on the total amount of social employment, resulting in the rise of unemployment. For example, in the United States, the unemployment rate experienced a remarkable surge, skyrocketing from a near-record low of 3.5% in February 2020 to an alarming 14.7% by April 2020. This level of unemployment has not been seen since the Great Depression. The imposition of strict lockdowns and social distancing policies played a role in this rapid increase in unemployment rates (Borjas & Cassidy, 2020; Rojas et al., 2020).

According to Coibion et al. (2020b), there are three main characteristics of the pandemic's twist on the labor market. First, job losses were much higher than expected. Second, many unemployed individuals are not actively seeking new jobs. Third, the labor participation rate has fallen sharply.

Working hours loss is another distortion that the pandemic imposes on the labor market. According to ILO Monitor's 5th edition (International Labour Organization, 2020), the global workforce experienced a significant decline in working hours during the first quarter of 2020, equivalent to approximately 155 million full-time jobs or 5.4% of total working hours compared to the previous quarter. It is important to note that the factors contributing to the decline in working hours were not uniform across the countries. In some countries, the reduction in working hours was primarily due to shorter workweeks or employees being placed on temporary leave, resulting in a situation where they were technically employed but not actively working. On the other hand, in certain countries, the main driver of the decline was the increase in unemployment and inactivity among the population.

2.4. Summary

Through the review of the above literature, we can further explore the internal mechanism of the pandemic's impact on consumption and the corresponding labor supply. The first is the direct factor of changes in consumption, households change their behavior to consume, either because of mandatory savings through containment measures or due to fear of infection. Secondly, the pandemic has hit every aspect of the economy. The labor market is twisted, not only in terms of higher unemployment and lower labor force participation but also in terms of fewer working hours. Consequently, it directly leads to a decline in household income, which is the determinant of consumption.

As we conclude, the pandemic and the regulation measures that aim to deal with it both have a direct impact on household consumption. In the meanwhile, they also hit the labor market, causing income to decline, and giving rise to a shock to household income. These ideas inspire us, and the theoretical model in the next section will be constructed based on this.

However, the previous studies have only explored the impact of the pandemic on household consumption in empirical terms, without further exploring the underlying mechanism behind it. This study first constructs a theoretical model and uses mathematical expression to explore the transmission mechanism of the pandemic on consumption and the corresponding labor supply. Secondly, this study uses the data of different countries from 2019 to 2022 for the empirical test, while most previous studies are limited to one country without international comparison. Finally, a simulation is carried out to confirm that the model has realistic explanatory power.

3. The theoretical model

3.1. Optimal consumption decisions of households

We propose a two-period model in which there is no pandemic in the first period and there is one in the second period. We model the utility function of the representative household as follows:

$$U(C_1, C_2) = C_1^{1-\alpha} C_2^{\alpha}, \tag{1}$$

where C_1 is the consumption quantity of households in the first period, and C_2 is the consumption quantity of households in the second period. We assume that the Cobb-Douglas utility function exhibits constant returns to scale.

There are many precedents in the field of economics for using the Cobb-Douglas function to describe consumers' two-period utility. For example, Seidman (1990), together with Cargill and Parker (2004), used exactly the same functional form as above. Many other studies made some variations on it, such as Guo and Zhang (2023), but have not departed from the form of the Cobb-Douglas function.

In the general Cobb-Douglas utility function, the parameter α refers to the consumer's preference for two goods, and in this case, it refers to the consumer's intertemporal preference. In addition, 1 – α and α are the share of consumption in each period when other variables are constant (i.e., the interest rate is zero, and there are no exogenous shocks). According to the life-cycle hypothesis and the permanent income hypothesis, consumers tend to smooth consumption, they thus prefer to divide the share of consumption in the two periods in half, so α = 0.5. Rajasekharan and Koivunen (2014) made such a setting. In addition, due to the preference of consumers for time, the proportion of consumption in the first period may be slightly higher considering the problem of time depreciation. Guo and Zhang (2023) set α = 0.49. However, the quantity difference between the two is very small and has little effect on the result, so we set α = 0.5 in the later part for simplicity.

We assume that the household's budget constraint in the first period is:

$$P_1 C_1 + S = w_1 L_1, \tag{2}$$

where P_1 is the price of consumer goods in the first period, S is the savings of households, w_1 is the wage rate, and L_1 is the labor supply of households in the first period.

The budget constraint in the second period is:

$$P_2 C_2 = w_2 L_2(Epi) + (1+r)S, \tag{3}$$

where P_2 is the price of consumer goods in the second period, and w_2 is the wage rate in the second period. $L_2(Epi)$ is the labor supply in the second period and Epi is the severity of COVID-19, which implies the labor supply of households in the second period is affected by the pandemic. r is the interest rate.

Combining Equations (2) and (3), we can obtain the household's intertemporal budget constraint:

$$P_1 C_1 + \frac{P_2 C_2}{1+r} = w_1 L_1 + \frac{w_2 L_2(Epi)}{1+r}. \tag{4}$$

We normalize P_1 as 1 here and rewrite P_2 as P, which implies the level of price change in the relative sense. Thus, $(P - 1) \times 100\%$ denotes the rate of price change.

Therefore, we can rewrite the household's intertemporal budget constraint as:

$$C_1 + \frac{PC_2}{1+r} = w_1 L_1 + \frac{w_2 L_2(Epi)}{1+r} = M. \tag{5}$$

We use M to represent the present value of the household's two-period total wealth.

Then, we maximize the household's utility function subject to Equation (5), the solution can be obtained:

$$\frac{C_2}{C_1} = \frac{\alpha(1+r)}{P(1-\alpha)}. \tag{6}$$

Substituting the above solution into the intertemporal budget constraint, we can obtain the optimal consumption of the household in the two periods:

$$C_1^* = (1-\alpha)M; \tag{7}$$

$$C_2^* = \frac{\alpha(1+r)}{P} M. \tag{8}$$

3.2. Two hypotheses of the impact of the pandemic on labor supply

The labor supply of households has been seriously affected by the pandemic. However, in what ways does the pandemic affect labor supply? The exact mechanism or mathematical expression of this is yet unknown to us. Thus, to determine the specific impact channels, we need to make some assumptions here. Inspired by Liu and Wang (2022), we propose two hypotheses. Hypothesis 1 assumes that the pandemic itself has no direct impact on the labor supply, but indirectly exerts a negative impact on the labor supply by influencing the regulation stringency, which can be expressed as $L(Reg(Epi))$. In contrast, hypothesis 2 assumes that the pandemic itself has a direct impact on the labor supply, and at the same time, it has an indirect impact on the labor supply through the influence of regulation stringency, which can be expressed as $L(Epi, Reg(Epi))$.

To examine the two hypotheses, we set up a mediation effect model to test whether the pandemic has a direct impact on the labor supply.

