Monetary Policy with Racial Inequality*

Makoto Nakajima
FRB Philadelphia

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Abstract

This paper presents a heterogeneous-agent New-Keynesian model featuring racial inequality in terms of income, wealth, and labor market risks, and studies how monetary policy affects different racial groups differently. The calibrated model can replicate the fact that an accommodative monetary policy shock narrows the Black-White unemployment rate gap, as the higher job separation rate among Black workers make the value of their job more sensitive to a monetary policy shock. The model indicates that Black and Hispanic workers benefit more from accommodative monetary policy than White workers, since they are more likely to be liquidity constrained and thus hand-to-mouth, and they face higher labor market risks, which are mitigated by accommodative monetary policy. For example, average welfare gain of Black workers from an accommodative monetary policy shock is more than 20 times larger than that of (middle-class) White workers.

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Keywords: monetary policy, racial inequality, labor market, unemployment, wealth distribution, hand-to-mouth, business cycle, heterogeneous agents.

*Address: Research Department, Federal Reserve Bank of Philadelphia. Ten Independence Mall, Philadelphia, PA 19106-1574. E-mail: makoto.nakajima@gmail.com. I thank seminar participants at CIGS and UAB for their comments and suggestions. The views expressed here are mine and do not necessarily reflect the views of the Federal Reserve Bank of Philadelphia or the Federal Reserve System.

1 Introduction

As inequality in income and wealth grew over time, and significant racial inequality is more keenly recognized, the question as to what the monetary authority can and should do about racial inequality has becomes an important question. According to the conventional view, the only thing that the monetary authority can do is to smooth business cycles mainly using policy rate adjustments, and the long-term structural issues such as racial disparities cannot be affected by monetary policy. However, the opinion that the monetary authority has to do something to deal with the severe racial disparities is getting stronger. The Democratic presidential nominee Biden proposed in a speech in July 2020 that Congress amend the Federal Reserve Act to *"add to that responsibility and aggressively target persistent racial gaps in job, wages, and wealth."* The Federal Reserve is considered by many to have taken a step towards more emphasis on racial inequality already. For example, Chair Powell of the Federal Reserve unveiled the new strategy which *"emphasizes that maximum employment is a broad-based and inclusive goal"* in August 2020. However, it is fair to say that there is no consensus yet as to what the monetary authority can and should do to deal with racial inequality. The fact that the Federal Reserve has been hosting a series of Racism and the Economy conferences indicates that the role of the monetary authority is still an open question.

Against such background, this paper presents a heterogeneous-agent New-Keynesian (HANK) model with racial inequality in terms of labor market characteristics, and wealth, and studies how monetary policy affects workers of difference races differently. The goal of the paper is modest. It is not intended to answer why racial inequalities in income and wealth exist. Instead, I take the observed disparities in income and wealth as given, embed into a canonical HANK model in a tractable manner, so that the model can be used to study how monetary policy affects different racial groups differently. I use the HANK model, since it is an extension of the New-Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model, which is a workhorse model used by monetary authorities all over the world, and introducing heterogeneous agents is crucial in order to capture various dimensions of racial inequality. With these considerations in mind, I try to stay close to the standard NK-DSGE model as much as possible, but at the same time try to incorporate various dimensions of observed racial disparities. My hope is that the model presented in this paper can be a benchmark model to think about the interactions between monetary policy and racial inequality.

The HANK model that I build in this paper incorporates two important dimensions of racial differences that I present in the next section. First, Hispanic and Black workers face a higher risk of unemployment, and the risk rises disproportionately during a recession. When the shock driving the business cycle is common for all racial groups, this means that an accommodative monetary policy shock in the form of a lower policy rate brings down the unemployment rate of Hispanic and Black workers, and benefit them disproportionately. Indeed, Bartscher et al. (2021) compute that a -25bp reduction in the policy rate lowers the unemployment rate of Black workers 0.34pp more than that of White workers. And the model is successfully calibrated to replicate this empirical finding. Second, more Hispanic and Black workers are either poor or wealthy hand-to-mouth, i.e., liquidity constrained. The combination of the two is crucial in thinking about the role of monetary policy for different racial groups. The former implies that accommodative monetary policy could alleviate unemployment risks of

Hispanic and Black workers to a larger extent, while the latter implies that, since many of them are liquidity constrained, they gain more from a lower unemployment rate and a higher wage caused by accommodative monetary policy.

The main findings of the paper are obtained through three sets of experiments. First, I study the macroeconomic, distributional, and welfare effects of an accommodative (-25bp) monetary policy shock. I find that consumption of Hispanic and Black workers increases more from such policy action, and their welfare improves more as well. Specifically, the welfare gain among Black workers is more than 20 times larger than that of White workers. This result depends crucially on two things. First, there are more hand-to-mouth, especially poor hand to mouth, among Black and Hispanic workers. Second, they are exposed to a higher unemployment risk, which is mitigated to a greater degree by an accommodative monetary policy shock. Second, I assume that the economy is hit by a large negative total factor productivity (TFP) shock, which mimics the severity of the Great Recession, and compare the baseline model economy and the alternative model economy in which monetary authority responds twice as strong to a decline in output (accommodative monetary policy rule). Black and Hispanic workers are found to benefit more from accommodative monetary policy rule. Again, both their exposure to a higher unemployment risk and a higher proportion of hand-to-mouth are crucial in generating the larger welfare gains among racial minorities. Third, I study the cyclical properties of the model under the baseline monetary policy rule and the accommodative monetary policy rule. I find that Income and consumption volatility of Black and Hispanic workers declines more than three times compared with that of White workers under the accommodative monetary policy rule. Income and consumption of White workers does not decline significantly because they face a smaller unemployment risk from the start, and they are able to significantly smooth consumption using their savings, which make the countercyclical monetary policy less important for them.

Previous research shows that job displacements lead to large and persistent earnings losses for the affected workers (Jacobson et al. (1993), Davis and Wachter (2011), Farber (2011)). Therefore, if accommodative monetary policy can mitigate job displacements in recessions, the benefits are larger than what is implied by a lower unemployment rate induced by the monetary policy. And this could benefit racial minorities more, as they are more likely to lose a job in recessions. I investigate this channel by comparing the model with and without earnings loss upon job loss. I find that accommodative monetary policy benefits workers more in the presence of the earnings loss upon job loss, and the additional gains of preventing the earnings loss through accommodative monetary policy are larger for racial minorities.

This paper is intended to contribute to four strands of literature.[1] First, to the literature investigating the role of monetary policy in the presence of racial inequality, the current paper contributes by developing the first HANK model featuring racial inequality. This emerging literature includes a recent paper by Bartscher et al. (2021), who emphasize inequality in wealth holding and composition, but take empirical approach unlike the current paper. Another recent paper by Lee et al. (2021) emphasizes that consumption basket is different across racial groups, and thus the inflation rate they face also have different cyclical characteristics. They build a stylized macro model with two (Black and White) agents to study policy impli-

[1] Literature review is still incomplete and needs to include many more papers in the future.

cations. Aliprantis et al. (2019) ask what is behind the racial wealth gap, using a steady-state heterogeneous-agent model. Cajner et al. (2017) summarize racial difference in labor market outcomes over the past four decades and over the business cycle.

Second, the current paper extends the literature of HANK (heterogeneous-agent New-Keynesian) models by introducing racial differences. Papers such as Kaplan et al. (2018), Gornemann et al. (2021), and Bayer et al. (2020) combine the incomplete-market heterogeneous-agent model with aggregate uncertainty (Krusell and Smith (1998), which is Bewley-Aiyagari-Huggett model with aggregate shocks) with New-Keynesian nominal price rigidity, to investigate interactions between heterogeneity and monetary policy. The current paper is the first to introduce race as one dimension of heterogeneity into the otherwise standard HANK model. An important property of the HANK model is that if more consumers are either poor or wealthy hand-to-mouth, the model generates a stronger response of consumption when income increases. What the current paper emphasizes is that racial minorities are more likely to be hand-to-mouth, and thus their consumption (and welfare) are more strongly affected by monetary policy.