As for $Reg(Epi)$, we assume:

$$Reg(Epi) = \delta_0 + \delta_1 Epi, \tag{9}$$

where δ_0 denotes the basic regulation stringency in the absence of the pandemic (i.e., Epi = 0), and δ_1 denotes the influence coefficient of the pandemic on regulation stringency.

As for $L(Reg, Epi)$, we assume:

$$l = \frac{L_2}{L_1} = \gamma_0 + \gamma_1 Epi + \gamma_2 Reg, \tag{10}$$

where $\frac{L_2}{L_1}$ denotes the level of labor supply change (i.e., working hours change during the pandemic compared to the period without the pandemic). We use l to represent it, so $(l - 1)\times 100\%$ denotes the rate of labor supply change. In addition, γ_0 denotes the labor supply change in the absence of the pandemic. Given the small variation in working hours under normal circumstances, this value should theoretically be approximately equal to 1. Moreover, γ_1 denotes the direct impact of the pandemic on labor supply, and γ_2 represents the impact of regulation stringency on labor supply.

If both the coefficients δ_1 and γ_2 are significant, it indicates that the mediating effect of regulation stringency on labor supply exists.

If γ_1 is not significant, it indicates that the pandemic has no direct effect on labor supply, so hypothesis 1 is valid.

If γ_1 is significant, it indicates that the pandemic has a direct effect on labor supply, so hypothesis 2 is valid.

Therefore, we conduct an empirical test in Section 5, and the results suggest that hypothesis 2 is valid, which indicates that the impact of the pandemic on labor supply should take the form of $L(Epi, Reg(Epi))$. Thus, the pandemic has a direct impact on labor supply. The mathematical form of the impact of the pandemic on labor supply can be expressed as follows:

$$L_2(Epi) = [\gamma_0 + \gamma_1 Epi + \gamma_2 Reg(Epi)]L_1. \tag{11}$$

As we mentioned before, γ_0 should theoretically be approximately equal to 1, which is also confirmed by the empirical results in Section 5. Thus, we set γ_0 equal to 1 here. Then, we can rewrite Equation (11) as:

$$L_2(Epi) = L_1 + (\gamma_1 Epi + \gamma_2 Reg)L_1. \quad (12)$$

Since we have determined the mathematical form of $L_2(Epi)$, we can now express the specific form of C_2^*. Substituting Equation (5) into Equation (8), we obtain:

$$C_2^* = \frac{\alpha}{P}[(1+r)w_1L_1 + w_2L_2(Epi)]. \quad (13)$$

Then substituting Equation (12) into the above equation, we obtain:

$$C_2^* = \frac{\alpha(1+r)w_1 + \alpha w_2}{P}L_1 + \frac{\alpha w_2\gamma_1 L_1}{P}Epi + \frac{\alpha w_2\gamma_2 L_1}{P}Reg(Epi). \quad (14)$$

In addition, the specific form of the optimal savings is as follows:

$$S^* = w_1L_1 - C_1^* = \alpha w_1L_1 - \frac{1-\alpha}{1+r}w_2L_2 =$$
$$\alpha w_1L_1 - \frac{(1-\alpha)w_2L_1}{1+r} - \frac{(1-\alpha)w_2\gamma_1L_1}{1+r}Epi - \frac{(1-\alpha)w_2\gamma_2L_1}{1+r}Reg(Epi). \quad (15)$$

3.3. Comparative static analysis

Now that we have figured out the mathematical form of optimal consumption, we can conduct the comparative static analysis. Since the topic of this study is household consumption in the context of the pandemic, we will only discuss C_2^*.

(1) The impact of the pandemic on consumption

We are only discussing the direct impact of the pandemic here, so we ignore the impact of the pandemic on regulation stringency temporarily. So, *Reg* is no longer a function of *Epi* here.

Taking the partial derivative of Equation (14) with respect to *Epi*, we obtain:

$$\frac{\partial C_2^*}{\partial Epi} = \frac{\alpha w_2\gamma_1L_1}{P} < 0. \quad (16)$$

We assume that $\gamma_1 < 0$ here. This assumption will be empirically tested in Section 5. It can be seen that the pandemic has a negative effect on household consumption.

Dividing Equation (16) by Equation (13), the change rate of consumption to the epidemic severity can be calculated as:

$$\tilde{C}(Epi) = \frac{\frac{\partial C_2^*}{\partial Epi}}{C_2^*} = \frac{w_2\gamma_1L_1}{(1+r)w_1L_1 + w_2L_2} = \frac{\gamma_1 w}{1+r+lw}, \quad (17)$$

where $w = \frac{w_2}{w_1}$, which implies the level of wage change. Therefore, $(w - 1)\times 100\%$ denotes the rate of wage change.

(2) The impact of regulation stringency on consumption

Taking the partial derivative of Equation (14) with respect to *Reg*, we obtain:

$$\frac{\partial C_2^*}{\partial Reg} = \frac{\alpha w_2\gamma_2L_1}{P} < 0. \quad (18)$$

We assume that $\gamma_2 < 0$ here. It can be seen that regulation stringency has a negative effect on household consumption.

The change rate of consumption to regulation stringency can be calculated as:

$$\tilde{C}(Reg) = \frac{\frac{\partial C_2^*}{\partial Reg}}{C_2^*} = \frac{w_2\gamma_2 L_1}{(1+r)w_1L_1 + w_2L_2} = \frac{\gamma_2 w}{1+r+lw}. \quad (19)$$

(3) The impact of price level on consumption

Taking the partial derivative of Equation (13) with respect to P, we obtain:

$$\frac{\partial C_2^*}{\partial P} = -\frac{\alpha}{P^2}[(1+r)w_1L_1 + w_2L_2] < 0. \quad (20)$$

It can be seen that the price level has a negative effect on household consumption.

Since P represents the level of price change, $100\times P$ can be expressed as CPI. In addition, $\frac{\partial C_2{}^*}{\partial CPI} = \frac{\partial C_2{}^*}{\partial P} \times \frac{1}{100}$.

The change rate of consumption to the regulation stringency can be calculated as:

$$\tilde{C}(CPI) = \frac{\frac{\partial C_2^*}{\partial CPI}}{C_2^*} = -\frac{(1+r)w_1L_1 + w_2L_2}{100P[(1+r)w_1L_1 + w_2L_2]} = -\frac{1}{100P}. \quad (21)$$

(4) The impact of wage rate on consumption

Here, we make a deformation of Equation (13):

$$C_2^* = \frac{\alpha w_1}{P}[(1+r)L_1 + \frac{w_2}{w_1}L_2] = \frac{\alpha w_1}{P}[(1+r)L_1 + wL_2], \quad (22)$$

where $w = \frac{w_2}{w_1}$, which denotes the level of wage change.

Taking the partial derivative of the above equation with respect to w, we obtain:

$$\frac{\partial C_2^*}{\partial w} = \frac{\alpha w_1 L_2}{P} > 0. \quad (23)$$

It can be seen that wage has a positive effect on household consumption.

Since w represents the level of wage change, $(w - 1)\times 100\%$ is the rate of wage change, we express it as $\tilde{w}$. In addition, $\frac{\partial C_2{}^*}{\partial \tilde{w}} = \frac{\partial C_2{}^*}{\partial w} \times \frac{1}{100}$.

The change rate of consumption to the rate of wage change can be calculated as:

$$\tilde{C}(\tilde{w}) = \frac{\frac{\partial C_2^*}{\partial \tilde{w}}}{C_2^*} = \frac{L_2}{100[(1+r)L_1 + wL_2]} = \frac{l}{100(1+r+wl)}. \quad (24)$$

(5) The impact of interest rate on consumption

Taking the partial derivative of Equation (13) with respect to r, we obtain:

$$\frac{\partial C_2^*}{\partial r} = \frac{\alpha w_1 L_1}{P} > 0. \quad (25)$$

It can be seen that the interest rate has a positive effect on household consumption.

The change rate of consumption to the interest rate can be calculated as:

$$\tilde{C}(r)=\frac{\frac{\partial C_2^*}{\partial r}}{C_2^*}=\frac{w_1L_1}{(1+r)w_1L_1+w_2L_2}=\frac{1}{1+r+wl}. \tag{26}$$

(6) The impact of the pandemic on the saving rate

Using Equation (15), the saving rate can be calculated as follows:

$$s=\frac{S^*}{Y_1}=\frac{S^*}{w_1L_1}=\alpha-\frac{(1-\alpha)w}{1+r}-\frac{(1-\alpha)w\gamma_1}{1+r}Epi-\frac{(1-\alpha)w\gamma_2}{1+r}Reg(Epi). \tag{27}$$

Taking the partial derivative of Equation (27) with respect to *Epi*, we obtain:

$$\frac{\partial s}{\partial Epi}=-\frac{(1-\alpha)w\gamma_1}{1+r}>0. \tag{28}$$

It can be seen that the pandemic has a positive effect on the saving rate of households.

(7) The impact of regulation stringency on saving rate

Taking the partial derivative of Equation (27) with respect to *Reg*, we obtain:

$$\frac{\partial s}{\partial Reg}=-\frac{(1-\alpha)w\gamma_2}{1+r}>0. \tag{29}$$

It can be seen that regulation stringency has a positive effect on the saving rate of households.

All the variables and parameters appeared in the theoretical model and their meanings are demonstrated in Table 1.

Table 1. Variables and parameters

Variable	Explanation
C_1	Consumption quantity of households in the first period
C_2	Consumption quantity of households in the second period
L_1	Labor supply of households in the first period
L_2	Labor supply of households in the second period
l	Level of labor supply change (the ratio of L_2 to L_1)
w_1	Wage rate in the first period
w_2	Wage rate in the second period
w	Level of wage change (the ratio of w_2 to w_1)
P_1	Price of consumer goods in the first period
P_2	Price of consumer goods in the second period
P	Level of price change (the ratio of P_2 to P_1), so $100\times P$ can represent CPI
r	Interest rate
S	Savings of households
s	Saving rate of households
Epi	Epidemic severity
Reg	Regulation stringency

End of Table 1

Parameter	Explanation
α	Consumer's intertemporal preference
δ_0	The basic regulation stringency in the absence of the pandemic
δ_1	Influence coefficient of the pandemic on regulation stringency
γ_0	labor supply change in the absence of the pandemic
γ_1	Direct impact of the pandemic on labor supply
γ_2	Impact of regulation stringency on labor supply

4. Variables and data

4.1. Variables

The variables we used for the empirical study are shown in Table 2.

Table 2. Variables used in empirical analysis

Symbol	Variable	Explanation
Epi	Epidemic severity index	The variable that reflects the severity of the epidemic (0–100)
Reg	Regulation stringency	The variable that reflects the stringency of the regulation policy (0–100)
C	Consumption	Personal consumption expenditures
L	Average labor supply	Real weekly average working hours
l	Level of labor supply change	The ratio of labor supply in the pandemic period to labor supply in the non-pandemic period
W	Wage	Average hourly earnings
CPI	Consumer price index	Reflects the price level
r	Interest rate	Average annual interest rate
s	Saving rate	Reflects the level of household savings
Income	Income	Household disposable income
Vaccination	Vaccination	Total vaccinations per hundred

The epidemic severity index is constructed from two indicators, which are the number of new confirmed cases and the number of new deaths. That is because there have been so many different variants since the start of the COVID-19 pandemic with different levels of infectiousness and lethality, using a single indicator to capture the severity of the pandemic is inaccurate. For example, the Omicron variant is more transmissible but less pathogenic than the original coronavirus (Fan et al., 2022). Therefore, we use two indicators to construct an index that can more accurately reflect the severity of the epidemic during the period of different variants. The construction method is shown as follows:

First, we use the following formula to normalize the two indicators:

$$\bar{X}_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}}, \tag{30}$$

where $\overline{X}_i$ is the indicator that has been normalized, X_i is the value of the indicator, $X_{\max}$ is the maximum value of the indicator, and $X_{\min}$ is the minimum value of the indicator.

Second, we assign weights to the number of new confirmed cases and new deaths according to their impact on the epidemic severity. We set the weights for the number of new confirmed cases and new deaths to 0.6 and 0.4, respectively.

Finally, the normalized data series of the two indicators were added by weight to obtain a value between 0 and 1. It is then multiplied by 100 to convert it into an evaluation indicator between 0 and 100. The formula is as follows:

$$Epi = \left(0.6\overline{Case} + 0.4\overline{Death}\right) \times 100, \tag{31}$$

where $\overline{Case}$ and $\overline{Death}$ is the normalized indicator representing new confirmed cases and new deaths. Now we construct an index *Epi* that can reflect the severity of the epidemic more accurately.

In addition, for the labor supply variable, the indicator we use is "real" average working hours, which is constructed in a novel method. In macroeconomic analysis, the unemployment rate is generally used as an indicator of the labor market. However, for the shock of COVID-19, the unemployment rate is no longer a valid indicator of the labor market. The distortions in the labor market have unprecedented characteristics.

The measure of unemployment alone does not accurately capture the true extent of the disruption in the labor market. This is because many individuals may still retain their jobs but are not working (thus identified as employed), or they may have lost their employment but are not actively seeking new jobs (thus identified as inactive). Additionally, some households continue to work but with reduced hours (thus still identified as employed) (Lee et al., 2020). Using only one of these three measures does not accurately capture the labor market distortions.

Therefore, we construct the "real" average working hours based on the three indicators of weekly average working hours, unemployment rate, and labor force participation rate to reflect the real impact of the pandemic on the labor market. The construction method is as follows.