Third, the current paper extends the literature of developing macro model with search frictions in the labor market by introducing racial heterogeneity in labor market risks. Andolfatto (1996) and Merz (1995) first introduce search frictions in the labor market into a canonical real business cycle (RBC) model. Nakajima (2012a) and Krusell et al. (2010) introduce labor market search into the incomplete-market heterogeneous-agent model with aggregate uncertainty. Gornemann et al. (2021) add New-Keynesian friction into such model so that monetary policy can affect unemployment risks. The current paper is a natural extension of Gornemann et al. (2021) in the sense that monetary policy can affect different racial groups differently partly because they face different labor market risks.

Finally, the paper makes a small contribution to literature making computation of HANK models easier and more accessible. Solving a HANK model is not easy because one has to deal with a large state space (distribution of heterogeneous agents), and solving the optimal decision problem for diverse agents. The first paper that solves a heterogeneous-agent macro model (Krusell and Smith (1998)) employs global approximation, which implies that it takes a long time to solve for an equilibrium, especially when a researcher introduces richer heterogeneity. Therefore, various methods relying on local approximation (perturbation) have been developed. Reiter (2009) proposes the first popular local-approximation method to solve the HANK model. This method can be understood as an extension of the local-approximation method developed for solving a representative-agent macro model by Schmitt-Grohé and Uribe (2009). More recently, efficient continuous-time version of the local-approximation method is developed to solve the model in Kaplan et al. (2018), and a more efficient local-approximation method is developed to solve the model in Bayer et al. (2019).[2] The contribution of the current paper to this literature is modest; I develop a toolkit called `jhank` toolkit, which is available in Fortran90, Julia, and Matlab, to implement the local-approximation method by Reiter (2009) a little more easily. The current paper is an example of how to use the `jhank` toolkit.[3]

[2] Codes to implement these solution methods can be found at Moll's homepage (`https://benjaminmoll.com`) and Luetticke's homepage (`https://www.ralphluetticke.com/`).

[3] `jhank` toolkit will be available at `https://makotonakajima.github.io/jhank/`.

The remainder of the paper is organized as follows. Section 2 presents racial differences in terms of labor market characteristics and wealth holding. These are the facts that motivate the model constructed in Section 3. Section 4 provides details about parameterization of the model. Section 5 investigates wealth inequality generated by the calibrated model. The next three sections present the main results. Section 6 shows how workers of different racial groups are affected by a monetary policy shock. In Section 7, I assume that the model economy goes through a severe recession mimicking the Great Recession, and investigate how different monetary policy rules could mitigate the negative consequences facing different racial groups differently. Section 8 studies how different monetary policy rules can affect different racial groups differently over the business cycle. Section 9 investigates the importance of earnings loss upon losing a job, in evaluating the racial differences in the effects of monetary policy. Section 10 briefly discusses implications of racial differences for monetary transmission. Section 11 concludes. An Appendix follows, containing details about equations characterizing the equilibrium, and hand-to-mouth.

2 Racial Inequality in Income and Wealth

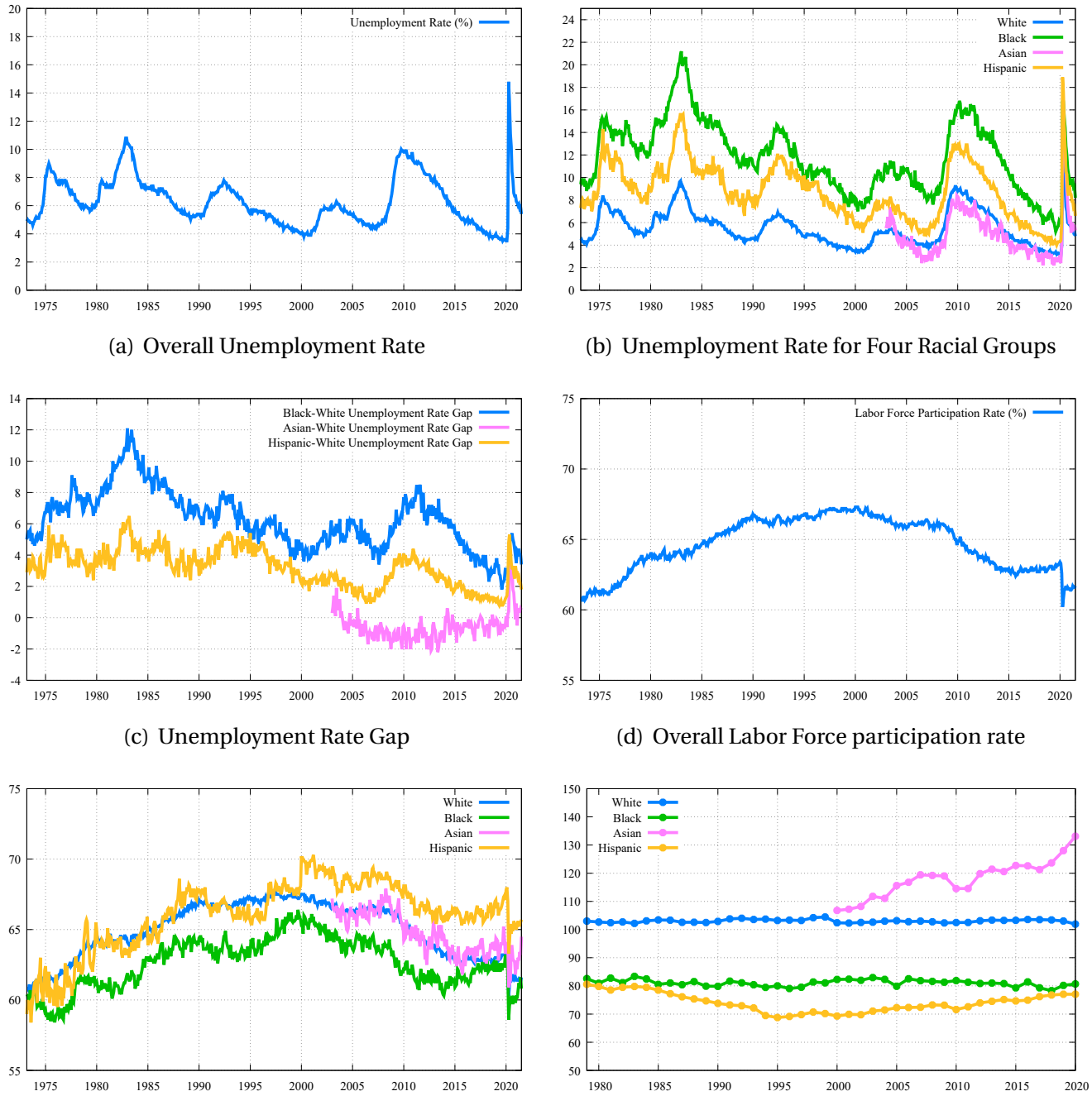
This section documents racial differences in the U.S. in terms of labor market characteristics (Section 2.1) and wealth holding (Section 2.2). I focus on four major racial groups in the U.S., namely, White, Asian, Hispanic, and Black. The stylized facts presented in these sections motivate how I embed racial differences in the model that I build in Section 3.

2.1 Labor Market Characteristics

This section presents differences in labor market characteristics across four racial groups (White, Asian, Hispanic, and Black).[4] Figure 1 shows the overall unemployment rate (Panel (a)), the unemployment rate for four racial groups (Panel (b)), the unemployment rate gaps (Panel (c)), the overall labor force participation rate (Panel (d)), the labor force participation rate for four racial groups (Panel (e)), and median usual weekly earnings, normalized by the overall median usual weekly earnings each year, for four racial groups (Panel (f)). All data are monthly frequency covering from 1973 to 2021, except for weekly earnings presented in Panel (f), which is annual and covers from 1979 to 2020.