The calculation of the unemployment rate is expressed as:

$$\frac{Total\ unemployed}{Total\ employed + Total\ unemployed}.$$

The calculation of the labor participation rate is expressed as:

$$\frac{Total\ employed + Total\ unemployed}{working\ age\ population}.$$

The calculation of aggregate labor supply (in terms of working hours) is shown as:

$$\begin{aligned}&aggregate\ labor\ supply = Total\ employed \times average\ working\ hours = \\ &working\ age\ population \times labor\ participation\ rate \times \left(1 - unemployment\ rate\right) \times \\ &average\ working\ hours.\end{aligned} \tag{32}$$

It can be seen that average working hours is the ratio of aggregate labor supply to total employed, so it can only represent the working hour loss of the employed population during the pandemic, the fast-growing unemployed and people who are inactive to search for jobs are not accounted for. Therefore, we use the ratio of aggregate labor supply to the working-age population to calculate the "real" average working hours, which can reflect the real working hour loss during the pandemic. The calculation formula is as follows:

$$real\ average\ working\ hours = \frac{aggregate\ labor\ supply}{working\ age\ population} =$$
$$average\ working\ hours \times labor\ participation\ rate \times \left(1 - unemployment\ rate\right). \quad (33)$$

In addition, the indicator selected for the consumption variable is personal consumption expenditure (quarterly). Since data on wage variables are scarce, this study uses data on monthly income per capita and divides it by monthly working hours to obtain an indicator of average hourly earnings as a proxy. The indicator selected for the variable of interest rate is the 10-year Treasury bond yield. In addition, the selected indicator of the saving rate is the gross national saving rate (quarterly). At last, the indicator selected for the income variable is the total household disposable income (quarterly).

4.2. Data

The data set used in this study comes from two sources. Data on the COVID-19 pandemic come from Our World in Data (n.d.). All other economic data are obtained from CEIC Data (n.d.).

This study selected 10 countries as samples (Australia, Canada, Chile, China, France, Germany, Japan, South Korea, the United Kingdom, and the United States). We selected the samples based on continents, including East Asia, North America, Europe, South America, and Oceania. In addition, Africa was not selected because the data of African countries are lacking. The selected countries have different geographical conditions, races, cultures, political systems, and levels of development. Our samples are therefore diverse and representative and can reflect how different populations around the world respond to the impact of COVID-19. Moreover, most of the countries we selected are members of the world's major economies, so the samples selected are representative of the world economy.

The data frequency is monthly, quarterly data were converted to monthly data (using the quadratic interpolation method). The period of data covers 48 months (4 years), from January 2019 to December 2022, and we include data from 2019 for comparison. For aggregate data, we divide it by the total population to obtain per capita data, and the monetary units of all countries are converted to US dollars.

The descriptive statistics for the variables are shown in Table 3. In addition, the line charts for regulation stringency and epidemic severity index of the sample countries are shown in Figure 1, and the line charts for real working hours are shown in Figure 2.

Table 3. Descriptive statistics

Variables	Explanation	Unit	Mean			Std. Dev.			Min			Max		
			2019	2020–2022	2019–2022	2019	2020–2022	2019–2022	2019	2020–2022	2019–2022	2019	2020–2022	2019–2022
Epi	Epidemic severity index	NA	NA	15.23	11.42	NA	19.19	17.87	NA	0	0	NA	100	100
Reg	Regulation stringency	NA	NA	48.16	36.12	NA	24.17	29.56	NA	0	0	NA	89.56	89.56
C	Consumption	Dollar	1,859	1,898	1,888	900.5	982.0	961.5	230	215	215	3,830	4,641	4,641
L	Labor supply (real working hours)	Hour	20.95	20.26	20.43	4.252	4.216	4.231	14.16	11.34	11.34	29.93	31.02	31.02
l	Level of labor supply change	NA	NA	0.991	1.000	NA	0.053	0.051	NA	0.705	0.705	NA	1.134	1.134
W	Wage	Dollar	20.92	22.61	22.19	10.55	11.72	11.45	1.880	1.980	1.880	38.48	54.11	54.11
CPI	Consumer Price Index	NA	101.1	105.7	104.5	0.794	5.810	5.416	99.80	94.59	94.59	102.9	128.1	128.1
r	Interest rate	%	1.431	1.689	1.624	1.297	1.601	1.533	–0.65	–0.62	–0.65	4.490	6.720	6.720
s	Saving rate	%	29.50	30.52	30.26	18.76	18.88	18.84	8.300	2.700	2.700	75.47	80.24	80.24
Income	Disposable income	Dollar	3,131	3,285	3,247	1,851	1,883	1,875	464	461	461	7,577	8,437	8,437
Vaccination	Total vaccinations per hundred	Person	NA	106.3	79.76	NA	103.5	100.8	NA	0	0	NA	319.4	319.4

Note: 2019 refers to the sample of 2019, 2020–2022 refers to the sample between 2020 and 2022, and 2019–2022 is the full sample. And the number of observations of the different periods is: 2019, n = 120; 2020–2022, n = 360; full sample, n = 480.

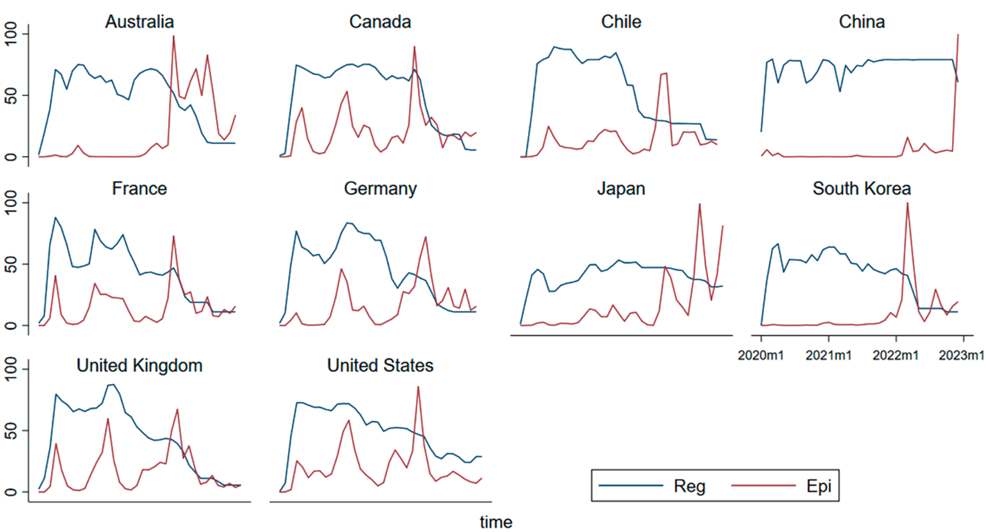

Figure 1. Regulation stringency and epidemic severity index (2020–2022)

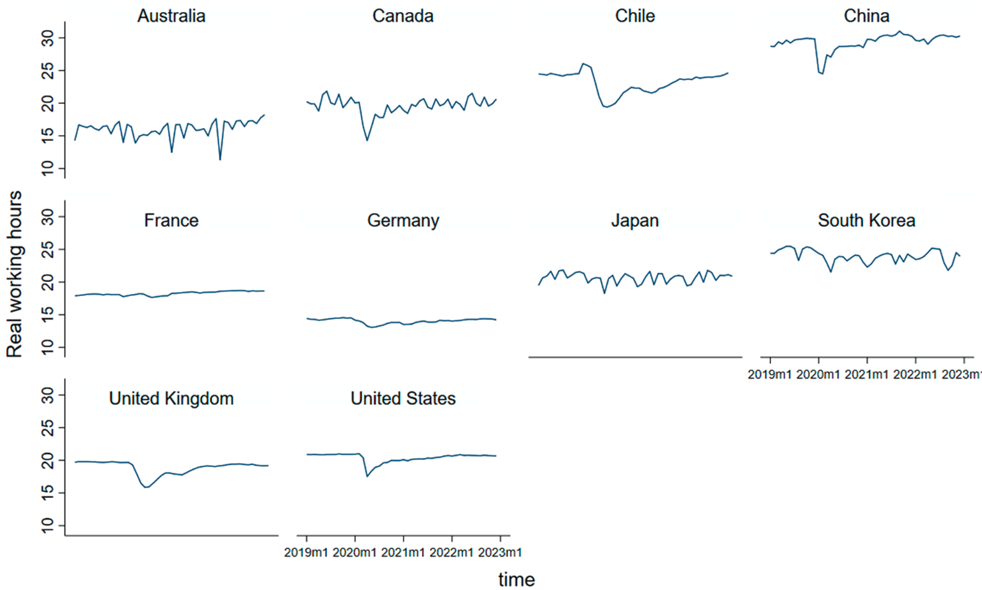

Figure 2. Real working hours (2019–2022)

5. Empirical study

5.1. Mediating effect test of the impact of the pandemic on the labor supply

Now we conduct an empirical test of the two hypotheses previously proposed in Section 3 regarding the effects of the pandemic on labor supply. Firstly, we will conduct a regression on Equation (9) to explore the impact of the epidemic severity on regulation stringency. It will answer the question of how the government takes measures to respond to the pandemic. We conduct two regressions, the first is an OLS regression and the second is a fixed effects regression. Considering that governments will relax regulations with the popularization of vaccines, we also add *Vaccination* (i.e., Number of vaccinations per hundred people) as a control variable. The regression results are shown in Table 4.

Table 4. The first step of the mediation effect test (Dependable variable: *Reg*)

	(1) OLS	(2) FE
Epi	0.193*** (3.10)	0.304*** (5.33)
Vaccination	–0.125*** (–10.88)	–0.137*** (–13.33)
Constant	58.565*** (35.27)	58.157*** (39.61)
Observations	360	360
R-squared	0.251	0.338

Note: statistics in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

The results show that the fixed effects regression is better, so we choose the results of the fixed effects model. As shown in the results, the constant is 58.157, which is significant at the 1% significance level, indicating that δ_0 is about 58, that is, the basic regulation stringency is 58. In addition, the coefficient of *Epi* is 0.304 which is significant at the 1% significance level, indicating that δ_1 is about 0.3, that is, for every one-point increase in the epidemic severity index, the regulation stringency increases by 0.3 points.

Secondly, we will conduct a regression on Equation (10) to explore the impact of the epidemic severity and regulation stringency on labor supply, and test whether there is a mediating effect of *Epi*. We divide *L* from 2020 to 2022 by the average value of *L* in 2019 to obtain *l*, which is the level of labor supply change. We conduct two regressions, the first is an OLS regression and the second is a fixed effects regression, adding *Vaccination* as a control variable. The results are shown in Table 5.

Table 5. The second step of the mediation effect test (Dependable variable: *l*)

	(1) OLS	(2) FE
Epi	–0.0004*** (–2.63)	–0.0003** (–2.27)
Reg	–0.005*** (–4.50)	–0.0006*** (–4.72)
Vaccination	0.0002*** (7.45)	0.0002*** (6.72)
Constant	0.999*** (130.92)	1.004*** (119.62)
Observations	360	360
R-squared	0.291	0.313

Note: statistics in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

We still choose the results of the fixed effects model. The results show that the coefficient of *Epi* is significant at the 5% significance level. We can conclude that hypothesis 2 is valid, which means that the pandemic has a direct effect on labor supply. Besides, γ_1 is –0.0003, that is, for every one-point increase in the epidemic severity index, the direct effect on labor supply is a 0.03% loss in working hours compared with what it would have been without the pandemic. We can interpret this as a choice made by households to reduce their working hours out of fear of infection. Furthermore, the constant is 1.004, which is significant at the 1% significance level, indicating that γ_0 is approximately equal to 1, which is consistent with our previous assumption. In addition, the coefficient of *Reg* is –0.0006, which is significant at the 1% significance level, indicating that γ_2 is –0.0006, that is, for every one-point increase in the regulation stringency, households will suffer a loss of 0.06% working hours. This can be interpreted as being due to the mandatory reduction of working hours by households as a result of the lockdown policy. Meanwhile, the coefficients δ_1 and γ_2 are both significant, indicating that the mediating effect of regulation stringency on labor supply exists. In addition, $\delta_1\gamma_2$ is about –0.00018, that is, the indirect effect on the labor supply of a one-point increase in the epidemic severity index is a loss of 0.018% working hours.

5.2. Empirical test of the model

Now we conduct the empirical test of the model results to explore the change in household consumption and saving rate during the COVID-19 pandemic. The line charts for per capita consumption of the sample countries are shown in Figure 3.

We take the log form of *C* as the explained variable in the first regression, *s* as the explained variable in the second regression, and *Epi*, *Reg*, log form of *w*, *CPI*, *r* as the explanatory variable, we also add *Income* as a control variable. We conducted two rounds of regression. Again, the first is OLS regression, and the second is fixed effect model regression. However, considering that many factors could affect the epidemic severity, such as the subway, wastewater, residential garbage, urban area, population density, temperature, and so on (Liu, 2020), it may create an endogeneity problem. Therefore, we also use the instrumental variable method to solve this problem. By definition, instrumental variables need to be correlated with endogenous variables and meanwhile uncorrelated with the error term. So, we choose *Vaccination* as our instrumental variable. It is linked to the epidemic severity because the more vaccinations the less likely people are to get COVID-19. At the same time, it is uncorrelated with the multitude of factors that influence the pandemic. It can be seen that *Vaccination* is an effective instrumental variable, so we use the instrumental variable method to conduct the third round of regression. The regression results are shown in Table 6 and Table 7.