The overall unemployment rate is countercyclical (Panel (a)), sharply rising during recessions and gradually going down during expansions. If we look at the unemployment rate for each racial group (Panel (b)), we can discern three characteristics. First, there are permanent differences in levels. The unemployment rate for Black workers is consistently the highest. The Hispanic unemployment rate is the second. The unemployment rate for White and Asian workers are similar and lower than that of Black and Hispanic workers. The average unemployment

[4] I follow the definitions of races used by the Census Bureau in terms of the three racial groups used in the empirical analysis — White, Black (same as African), and Asian. I exclude American Indians, Alaskan Natives, Native Hawaiians and Other Pacific Islanders, and Two or More Races from the analysis. These groups made up 2.1% of the labor force on average between 2003 and 2018. Hispanic is an identity and a Hispanic person can be of any race. When I compute numbers for Hispanics, I include all individuals who identify as Hispanic, regardless of the race of the individuals. When I compute numbers for Whites, Blacks, and Asians, I exclude those who identify as Hispanic.



(a) Overall Unemployment Rate

(b) Unemployment Rate for Four Racial Groups

(c) Unemployment Rate Gap

(d) Overall Labor Force participation rate

(e) Labor Force Participation Rate for Four Racial Groups

(f) Median Earnings Relative to Overall Median

Figure 1: Racial Differences in Labor Market Characteristics

rate is shown in Table 1. It is 11.8% for Blacks, and 8.8% for Hispanics, which are higher than the unemployment rate for Asians (4.9%) and Whites (5.5%). Second, although the levels are different, the unemployment rate for all racial groups move in sync. Table 1 contains the correlation coefficients between the overall unemployment rate and the unemployment rate for four

Table 1: Labor Market Statistics of Four Racial Groups

	Overall	White	Asian	Hispanic	Black
Unemployment Rate (UR)					
Average	6.29	5.53	4.90	8.75	11.80
Standard Deviation	1.70	1.56	2.05	2.50	3.12
Coefficient of Variation	0.27	0.28	0.42	0.29	0.26
Correlation with Overall UR	1.000	0.997	0.909	0.937	0.919
Unemployment Rate Gap					
Average	–	–	–0.57	3.22	6.27
Correlation with Overall UR	–	–	–0.019	0.655	0.702
Labor Force Participation Rate (LFPR)					
Average	64.7	64.9	64.7	66.0	62.6
Correlation with Overall LFPR	1.000	0.998	0.906	0.764	0.913
Real Median Usual Weekly Earnings					
Dollar Values	748	770	887	551	605
Relative to Overall	100.0	103.3	118.7	73.7	80.9

Note: Source for the unemployment rate and the labor force participation rate is the CPS, from March 1973 to July 2021, except for Asian, whose data are available from January 2003. The source for real median usual weekly wage is CPS, from 2003 to 2018.

racial groups. It is as high as 0.997 for White workers, and above 0.9 for all racial groups. Third, the unemployment rate for Hispanic and Black workers are more volatile, but the volatility is almost proportional to the level. As shown in Table 1, the standard deviation of the unemployment rate is 1.70 for the overall unemployment rate, but it is 1.56 for White workers, and 2.50 for Hispanics and 3.12 for Blacks. But if we compute the coefficient of variations, virtually normalizing by their respective mean, the coefficient is similar across all racial groups. It is 0.27 for the overall unemployment rate, 0.28 for White workers, 0.29 for Hispanic workers, and 0.26 for Blacks. Asians' coefficient of variation (0.42) is higher because their time series starts from 2003, and the short period contains two large recessions.

Panel (c) of Figure 1 contains the unemployment rate gaps. For example, Black-White unemployment rate gap is defined as the difference between the Black unemployment rate and the White unemployment rate. As shown in Table 1, the average unemployment rate gap is 3.2% for Hispanic and White, 6.3% for Black and White, while it is –0.6% between Asian and White. Since unemployment rate for Black and Hispanic workers is consistently higher and more volatile than that of White workers, the unemployment rate gaps are naturally also countercyclical, going up in recessions and going down in expansions. Also not surprisingly, the gaps for Hispanic and Black workers are correlated with the overall unemployment rate. The correlation coefficient with the overall unemployment rate is 0.70 for Black-White unemployment rate gap and 0.65 for Hispanic-White unemployment rate gap. For Asian-White gap, correlation is close to zero (–0.02) as the unemployment rate for White and Asian workers are almost on top of each other.

Although I will abstract from labor force participation decision in the model, let's look at the

labor force participation rate in the U.S. data, which is shown in Panels (d) and (e). As can be easily seen in Panel (d), the overall labor force participation rate gradually went up from 60.8% in 1973 to 67.3% in 2000, but gradually went down since. The participation rate is 63.3% in December 2019, before the COVID-19 pandemic started. Panel (e) shows the participation rate for four racial groups. As with the unemployment rate, the labor force participation rate for all racial groups exhibit a very similar trend as the overall participation rate. The correlation coefficient wit the overall participation rate is 0.998 for White workers, 0.906 for Asians, 0.764 for Hispanics, and 0.913 for Blacks (Table 1). The correlation for the Hispanic labor force participation rate is lower because of the jump in 2000. The Hispanic participation rate tracks closely the White participation rate until 2000, but is consistently higher than the White rate by a couple of percentage points after 2000. This might be due to some changes not related to actual changes of labor force participation decision among Hispanic workers. Also as with the unemployment rate, there are permanent differences in the level of the participation rate across racial groups. The participation rate for Blacks is consistently lower than other racial groups, while Asians' participation rate is close to that of White workers. The average Black labor force participation rate is 62.6%, while the rate is 64.9% for Whites and 64.7% for Asians. The average Hispanic participation rate is 66.0%, which is higher than the participation rate of White workers because of the jump in 2000.

Finally, Panel (f) of Figure 1 shows the median usual weekly earnings for four racial groups, normalized by the overall median usual weekly earnings for each year. The median weekly earnings of White workers is consistently higher than the overall median by 3%, as shown in Table 1. The median weekly earnings of Black workers is consistently lower by about 20% than the overall median, and the average ratio is 80.9%. The median Hispanic weekly earnings went down from 1978 to late 1990s, but went up since then, but consistently below Black median earnings. The average for Hispanic workers is 73.7% of the overall median. The median weekly earnings for Asian workers shows significant growth since their first observation in 2000. This is because the proportion with college degree among Asian workers is above 50%, unlike other racial groups, which implies that the median earnings of Asian workers is significantly affected by rising college premium. On average, the median weekly earnings of Asians turns out to be about 20% higher than the overall median earnings (118.7%).

I showed that the unemployment rate is consistently higher among Hispanic and Black workers, but it is because their job-finding rate is lower, or is it because their separation rate is higher? Table 2 contains information to answer this question. The numbers in the table are taken from Cajner et al. (2017), who use CPS microdata from 1994 to 2016 to compute monthly transition rates among three labor market status (employed, unemployed, and out-of-labor-force), separately for three racial groups (White, Hispanic, and Black) and two genders. Asians are not included in their analysis. In terms of the transition rates between employment and unemployment, which is the focus of the current paper, there are three takeaways from the first block of Table 2. First, both Hispanic and Black workers exhibit a higher separation (EU) rate than White workers, pushing up their unemployment rate. Among males, the EU transition probability is 2.2% per month for Hispanics, and 2.3% for Blacks, compared with 1.2% for Whites. There is a similar tendency among female workers. Second, Black workers have a lower job-finding rate (UE transition rate) than White workers, making their unemployment rate even lower. Among Black males, the UE transition rate is 18.2% per month, which is about

Table 2: Monthly Transition Rates

	Male			Female		
	White	Hispanic	Black	White	Hispanic	Black
EU rate	1.2	2.2	2.3	1.0	1.7	1.7
UE rate	25.6	28.4	18.2	25.0	20.4	17.2
EN rate	2.1	2.5	3.4	3.1	4.8	3.7
NE rate	4.6	7.5	4.9	3.8	5.1	4.5
UN rate	18.5	19.5	24.8	24.5	31.7	28.7
NU rate	2.4	5.1	5.1	1.7	3.3	4.0

Note: U = unemployment, E = employment, and N = out-of-labor-force. Monthly transition rates in percent. Source is Cajner et al. (2017). Based on the CPS microdata, longitudinally matched, from 1994 and 2016.