The results of the instrumental variable method show that the coefficient of *Epi* is significantly positive at the 1% significance level. It is counter-intuitive because it indicates that the pandemic has a positive impact on consumption, which is contrary to our model results and the previous studies. Therefore, we choose the results of the fixed effect model. The coefficient of *Epi* is –0.0005, which is significant at the 1% significance level, indicating that a one-point increase in the epidemic severity will decrease consumption by 0.05%. The coefficient of *Reg* is –0.0007, which is significant at the 1% significance level, indicating that a one-point increase in regulation stringency will decrease consumption by 0.07%. The coefficient of *lnW* is 0.19, which is significant at the 1% significance level, indicating that a 1% increase in wages will lead to a 0.19% increase in consumption. The coefficient of *CPI* is –0.005, which

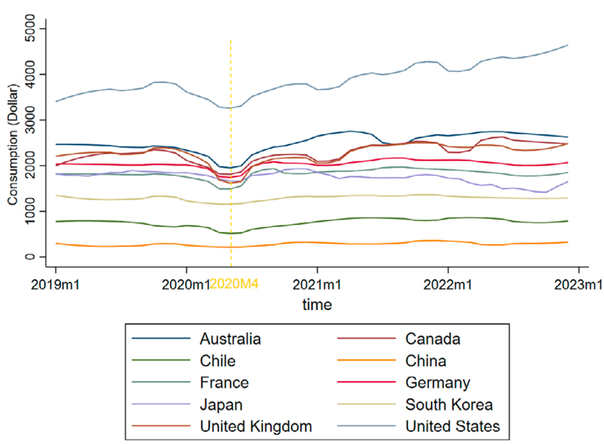

Figure 3. Consumption per capita (2019–2022)

Table 6. Results of consumption (Dependable variable: *lnC*)

	(1) OLS	(2) FE	(3) IV
Epi	0.002** (2.36)	–0.0005*** (–2.64)	0.003*** (5.30)
Reg	–0.001 (–1.42)	–0.0007*** (–5.02)	–0.001*** (–5.64)
lnW	0.698*** (33.79)	0.187*** (4.48)	0.260*** (4.67)
CPI	0.027*** (7.16)	–0.005*** (–3.30)	–0.003* (–1.69)
r	0.027** (2.15)	0.006 (0.84)	0.015* (1.73)
Income	0.000*** (5.71)	0.000*** (14.02)	0.000*** (10.02)
Vaccination	–0.001*** (–7.03)	0.000*** (7.70)	
Constant	2.477*** (7.18)	6.774*** (38.16)	6.417*** (30.02)
Observations	480	480	480
R-squared	0.908	0.536	0.131

Note: statistics in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 7. Results of saving rate (Dependable variable: *s*)

	(1) OLS	(2) FE	(3) IV
Epi	–0.056* (–1.86)	0.018* (1.90)	0.029 (1.27)
Reg	–0.015 (–0.95)	0.031*** (4.95)	0.029*** (3.92)
lnW	–17.557*** (–19.18)	–10.114*** (–5.17)	–9.917*** (–5.22)
CPI	–1.519*** (–9.12)	–0.257*** (–4.01)	–0.253*** (–4.27)
r	–2.664*** (–4.75)	0.381 (1.22)	0.408 (1.34)
Income	0.008*** (25.85)	0.004*** (7.27)	0.004*** (7.37)
Vaccination	0.077*** (10.51)	0.001 (0.45)	
Constant	211.984*** (13.86)	71.622*** (8.64)	70.651*** (9.67)
Observations	480	480	480
R-squared	0.743	0.211	0.209

Note: statistics in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

is significant at the 1% significance level, indicating that a 1% increase in *CPI* will decrease consumption by 0.5%. The coefficient of *r* is 0.006, which is not significant, but the figure indicates that a 1% increase in interest rate will lead to a 0.006% increase in consumption.

The results of the fixed effect model show that the coefficient of *Epi* is 0.018, which is significant at the 10% significance level, indicating that a one-point increase in epidemic severity will increase the saving rate by 0.018%. The coefficient of *Reg* is 0.031, which is significant at the 1% significance level, indicating that a one-point increase in regulation stringency will increase the saving rate by 0.031%.

Since we have obtained the important parameters for the theoretical model, we can calculate the specific numerical results of the model. Furthermore, the model results are compared with empirical results, and then a modification and a realistic simulation of the model are made.

6. Further discussion

6.1. Model results

Based on the empirical study in Section 5, we can set specific values for the theoretical model, which are shown in Table 8.

Where α equals 0.5, we assume households are indifferent to the consumption between the two periods. The values of γ_1, γ_2 and δ_1 are determined by the empirical results in Section 5. The value of l is calculated by dividing the average labor supply from 2020 to 2022 by the average of 2019 (the specific values refer to Table 3). The value of w is calculated by dividing the average wage from 2020 to 2022 by the average of 2019. The value of P is calculated by dividing the average CPI from 2020 to 2022 by the average of 2019. Moreover, we use the average interest rate from 2019 to 2022 as the value of r.

Substituting the above values into the equations of the comparative statics analysis, we obtain the numerical results of the theoretical model shown in Table 9.

Now we compare the calculated numerical results with the empirical results.

Firstly, we compare the results for consumption. As for the pandemic factors, for empirical results, the coefficients of *Epi* and *Reg* are –0.05% and –0.07%, while the model results are –0.016% and –0.031%. There is a certain gap between the two, and the numerical values of the empirical results are larger than those of the model results. As for the economic factors, for empirical results, the coefficients of *CPI*, $\tilde{w}$ and *r* are –0.5%, 0.19%, and 0.006%, while the model results are –0.967%, 0.469%, and 0.005%. Except for *r*, the rest of the economic variables do not fit well. However, the signs of the model results are consistent with those of the empirical results, that is, our theoretical model can explain the direction of the real changes.

Secondly, we compare the results for the saving rate. For empirical results, the coefficients of *Epi* and *Reg* are –0.018% and –0.031%, while the model results are 0.016% and 0.032%. The model results are strongly consistent with the empirical results. This shows that for the saving rate, our model can explain the reality well.

Table 8. Numerical setting of the model

Parameter	Value	Parameter	Value
α	0.5	l	0.967
γ_1	–0.0003	w	1.08
γ_2	–0.0006	P	1.045
δ_1	0.3	r	0.016

Table 9. Numerical results of the model

Variable	Value	Explanation
$\tilde{C}(Epi)$	–0.016%	A one-point increase in the epidemic severity index will reduce consumption by 0.016%
$\tilde{C}(Reg)$	–0.031%	A one-point increase in the regulation stringency will reduce consumption by 0.031%
$\tilde{C}(CPI)$	–0.957%	A one-point increase in the CPI will reduce consumption by 0.957%
$\tilde{C}(\tilde{w})$	0.469%	A 1% increase in wage will increase consumption by 0.469%
$\tilde{C}(r)$	0.005%	A 1% increase in interest rate will increase consumption by 0.005%
$\frac{\partial s}{\partial Epi}$	0.016%	A one-point increase in the epidemic severity index will increase the saving rate by 0.016%
$\frac{\partial s}{\partial Reg}$	0.032%	A one-point increase in the regulation stringency will increase the saving rate by 0.032%

6.2. Modification of the model

For consumption, the reason for the gap between the theoretical model and the empirical results is that our model only introduces the pandemic factor into the budget constraint. That is, our model can only explain changes in consumption due to changes in income. However, as we mentioned before, besides the income factor, there are direct channels through which the pandemic affects household consumption. For example, fear of infection, this kind of factor directly causes households to reduce consumption while it cannot be expressed through mathematical models. Nevertheless, we can find ways to show it indirectly.