70% of the White males' UE transition rate (25.6%). The job-finding rate for Black and White females is similar to their male counterparts. Third, however, Hispanic males have a higher UE transition rate (28.4%) than White males. Probably this is due to the type of jobs and industries that many Hispanic workers work in. This is why the unemployment rate among Hispanic workers is lower than the Black unemployment rate even thought both racial groups exhibit similarly high separation rate. Among Hispanic females, the job-finding rate is slightly lower than White females, but still higher than Black females.

In terms of the flow rates going into and getting out of labor force, what stands out is that all transition rates are higher among Black and Hispanic workers than White workers. In other words, labor market status is less stable among Black and Hispanic workers. Specifically, Black and Hispanic workers exhibit a higher EN rate, NE rate, UN rate, and NU rate, compared with White workers. Black and Hispanic workers exhibit a higher probability of getting out of labor force (E+U into N) and a higher probability of coming back to labor force (N to E+U) than White workers.

2.2 Hand-to-Mouth and Wealth Holding

In this section, I use the 2004 wave of the Survey of Consumer Finances (SCF), and document wealth inequality across racial groups. Table 3 summarizes the results. I use the 2004 wave, because the data are not affected by the Great Recession, but as Kaplan et al. (2014) show, the fraction of hand-to-mouth households remains stable between 1989 and 2010. Regarding sample selection, I follow Kaplan et al. (2014) and include households whose head is between 22 and 79 years old, and report strictly positive non-financial income (sum of wage income from work, and various transfers from the government, such as unemployment insurance, and social security). Since the SCF over-samples wealthier households, I use the sample weights provided by the SCF in computing all statistics. There are five columns. The first column includes all racial groups. The second column includes only households whose head is White. The third column is labeled as Asian, but indeed includes households whose head is "other" racial groups, i.e, neither White, Hispanic, or Black. I label this column as Asian, because among the households with "other" races, Asians are dominant, but this groups includes many house-

Table 3: U.S. Wealth Distribution for Four Racial Groups

	Overall	White	Asian	Hispanic	Black
Measures of Hand-to-Mouth Households, following Kaplan et al. (2014)					
Total Hand-to-Mouth	30.3	24.9	31.2	51.8	44.2
Poor Hand-to-Mouth	10.7	6.7	12.5	28.7	18.8
Wealthy Hand-to-Mouth	19.7	18.2	18.7	23.1	25.5
Alternative Measures of Hand-to-Mouth					
% with Non-Positive Net Worth	9.0	6.8	6.5	13.9	18.4
% with Non-Positive Total Wealth	9.9	6.6	10.3	22.1	18.2
% with Total Wealth $\leq$ 1-Week Earnings	14.5	9.9	15.2	33.5	25.8
Measures of Wealth, following Kaplan et al. (2014)					
Mean Total Wealth	314,945	389,187	282,150	84,646	88,962
Relative to White	80.9	100.0	72.5	21.7	22.9
Median Total Wealth	75,475	104,510	77,530	9,291	17,938
Relative to White	72.2	100.0	74.2	8.9	17.2
Mean Liquid Wealth	86,135	113,216	46,349	5,755	8,653
Median Liquid Wealth	2,166	4,688	4,643	106	137
Mean Illiquid Wealth	228,809	275,971	235,802	78,891	80,308
Median Illiquid Wealth	68,000	94,000	78,000	6,300	17,000
Alternative Measures of Wealth					
Mean Net Worth	454,082	563,058	386,869	130,945	111,112
Relative to White	80.6	100.0	68.7	23.3	19.7
Median Net Worth	91,270	133,950	137,900	15,800	20,250
Relative to White	68.1	100.0	102.9	11.8	15.1
Home Ownership Rate	69.4	76.6	55.2	47.1	50.2
Vehicle Ownership Rate	87.8	91.8	84.6	81.8	71.7

Note: The source is the 2004 wave of the Survey of Consumer Finances (SCF). I use the Extract Public dataset. Following Kaplan et al. (2014), I select households whose head is between 22 and 79 years old, and their non-financial income is strictly positive. Since the SCF over-samples wealthier households, I use the sample household weights provided by the SCF. With the Extract Public dataset, Asians are bunched together with all the other (other than White, Hispanic, or Black) racial groups.

holds who are not White, Asian, Hispanic, or Black. This is a limitation of using the Extract Public Dataset of the SCF; I plan to use the raw SCF dataset, which allows me to separately identify Asian households, in the future. The fourth and the fifth columns are associated with households whose head is Hispanic and Black, respectively.

The first block of Table 3 summarizes the fraction of households which are classified as hand-to-mouth according to the definition of Kaplan et al. (2014).[5] Simply put, households whose liquidity is less than half of the non-financial income per pay period (2 weeks for the U.S.) is classified as hand-to-mouth. Moreover, if a household which is classified as hand-to-mouth has zero or negative illiquid wealth, the household is classified as poor hand-to-mouth, while

[5] See Appendix C for more details about how Kaplan et al. (2014) define hand-to-mouth.

a hand-to-mouth household with strictly positive illiquid wealth is called wealthy hand-to-mouth. Again following Kaplan et al. (2014), liquid wealth is the sum of checking, saving, money market, and call accounts, directly held pooled investment funds, directly held individual stocks and bonds, net of credit card balance. Illiquid asset is the sum of certificate of deposits, saving bonds, cash value of life insurance, all kinds of retirement accounts, value of primary and other residences, net equity in non-residential real estate, net of mortgages and other types of home equity loans. Total wealth is the sum of liquid and illiquid wealth. Overall, 30.3% of all households are hand-to-mouth. About 1/3 of them (10.7% of total) are poor hand-to-mouth, while the remaining 2/3 (19.7%) are wealthy-hand-to-mouth. These numbers are very close to the numbers that Kaplan et al. (2014) obtain using pooled data from 1989 to 2010. According to them, the fraction of hand-to-mouth is 31.2%, 39% of which (12.1% of total households) is poor hand-to-mouth, while the remaining 62% (19.2% of total) are wealthy hand-to-mouth.

As can be seen from the second to fifth columns of the first block, there is significant heterogeneity in terms of the proportions of hand-to-mouth across racial groups. Among White households, there are less hand-to-mouth households. The total fraction of hand-to-mouth households among White is 24.9%, among which 6.7% are poor hand-to-mouth and 18.2% are wealthy hand-to-mouth. All numbers are below the overall numbers. The fractions of hand-to-mouth among Asian households are close to the overall fractions; among Asian households, 12.5% are poor hand-to-mouth, and 18.7% are wealthy hand-to-mouth, and thus 31.2% are total hand-to-mouth households. On the other hand, there are more hand-to-mouth households among Hispanics and Blacks. Among Hispanic households, more than half (51.8%) households are hand-to-mouth. Among them, the fraction of poor hand-to-mouth households is particularly high, at 28.7%. This number is close to three times higher than the overall fraction, and more than four times larger than the fraction of poor hand-to-mouth among White households. The fraction of wealthy hand-to-mouth is only slightly higher than the overall fraction, at 23.1%. Among Black households, the fraction of hand-to-mouth is close to half (44.2%). Among those 44.2%, 18.8% are poor hand-to-mouth, and 25.5% are wealthy hand-to-mouth. The fractions of poor hand-to-mouth and wealthy hand-to-mouth are both higher than the overall fractions.

The second block of Table 3 contains the fractions of hand-to-mouth based on alternative definitions. In the first line, I define hand-to-mouth as households whose net worth is zero or negative. Net worth is a more comprehensive measure than the total wealth, used by Kaplan et al. (2014). On top of all the items included in the total wealth, net worth includes other managed financial assets (annuities and trusts), other misc financial assets, net equity of vehicles (value of vehicles minus the outstanding value of car loans), value of businesses, other misc non-financial assets, net of education loans and other installment loans, and other debt. Overall, 9.0% of households have zero or negative net worth position. Among White and Asians, the fraction is lower, at 6.8% and 6.5%, respectively. Among Hispanic (13.9%) and Black (18.4%) households, more households have zero or negative net worth position. If I use zero or negative total wealth position to define hand-to-mouth, the fractions are similar to the previous case. Overall, 9.9% of households are hand-to-mouth, by holding zero or negative total wealth position. The fraction based on total wealth position is higher among Asians (10.3%) and Hispanics (22.1%), but similar for other racial groups. If I define hand-to-mouth as total wealth

less than half of non-financial income per pay period (2 weeks), the fraction of hand-to-mouth is obviously higher. Overall, 14.5% of households are hand-to-mouth, compared with 9.9% when zero is used as the threshold. Not surprisingly, all racial groups exhibit a higher fraction of hand-to-mouth. The fraction for White, Asian, Hispanic, and Black households are 9.9%, 15.2%, 33.5%, and 25.8%, respectively.