We decompose the total consumption change into the indirect change caused by income and the direct change caused by the pandemic, namely the income effect and the direct effect. Taking the empirical results as the total effect and the model results as the income effect, the direct effect can be expressed indirectly.

Now, we divide our model results by the empirical estimates. Through the calculation, we conclude that for *Epi*, the proportion of the income effect in the total effect is about 32%, which indicates that 68% of the impact of epidemic severity on consumption is through direct effects. For *Reg*, the proportion of the income effect in the total effect is about 44%, which indicates that 56% of the impact of regulation stringency on consumption is through direct effects.

With these two numerical values, we can modify our theoretical model. Now we just need to divide the results of the original comparative statics by 32% and 44%, and we can then obtain the total impact of the pandemic factor on consumption.

6.3. Realistic simulation of the model

Now, we conduct realistic simulations using real-world data from different countries, selecting the first quarter and the second quarter of 2020 for comparison. In other words, how much does consumption decrease in 2020Q2 compared to 2020Q1? Since the time interval is very short, we ignore changes in economic factors such as wages and prices. That is, we assume that the change in consumption between the two periods is entirely due to the pandemic factors. According to the conclusions of Sections 3.3 and 6.2, we derive the revised calculation formula of *Epi* and *Reg* as follows.

$$\tilde{C}_i^*(Epi) = \frac{\gamma_1}{0.32(1+r+l)}\Delta Epi, \tag{34}$$

$$\tilde{C}_i^*(Reg) = \frac{\gamma_2}{0.44(1+r+l)}\Delta Reg, \tag{35}$$

where $\tilde{C}_i^*\left(Epi\right)$ is the consumption change of the country i caused by the epidemic severity, $\tilde{C}_i^*\left(Reg\right)$ is the consumption change of the country i caused by the regulation stringency. Adding the two together, we can obtain the aggregate consumption change of this country.

In addition, the *Epi* index is constructed based on the three-year pandemic period while the distribution of the epidemic severity index is not uniform. However, the period we select is the early stage of the pandemic. If we use the original epidemic severity index, the problem of inaccurate simulation may occur. For example, a country with the largest outbreak in 2022 will have its severity index deflated in the first half of 2020. This problem does not arise with the policy stringency index since its distribution is uniform. Thus, we re-normalize the larger epidemic severity of the two periods to 100 and then subtract them to get Δ*Epi*, which better reflects the change in the severity of the epidemic.

We calculated the simulation results using the modified model and then compared them with real-world data. The results are shown in Table 10.

Table 10. Realistic simulation of the model

Country	Real-world data	Simulation results
Australia	–13%	–6.4%
Canada	–10%	–9.2%
Chile	–21%	–10.4%
China	–9%	1.8%
France	–11%	–7.7%
Germany	–10.8%	–6.5%
Japan	–7.3%	–5.9%
South Korea	–3.2%	–0.1%
United Kingdom	–23.8%	–9.1%
United States	–7%	–8.7%

It can be seen that except for China, the signs of the simulation results of other countries are consistent with the direction of the real consumption changes. In addition, except for Chile and the United Kingdom, the simulation results are close to the real data, indicating that our theoretical model has a strong realistic explanatory power.

The simulation error in China is caused by the following reasons. First, our calculation results are based on the sum of the two indicators of epidemic severity and regulation stringency. The higher the epidemic severity and the policy stringency, the lower the consumption will be. For the average country, they both increase at the same time, and consumption will decrease accordingly. In contrast, China has implemented very strict regulation policies from the early stage of COVID-19, and the increased regulation stringency in the two periods is very limited, so the simulated consumption reduction rate due to the regulation stringency is very low. At the same time, due to China's strict regulation policies, the epidemic severity in China in the second phase is lower than that in the first phase, so the simulated consumption will increase due to the reduced severity of COVID-19. The sum of the two effects results in a positive simulation. However, in reality, the exceptionally strict pandemic prevention policies make the change rate of consumption negative. Second, since the first quarter is the Spring Festival period in China, the consumption of Chinese residents is naturally larger compared to the second quarter, which also widens the simulation error. In general, the error between China's reality and model simulation has its own particularities.

Moreover, it can also be seen that the North American countries (Canada and the United States) have the best simulation results compared to other regions, this may be due to the following reasons. First, to simplify the analysis, we have assumed that economic factors are constant, which can be a source of error. Thus, the reason why the forecast of North American countries is closer to reality may be that the economic factors in North America have experienced less variation. Second, the United States is the only country where the consumption change rate of the forecast results is larger than the real data, which may also be caused by the difference in consumption habits of residents: Habits exhibit substantial effects on the consumption choices of U.S. households (Drechsel-Grau & Schmid, 2013). The consumption ratchet effect of North American residents is more prominent, so they tend to maintain the original consumption level after suffering an income shock.

7. Policy recommendations

Now, this study provides some policy implications according to the previous analysis and results. Although the regulation policies can effectively control the pandemic and protect people's lives and health, they would have a negative impact on consumption and other sectors. The policymaker needs to keep a balance between pandemic prevention and the economy. Moreover, if the government wants to stimulate consumption, measures should be taken to ensure employment, and new working patterns need to be encouraged such as working from home to prevent a decline in the working hours of the employed.

Specifically, how can our model make policy recommendations in case of another public health emergency in the future?

The first thing to note is that our model is of general interest. Our model analyzes the specific mechanism of the impact of COVID-19 on consumption and presents it in mathematical form. Compared with other empirical papers, our results are not limited to time and space. That is, our model is applicable in any country, as the realistic simulation results in this study have confirmed the validity and explanatory power of the model. Besides, during public health emergencies, individuals' risk perception, emotions (especially fear), and coping behaviors are interconnected, influencing their responses and creating similar psychological and behavioral mechanisms (Liu & Fu, 2024; Zhao et al., 2023). Therefore, our model can also be applied to any future situation as it analyzes the specific mechanisms of individuals in the face of a crisis and hence an economic shock.

Based on Equations (34) and (35), our model can predict the impact of changes in epidemic severity and regulation stringency on consumption. In addition, according to many existing pieces of literature, we can also predict the impact of policy stringency on epidemic severity. Therefore, when the policymaker faces the next crisis, this model can be used in advance to assess the overall impact of the stringency of regulation measures on consumption. Now that we know how changes in regulation stringency affect consumption, how should the government keep a balance between consumption and pandemic prevention to achieve the optimal possible policy?