The third block of Table 3 shows mean and median total wealth, liquid wealth and illiquid wealth, for all households as well as four racial groups. Across all households, mean total wealth is 315,000 dollars in current dollars in 2004, while median total wealth is 75,000 dollars. For both mean and median total wealth, minority groups hold less wealth than White households. Mean wealth of Asian, Hispanic, and Black households are 72.5%, 21.7%, and 22.9% of mean wealth of White households. The median total wealth is similarly unequally distributed for minority groups. Median total wealth for Asian, Hispanic, and Black households are 74.2%, 8.9%, and 17.2%, of median total wealth of White households, respectively. For all households, liquid wealth makes up a smaller portion of total wealth, but the fraction is significantly smaller for Hispanic and Black households. Median liquid asset holding for Hispanic households is only 106 dollars. For Black households, it is only 137 dollars. This small liquid asset holding shows up as the large fraction of hand-to-mouth households for these two racial groups. The last block of Table 3 contains alternative measures of wealth holding. Both mean and median net worth holding for four racial groups are as unequally distributed as total wealth. The last two rows show the fraction of households with housing, and that with vehicles. In general, minority groups exhibit a lower homeownership rate, which shows up as smaller illiquid wealth holding as well as smaller total wealth holding for minority groups. The homeownership rate for White households is 76.6%, while the homeownership rate for Asian, Hispanic, and Black households are 55.2%, 47.1%, and 50.2%, respectively. Vehicle ownership is also higher among White households compared with minority households. For White households, the vehicle ownership rate is 91.8%, while it is 84.6% for Asian households, 81.8% for Hispanic households, and 71.7% for Black households.

3 Model

Time is discrete and infinite, starting from 0. The economy is populated by workers, investment firms, capital firms, labor firms, intermediate good firms, final good firms, mutual funds, the government, and the monetary authority. The model is indented to stay close to the canonical heterogeneous-agent model with New Keynesian nominal frictions, with multiple types capturing different races. As I describe more details in the next section, I assume four types, corresponding to White, Asian, Hispanic, and Black.

3.1 Worker

There are mass of infinitely-lived workers. The problem of a worker is the following:

$$\max_{\{c_t,a_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_s^t u(c_t) \tag{1}$$

subject to:

$$c_t + p_t^a a_{t+1} = (p_t^a + d_t)a_t + \begin{cases} (1-\tau_t)w_t p_t \eta_s & \text{if } e_t = 1 \\ \min(\phi_0 w_t p_t \eta_s, \phi_1 \overline{w\eta}_s) & \text{if } e_t = 2 \end{cases} \tag{2}$$

$$a_{t+1} \geq \begin{cases} 0 & \text{if } h_t = 1 \\ (1-\delta_a)a_t & \text{if } h_t = 2 \end{cases} \tag{3}$$

A worker is characterized by a permanent type s, persistent idiosyncratic productivity shock p_t, unemployment shock $e_t \in \{1, 2\}$, wealthy hand-to-mouth shock $h_t \in \{1, 2\}$, and asset holding a_t. p_t follows a first-order Markov process, with transition probabilities $\pi_{p_{t+1}|p_t,e_t,e_{t+1}}$. The transition probabilities also depend on the employment status in period t and $t+1$, in order to capture earnings loss upon losing a job, which is widely documented (Farber (2011)). I will come back to the details of $\pi_{p_{t+1}|p_t,e_t,e_{t+1}}$ in Section 4, and investigate implications of the earnings loss in Section 9. As for the unemployment shock, $e_t = 1$ denotes being employed, while $e_t = 2$ denotes being unemployed. $\pi_{e_{t+1}|s,e_t}$ denote the transition probabilities of e for a type-s worker. Specifically, when a worker is employed, the worker loses its job and becomes unemployed in the next period at a type-s specific but exogenous separation rate λ_s. If the worker is unemployed, the worker finds a job and becomes employed at a job-finding rate $f_{s,t}$, which is endogenously determined, as explained below. The wealthy hand-to-mouth shock h_t is i.i.d. and $h_t = 1$ with probability π_s^h and $h_t = 2$ with probability $1 - \pi_s^h$. Notice that the probability of wealthy hand-to-mouth shock is also type-specific.

In the maximand (1), β_s is the type-s specific time discount factor. $u(c)$ is the period utility function with the functional form of $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$, where σ is the coefficient of relative risk aversion. c_t is consumption. $\mathbb{E}$ is an expectation operator. (2) is the budget constraint, and (3) represents the liquidity constraint. In equation (2), p_t^a is the price of assets, and d_t is dividend payout from assets. The non-financial income in (2) depends on the current employment status. For the employed ($e_t = 1$), τ_t is the UI tax rate, w_t is the wage per efficiency unit, and η_s is the productivity for type-s worker. An unemployed ($e_t = 2$) receives UI benefits. The amount of UI benefits is the replacement rate ϕ_0 times the would-be (pre-tax) labor income, with the upperbound of $\phi_1 \overline{w\eta}_s$, where $\overline{w}$ is the steady-state wage, and $\overline{\eta}_s$ is the average η_s across all groups.

The liquidity constraint (3) has two cases depending on the realization of the wealthy hand-to-mouth shock h_t. If $h_t = 1$, the worker is not subject to hand-to-mouth shock, and the liquidity constraint basically states that the worker cannot borrow, but can use all the assets for consumption. If $h_t = 2$, the worker is liquidity constrained in a way that captures wealthy hand-to-mouth. Specifically, a_{t+1} is constrained to be above $(1-\delta_a)a_t$. In other words, the worker which is subject to the wealthy hand-to-mouth shock can use only a fraction δ_a of the current asset holding a_t for current consumption, and the remaining $(1-\delta_a)a_t$ remains illiquid and cannot be used for current consumption. This is a simplified way to introduce wealthy hand-to-mouth in a model which abstracts from two-asset setup like the one developed by Kaplan et al. (2018). In a related but more realistic (but less simple) set up, Bayer et al. (2020) assume that workers can adjust illiquid capital holding with a fixed probability.

3.2 Investment Firm

Competitive investment firms purchase final goods from final good producing firms and convert into investment goods and sell to capital firms at price p_t^i, subject to a quadratic investment adjustment cost, and a marginal efficiency of investment (MEI) shock b_t (Justiniano et al. (2010)). The problem of investment firms is as follows:

$$\max_{\{i_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \prod_{s=0}^{t} \left(\frac{1}{1+r_s}\right) \left[i_t b_t \left(p_t^i - \frac{\psi_i}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \right) - i_t \right] \tag{4}$$

The term $\frac{\psi_i}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2$ represents the quadratic investment adjustment cost. The MEI shock follows the AR(1) process below:

$$\log b_{t+1} = \rho_b \log b_t + \epsilon_{t+1}^b \tag{5}$$

where $\epsilon_{t+1}^b \sim N(0, \sigma_b^2)$. Future profits are discounted by real interest rate r_t, where $r_0 = 0$. Current profits of investment firms can be defined as:

$$d_t^{inv} = i_t b_t \left(p_t^i - \frac{\psi_i}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \right) - i_t \tag{6}$$

3.3 Capital Firm

The problem of competitive capital firms can be characterized as follows:

$$\max_{\{k_t, n_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \prod_{s=0}^{t} \left(\frac{1}{1+r_s}\right) \left[r_t^k n_t k_t - p_t^i i_t b_t \right] \tag{7}$$

subject to:

$$k_{t+1} = (1 - \delta_0 n_t^{\delta_1}) k_t + i_t b_t \tag{8}$$

Following Greenwood et al. (1988), $\delta_0 n_t^{\delta_1}$ is the depreciation rate which depends on the level of utilization n_t. Current profits of the capital firms are:

$$d_t^{cap} = r_t^k n_t k_t - p_t^i i_t b_t \tag{9}$$

3.4 Labor Firm

Labor firm can be unmatched or matched with a worker. An unmatched labor firm can post a vacancy in a type-s market by paying a vacancy posting cost κ_s. If matched, the firm and the worker sells labor services to intermediate firms, and the income is shared between the worker (wages) and the firm (profits). The bargaining is simplified by an exogenous sharing rule. Each

period, after production, the match is destroyed at the separation rate λ_s. The value function of a labor firm matched with type-(s,p) worker can be recursively defined as follows:

$$J_t(s,p) = (x_t - w_t)p\eta_s + \mathbb{E}_t \frac{1-\lambda_s}{1+r_{t+1}} \sum_{p'} \pi_{p'|p,1,1} J_{t+1}(s,p') \tag{10}$$

where x_t is the rental rate of labor services or labor productivity per efficiency unit. w_t is the wage per efficiency unit, and the firm keeps $x_t - w_t$ as its profits per efficiency unit. The type-s of the worker that the firm is matched to does not change, but the individual labor productivity p changes according to $\pi_{p'|p,e=1,e'=1}$, where $e = e' = 1$ means the worker remains employed. Unmatched firms keep entering the markets until the expected profits of entering are equal to vacancy posting cost, as follows:

$$\kappa_s = \frac{\mu v_{s,t}^{\alpha} u_{s,t}^{1-\alpha}}{v_{s,t}} \sum_{p} \pi_{p|s,e=2} J_t(s,p) \tag{11}$$

$m(v_{s,t}, u_{s,t}) = \mu v_{s,t}^{\alpha} u_{s,t}^{1-\alpha}$ is the matching function, where μ is the matching efficiency, and α is the elasticity of matches with respect to the number of vacancies posted. $v_{s,t}$ and $u_{s,t}$ are the number of vacancies and the number of unemployed workers in type-s market, respectively. Labor market search and matching occurs before production in period t. $\pi_{p|s,e=2}$ denotes the distribution of individual productivity p among the currently unemployed ($e = 2$) workers of type-s. The job-finding rate for a type-s worker, $f_{s,t}$, can be characterized as:

$$f_{s,t} = \frac{\mu v_{s,t}^{\alpha} u_{s,t}^{1-\alpha}}{u_{s,t}} \tag{12}$$

In terms of the surplus sharing rule between a firm and a worker in a match, I assume the following ad-hoc wage rule:

$$w_t = \omega_0 \overline{x} + \omega_1 (\log x_t - \log \overline{x}) + \omega_2 (\log \pi_t - \log \overline{\pi}) \tag{13}$$

ω_0 captures the worker's share out of total surplus in the steady state, with $\overline{x}$ being the steady-state rental rate of labor services or labor productivity. ω_1 captures the elasticity of wage with respect to labor productivity. ω_2 is intended to capture nominal wage rigidity. In particular, when $\omega_2 < 0$, a higher current inflation rate implies a lower real wage. Current total profits of labor firms in period t, d_t^{lab}, can be characterized as follows:

$$d_t^{lab} = \int \mathbb{1}_{e=1}(x_t - w_t)p\eta_s \, d\, m_{t+1} - \sum_s \kappa_s v_{s,t} = (x_t - w_t)\ell_t - \sum_s \kappa_s v_{s,t} \tag{14}$$

3.5 Final Good Firm

Following the standard New Keynesian model, there are continuum of intermediate good firms indexed by $i \in [0,1]$ producing differentiated output $y_t(i)$ at nominal prices $P_t(i)$. These intermediate goods are bundled into a final output y_t with the following production function, with elasticity of substitution among intermediate goods $\epsilon_p > 1$.

$$y_t = \left(\int_0^1 y_t(i)^{\frac{\epsilon_p - 1}{\epsilon_p}} di \right)^{\frac{\epsilon_p}{\epsilon_p - 1}} \tag{15}$$

Profit maximizing problem of a representative final good firm is:

$$\max_{\{y_t(i)\}} P_t \left(\int_0^1 y_t(i)^{\frac{\epsilon_p - 1}{\epsilon_p}} di \right)^{\frac{\epsilon_p}{\epsilon_p - 1}} - \int_0^1 P_t(i) y_t(i) di \tag{16}$$

First order condition with respect to an intermediate goods output $y_t(i)$ is:

$$y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon_p} y_t \tag{17}$$

This is virtually a demand function by the final good firm, taken as given by intermediate good firms. The aggregate price index P_t in the equation above is characterized by:

$$P_t^{1-\epsilon_p} = \int_0^1 P_t(i)^{1-\epsilon_p} di \tag{18}$$

Final good firms make zero profit in equilibrium.

3.6 Intermediate Good Firm

Intermediate good firms produce differentiated goods i, using the following production technology:

$$y_t(i) = z_t (k_t(i) n_t(i))^{\theta} \ell_t(i)^{1-\theta} \tag{19}$$

where $k_t(i)$ is capital, $n_t(i)$ is the level of utilization, and $\ell_t(i)$ is labor used by the intermediate firm i. z_t is total factor productivity shock and follows the following AR(1) process:

$$\log z_{t+1} = \rho_z \log z_t + \epsilon_{t+1}^z \tag{20}$$

where $\epsilon_{t+1}^z \sim N(0, \sigma_z^2)$. The nominal profit of the intermediate good firm i, $D_t(i)$, is as follows:

$$D_t(i) = P_t(i) y_t(i) - R_t^k (k_t(i) n_t(i)) - X_t \ell_t(i) - \frac{\psi_1}{2} \left(\frac{P_t(i)}{P_{t-1}(i)} - \overline{\pi} \right)^2 y_t P_t - \psi_0 P_t \tag{21}$$

$P_{t-1}(i)$ is the nominal price of intermediate good i in the previous period. P_t is the aggregate price of intermediate goods in the current period, taken as given by an intermediate good firm i. R_t^k and X_t are nominal rental rate of capital and nominal rental rate of labor, respectively. Following the standard New-Keynesian setup (Rotemberg (1982)), I assume a quadratic nominal price adjustment cost, with ψ_1 determining the degree of nominal price rigidity. $\overline{\pi}$ is the steady-state inflation rate. ψ_0 is a fixed cost, which ensures that profits (and dividends) are zero in the steady-state.

Dividing by the nominal price of intermediate goods P_t, real profit of an intermediate good firm i is:

$$\frac{D_t(i)}{P_t} = \frac{P_t(i)}{P_t} y_t(i) - \frac{R_t^k}{P_t} (k_t(i) n_t(i)) - \frac{X_t}{P_t} \ell_t(i) - \frac{\psi_1}{2} \left(\frac{P_t(i)}{P_{t-1}(i)} - \overline{\pi} \right)^2 y_t - \psi_0 \tag{22}$$

And the optimization problem of an intermediate good firm i is as follows:

$$\max_{\{P_t(i),(k_t(i)n_t(i)),\ell_t(i)\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \prod_{s=0}^{t} \left(\frac{1}{1+r_s}\right) \frac{D_t(i)}{P_t} \tag{23}$$

subject to:

$$y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon_p} y_t \tag{24}$$

$$y_t(i) = z_t(k_t(i)n_t(i))^{\theta} \ell_t(i)^{1-\theta} \tag{25}$$

3.7 Government

The government runs the unemployment insurance (UI) program. The budget of the UI program is balanced each period, by adjusting the UI tax rate τ_t each period. The government budget constraint is as follows:

$$\tau_t \int \mathbb{1}_{e=1} w_t p \eta_s \, d\, m_{t+1} = \int \mathbb{1}_{e=0} \min(\phi_0 w_t p \eta_s, \phi_1 \overline{w\eta}_s) \, d\, m_{t+1} \tag{26}$$

where m_{t+1} is the type distribution of workers in period t after labor market transitions.