According to the theoretical analysis of Hall et al. (2020), there is a trade-off relationship between household's consumption and the mortality rate of COVID-19. For example, when the mortality rate is 0.81%, individuals under age 50 averagely are willing to reduce consumption by 6.2% to avoid the pandemic. Therefore, when the next crisis comes, the policymaker can react quickly, conduct experiments to determine the mortality rate of a certain epidemic, and then work out the optimal consumption trade-off (i.e., the optimal consumption reduction rate) based on Hall's model, and finally implement the optimal regulation stringency policy according to our model.

In fact, according to our previous analysis and results, we can propose a formula to calculate the optimal policy stringency as follows:

$$\Delta C^{*} = \frac{\gamma_1}{0.32(1+r+l)}(\Delta Epi - \psi \Delta Reg) + \frac{\gamma_2}{0.44(1+r+l)}\Delta Reg\,, \tag{36}$$

where ΔC^{*} is the degree of optimal consumption reduction, ψ is the influence coefficient of regulation stringency on epidemic severity (i.e., a shock).

Here we provide a calculation example for the specific policy-making in case of a possible future crisis. If the mortality rate in the next pandemic is 0.81%, as mentioned before, the optimal consumption reduction rate will be 6.2% for age groups under 50. It is worth noting that the proportion of consumption for individual's willing to trade off increases with age (e.g., 0.3% of consumption for age groups under 20, while 22.9% of consumption for age groups under 65). Considering the externality of the epidemic and the non-exclusivity of the epidemic prevention policy, it is impossible for the government to formulate different policies according to different age groups. Therefore, we can assume that the government adopts a compromise policy, that is, to meet the optimal consumption trade-off for age groups under 50 (i.e., a 6.2% reduction of the total consumption in our previous example).

Now using Equations (34) and (35) again, we first assume $r + l$ equals 1, where r is the interest rate and l is the level of labor supply change. As mentioned before, according to ILO, the total labor supply suffered a 5.4% loss in Q1 2020, then l is 94.6% in case of the COVID-19 crisis. If we add the interest rate, the value of $r + l$ is approximately equal to 1.

Please note that for the sake of analysis, we assume this value to be 1 here, but different countries will need to set this value according to their own specific situations when facing the next crisis. Then we can obtain the marginal change in consumption due to epidemic severity and regulation stringency, which is approximately –0.047% and –0.068%, respectively. Moreover, according to Tian et al. (2021), the one-point increase in policy stringency would reduce pandemic severity by –0.35, we thus set ψ equals 0.35. Furthermore, we assume that the government predicts the epidemic severity will increase by 50% in the next period, that is, ΔEpi equals 50. Since the government is making policies in the first period of the pandemic, then $\Delta Reg = Reg$. Now, substituting all the numerical values into Equation (36), we can obtain:

$$-6.2\% = -0.047\% \times (50 - 0.35Reg) - 0.068\% \times Reg\ . \quad (37)$$

Solving the above equation, we can obtain the optimal regulation stringency: $Reg^* \approx 74$. That is, in this specific situation, the government should implement pandemic control measures at a 74-regulation stringency to keep the balance between consumption and pandemic prevention. More illustration of how the optimal policy implementation reacts to the expected epidemic severity change and the optimal consumption reduction rate can be seen in Figure 4.

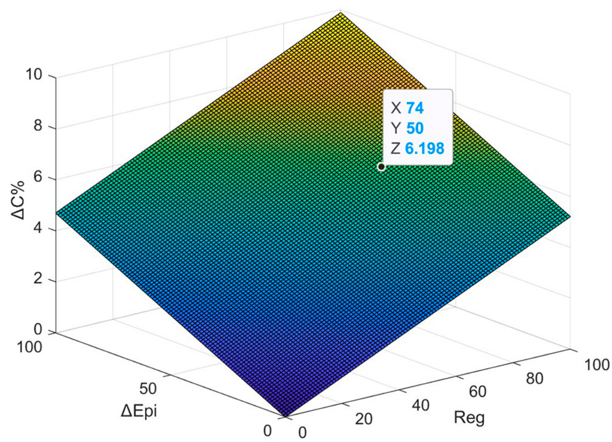

Figure 4. Policy simulation (the x-axis denotes the optimal regulation stringency, the y-axis denotes expected epidemic severity change and the z-axis denotes the optimal consumption reduction rate)

8. Conclusions

The COVID-19 pandemic caused a dramatic shock to the global economy, household consumption is one of the sectors that has been seriously affected. To present the mechanism of the impact of the pandemic on consumption and labor supply, this study constructed a theoretical model and empirically tested it. The research effectively captures the impact of the pandemic in various countries and explains the observed differences. It takes into account the existing regulatory measures in different countries, the severity of the pandemic, as well as the political implications arising from the government's actions to find a balance between pandemic prevention and economic outcomes. The main findings of this study are shown as follows.

First, the labor supply of households has been affected during the pandemic. The pandemic not only has a direct impact on working hours but also has an indirect impact on working hours through the mediation of regulation measures. Second, the epidemic severity and regulation measures have a negative impact on household consumption. Both influence consumption through income effect and direct effect, among which the income effect of the epidemic severity accounts for 32% of the total effect. And for regulation stringency, the income effect accounts for 44% of the total effect. In addition to the economic factors, rising prices will also reduce consumption, while higher wages and interest rates can boost consumption. Third, the increasing epidemic severity and regulation stringency will both enhance the household's propensity to save.

Finally, our study also has several limitations. The first is about the theoretical model. We only build a simple static model, and although we use a two-period model to introduce the time factor, the model still does not have strong dynamic performance. For example, due to the intrinsic flaw of the static model, households only have savings in the first period of their budget constraints, but not in the second. As mentioned before, the decline in household consumption is partly due to precautionary savings. While our model does explain the increasing saving rate out of the pandemic, it cannot reflect the decrease in consumption. Thus, it may be possible to extend the static model to a dynamic version in future studies so that we can explore the interaction effect of saving and consumption more deeply.

Furthermore, to simplify the analysis, we only consider labor income in the household income and do not consider other factors such as income from financial assets or government transfers. More realistic factors can be added to the model in the future. Moreover, as previously mentioned in this study, our model only introduces the pandemic factor into the budget constraint, so it can only reflect changes in consumption caused by changes in income. Other direct factors, such as fear of infection and uncertainty of the future, are not reflected in the model. In the future, it may be possible to find ways to internalize these factors and represent them in the mathematical model. The second is about data. The sample size we used is not sufficient, only ten countries, and we can collect data from more countries in the future. In addition, for some indicators, we only find quarterly data. As a result, we have to use a method to convert it to monthly data, which may cause some distortion problems. The third is about the empirical study. Our regression models are relatively not sufficient and can be further extended in the future.

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