3.8 Monetary Authority

Monetary policy is characterized by the following Taylor rule with interest rate smoothing:

$$\frac{R_t}{\overline{R}} = \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_R} \left(\frac{\pi_t}{\overline{\pi}}\right)^{(1-\rho_R)\phi_\pi} \left(\frac{y_t}{\overline{y}}\right)^{(1-\rho_R)\phi_y} s_t \tag{27}$$

where the first term represents the interest rate smoothing, and ρ_R is the smoothing parameter. s_t is a monetary policy shock, which follows the AR(1) process below.

$$\log s_{t+1} = \rho_s \log s_t + \epsilon_{t+1}^s \tag{28}$$

where $\epsilon_{t+1}^s \sim N(0, \sigma_s^2)$. The assumed timing is that R_t is applied to nominal asset saved in period t (and return is paid in period $t+1$). ϕ_π and ϕ_y represent the response of monetary authority against inflation and output, respectively. Taking log of both sides yields:

$$\begin{aligned}\log R_t = (1-\rho_R)\log \overline{R} + \rho_R \log R_{t-1} \\ + (1-\rho_R)[\phi_\pi(\log \pi_t - \log \overline{\pi}) + \phi_y(\log y_t - \log \overline{y})] + \log s_t\end{aligned} \tag{29}$$

3.9 Mutual Funds

Workers own all the firms through mutual funds. The price of a share of mutual funds is p_t^a and the dividend of mutual funds is d_t. d_t can be defined as follows:

$$d_t = d_t^{inv} + d_t^{cap} + d_t^{lab} + d_t^{int} \tag{30}$$

where d_t^{inv},d_t^{cap}, d_t^{lab} and d_t^{int} denote period-t dividends from investment firms, capital firms, labor firms, and intermediate good firms, respectively. Total number of mutual fund shares is fixed at $\overline{a}$. The rate of return of assets, r_{t+1} can be defined as follows:

$$1 + r_{t+1} = \frac{p_{t+1}^a + d_{t+1}}{p_t^a} \tag{31}$$

3.10 Characterizing the Equilibrium

In this section, I will derive some equations that characterize the equilibrium. The complete list of equations characterizing the equilibrium is in Appendix A. Worker's optimal saving decision is characterized by the following equations:

$$u'(c_t) = \beta_s \mathbb{E}_t \frac{p_{t+1}^a + d_{t+1}}{p_t^a} u'(c_{t+1}) \tag{32}$$

$$a_{t+1} = \begin{cases} \max\{(p_t^a + d_t)a_t + (1-\tau_t)w_t p_t \eta_s - c_t, \underline{a}_t\} & \text{if } e_t = 1 \\ \max\{(p_t^a + d_t)a_t + \min(\phi_0 w_t p_t \eta_s, \phi_1 \overline{w}\overline{\eta}_s) - c_t, \underline{a}_t\} & \text{if } e_t = 2 \end{cases} \tag{33}$$

where

$$\underline{a}_t = \begin{cases} 0 & \text{if } h_t = 1 \\ (1-\delta_a)a_t & \text{if } h_t = 2 \end{cases} \tag{34}$$

As for investment firms, taking first order condition yields the following equilibrium condition:

$$b_t p_t^i = 1 + \frac{b_t \psi_i}{2}\left[3\frac{i_t^2}{i_{t-1}^2} - 4\frac{i_t}{i_{t-1}} + 1\right] - \mathbb{E}_t \frac{b_{t+1}\psi_i}{1+r_{t+1}} \frac{i_{t+1}^2}{i_t^2}\left[\frac{i_{t+1}}{i_t} - 1\right] \tag{35}$$

Notice that, if we impose steady-state conditions ($i_{t-1} = i_t = i_{t+1}$ and $b_t = b_{t+1} = 1$), the above equation becomes $p_t^i = 1$.

Capital firms decide the utilization rate and the capital accumulation. Taking the first order condition with respect to utilization rate h_t in the problem of capital firms yields:

$$r_t^k = p_t^i \delta_0 \delta_1 n_t^{\delta_1 - 1} \tag{36}$$

The first order condition with respect to k_{t+1} yields:

$$p_t^i = \mathbb{E}_t \frac{1}{1+r_{t+1}}\left[r_{t+1}^k n_{t+1} + (1-\delta_0 n_{t+1}^{\delta_1})p_{t+1}^i\right] \tag{37}$$

As for the intermediate good firms and final good firms, we focus on a symmetric equilibrium in which all intermediate firms choose the same price in period t. Therefore $P_t = P_t(i)$ and $y_t = y_t(i)$ for all i in equilibrium. The Lagrangian for an intermediate good firm i is as follows:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \prod_{s=0}^{t} \left(\frac{1}{1+r_s}\right)\left[\frac{P_t(i)}{P_t} y_t(i) - \frac{R_t^k}{P_t}(k_t(i)n_t(i)) - \frac{X_t}{P_t}\ell_t(i) - \frac{\psi_1}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - \overline{\pi}\right)^2 y_t \right.$$
$$\left. -\psi_0 + \lambda_t^f \left\{y_t(i) - \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon_p} y_t\right\} + mc_t\left\{z_t(k_t(i)n_t(i))^\theta \ell_t(i)^{1-\theta} - y_t(i)\right\}\right] \tag{38}$$

where mc_t is the Lagrange multiplier for production technology, and can be interpreted as the marginal cost of producing one unit of intermediate goods. First order conditions are:

$$\frac{P_t(i)}{P_t} + \lambda_t^f - mc_t = 0 \tag{39}$$

$$\frac{R_t^k}{P_t} - mc_t z_t \theta (k_t(i) n_t(i))^{\theta-1} \ell_t(i)^{1-\theta} = 0 \tag{40}$$

$$\frac{X_t}{P_t} - mc_t z_t (1-\theta)(k_t(i) n_t(i))^{\theta} \ell_t(i)^{-\theta} = 0 \tag{41}$$

$$\left[\frac{1}{P_t} y_t(i) - \psi_1 \left(\frac{P_t(i)}{P_{t-1}(i)} - \overline{\pi}\right) y_t \frac{1}{P_{t-1}(i)} + \lambda_t^f \epsilon_p P_t(i)^{-\epsilon_p - 1} P_t^{\epsilon_p} y_t\right] + \mathbb{E}_t \frac{1}{1+r_{t+1}} (-\psi_1) \left(\frac{P_{t+1}(i)}{P_t(i)} - \overline{\pi}\right) y_{t+1} P_{t+1}(i)(-P_t(i)^{-2}) = 0 \tag{42}$$

substituting in $r_t^k = R_t^k / P_t$, $x_t = X_t / P_t$, $\pi_t = P_t / P_{t-1}$, $P_t(i) = P_t$, $y_t(i) = y_t$, $k_t(i) n_t(i) = k_t n_t$, and $\ell_t(i) = \ell_t$, the above conditions become:

$$1 + \lambda_t^f - mc_t = 0 \tag{43}$$

$$r_t^k = mc_t z_t \theta (k_t n_t)^{\theta-1} \ell_t^{1-\theta} \tag{44}$$

$$x_t = mc_t z_t (1-\theta)(k_t n_t)^{\theta} \ell_t^{-\theta} \tag{45}$$

$$\left[y_t - \psi_1 (\pi_t - \overline{\pi}) y_t \pi_t + \lambda_t^f \epsilon_p y_t\right] + \mathbb{E}_t \frac{1}{1+r_{t+1}} \left[\psi_1 (\pi_{t+1} - \overline{\pi}) y_{t+1} \pi_{t+1}\right] = 0 \tag{46}$$

By substituting out λ_t^f:

$$r_t^k = mc_t z_t \theta (k_t n_t)^{\theta-1} \ell_t^{1-\theta} \tag{47}$$

$$x_t = mc_t z_t (1-\theta)(k_t n_t)^{\theta} \ell_t^{-\theta} \tag{48}$$

$$\left[y_t - \psi_1 (\pi_t - \overline{\pi}) y_t \pi_t + (mc_t - 1)\epsilon_p y_t\right] + \mathbb{E}_t \frac{1}{1+r_{t+1}} \left[\psi_1 (\pi_{t+1} - \overline{\pi}) y_{t+1} \pi_{t+1}\right] = 0 \tag{49}$$

Notice that $P_{t-1}(i)$ is eliminated from the system of equations characterizing the optimal decision of intermediate good firms, which means that we do not need to keep track of price levels. The amount of dividends from intermediate good firms, d_t^{int}, can be computed as follows:

$$d_t^{int} = y_t - r_t^k n_t k_t - x_t \ell_t - \frac{\psi_1}{2} (\pi_t - \overline{\pi})^2 y_t - \psi_0 \tag{50}$$

Total number of mutual fund shares and aggregate labor supply are obtained by aggregating up individual worker's share holding and labor supply:

$$\overline{a} = \int a \, d\, m_t \tag{51}$$

$$\ell_t = \int \mathbb{1}_{e=1} p \eta_s \, d\, m_t \tag{52}$$

Aggregating up the budget constraint of individual households yields the following:

$$c_t = d_t + w_t \ell_t \tag{53}$$

Substituting the dividends yields the following aggregate resource constraint:

$$y_t = c_t + i_t + b_t i_t \frac{\psi_i}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2 + \sum_s \kappa_s v_{s,t} + \frac{\psi_1}{2}(\pi_t - \overline{\pi})^2 y_t + \psi_0 \tag{54}$$

The left-hand-side is total output. The right-hand-side consists of aggregate consumption expenditures, investment, investment adjustment cost, vacancy posting cost, nominal price adjustment cost, and fixed cost of production.

Although aggregate bond supply is assumed to be zero in equilibrium by assumption, no arbitrage condition between mutual fund shares and nominal bonds has to hold, which is characterized as follows:

$$R_t = \mathbb{E}_t \pi_{t+1}(1 + r_{t+1}) \tag{55}$$

Notice that R_t is the return of nominal bond from period t to $t+1$, so is determined in period t, while realized return of real assets r_{t+1} and the realized inflation rate π_{t+1} are realized in period $t+1$.

4 Calibration

One period is a quarter. I assume 4 permanent types, with $s = 1$ representing White, $s = 2$ representing Asian, $s = 3$ representing Hispanic (can be White, Asian, or African), and $s = 4$ representing African/Black. Calibration is summarized in Table 4 for most parameters and Table 5 for type-specific parameters. The coefficient of relative risk aversion parameter is set at $\sigma = 2.0$, or intertemporal elasticity of substitution of $1/\sigma = 0.5$, a commonly-used value. The discount factor is assumed to be type specific. I use the discount factor for the White to match the quarterly economy-wide capital output ratio of 12 (3 in annual frequency). The discount factors for the other three types are calibrated to match the fraction of poor hand-to-mouth within each type, documented in Table 3. As a result, β for White, Asian, Hispanic, and Black are 0.9802, 0.9097, 0.8325, and 0.8474, respectively. β for minority groups are low, compared with typically-used values, because a low β is needed to match the large fraction of poor hand-to-mouth. Note that this strategy underestimates the proportion of hand-to-mouth individuals among White. I will come back to this issue in Section 5. The total supply of mutual fund shares is normalized to $\overline{a} = 1$.

The transition probabilities of individual labor productivity shock p depend on the employment status before and after the employment transition in period t. If a worker is employed and remains employed $e_t = e_{t+1} = 1$, the transition probabilities are discrete version of an AR(1) shock with the persistence ρ_p and the standard deviation σ_p. $\rho_p = 0.9160$ and $\sigma_p = 0.3085$ are taken from estimates by Storesletten et al. (2001). σ_p is the average between its values in expansions and recessions, estimated by Storesletten et al. (2001). Since they estimate the parameters using annual data, I assume that, with probability of 0.75 (three quarters out of four),

Table 4: Summary of Calibration: Main Parameters

	Value	Description	Target
σ	2.0000	Relative risk aversion	Standard in literature.
β_1	0.9802	Discount factor (White)	$\overline{k}/\overline{y} = 12$.
β_2	0.9097	Discount factor (Asian)	12.5% are poor hand-to-mouth.
β_3	0.8325	Discount factor (Hispanic)	28.7% are poor hand-to-mouth.
β_4	0.8474	Discount factor (Black)	18.8% are poor hand-to-mouth.
ρ_p	0.9160	Persistence of individual productivity shock	Storesletten et al. (2001).
σ_p	0.3085	S.D. of individual productivity shock	Storesletten et al. (2001).
δ_p	0.1096	Earnings loss upon job loss	Farber (2011).
δ_a	0.0477	Liquidity for wealthy hand-to-mouth	Ratio of credit limit to wealth.
ω_0	0.9700	Steady-state wage share	Nakajima (2012b).
ω_1	0.4490	Sensitivity of wage to labor productivity.	Nakajima (2012b).
ω_2	–0.1326	Nominal wage stickiness.	Gertler et al. (2008).
ϕ_0	0.4610	UI replacement rate	Avg across U.S. states.
ϕ_1	0.5120	Upperbound of UI benefits	Avg across U.S. states.
μ	0.7743	Matching efficiency	Avg job-finding rate is 63.4%.
α	0.6810	Matching elasticity	Bartscher et al. (2021).
ψ_i	0	Investment adjustment cost.	Volatility of PCE.
δ_0	0.0150	Avg depreciation rate	From NIPA.
δ_1	1.5833	Curvature of depreciation cost	Utilization rate $n = 1$ in steady state.
ϵ_p	20.000	Elasticity of substitution	Price mark-up of 5%.
θ	0.3000	Capital share of production	Labor share = 2/3.
ρ_z	0.9500	Persistence of TFP shock	Standard in literature.
σ_z	0.0031	S.D. of TFP shock	Justiniano et al. (2010).
ρ_b	0.8100	Persistence of MEI shock	Justiniano et al. (2010).
σ_b	0.1870	S.D. of MEI shock	Justiniano et al. (2010).
ψ_0	0.1474	Fixed cost of production	Steady-state profit = 0.
ψ_1	38.080	Price adjustment cost	Avg price duration = 5 quarters.
$\overline{a}$	1.0000	Total supply of mutual fund shares	Normalization.
ρ_R	0.8000	Interest rate smoother	Standard in literature.
ϕ_π	1.5000	Taylor response parameter to inflation	Standard Taylor rule.
ϕ_y	0.1250	Taylor response parameter to output	Standard Taylor rule.
$\overline{\pi}$	1.0050	Avg inflation rate	Annual inflation rate of 2%.
$\overline{R}$	1.0138	Avg nominal interest rate	Endogenously obtained.
ρ_s	0.6100	Persistence of monetary policy shock	Kaplan et al. (2018).
σ_s	0.0025	S.D. of monetary policy shock	Standard in literature.

Note: Quarterly frequency.

the individual productivity remains the same, while, with probability of 0.25 (one quarter out of four), individual productivity changes according to the discretized Markov process using the annual productivity shock. When a worker was employed but loses the job during the employ-

Table 5: Calibration: Different Types

s (Type)	π_s	η_s	f_s	λ_s	u_s/π_s	v_s	κ_s	π_s^h
1 (White)	68.2500	1.0303	65.9900	3.7950	5.4381	0.0300	1.1891	0.1949
2 (Asian)	5.0800	1.1869	69.7600	3.5900	4.8943	0.0022	1.3662	0.2133
3 (Hispanic)	15.2800	0.7368	69.1100	6.1960	8.2278	0.0111	0.4876	0.3243
4 (Black)	11.3900	0.8095	49.4600	6.4400	11.5206	0.0060	0.7165	0.3134

Note: π_s is the fraction of each type, in percent. η_s is productivity of each type, normalized such that the overall average is one. Both are obtained from the CPS. f_s is the quarterly job-finding rate, in percent. λ_s is the quarterly separation rate, in percent. They are obtained from Cajner et al. (2017) and converted from monthly numbers to quarterly ones. u_s is the number of unemployed workers of type-s. u_s/π_s is the unemployment rate, which is implied by the job-finding rate and the separation rate, in the steady-state distribution. v_s is the number of vacancy postings. κ_s is the vacancy posting cost. They are obtained from the steady-state conditions of the model. π_s^h is the probability of the wealthy hand-to-mouth shock, obtained from the proportions of wealthy hand-to-mouth in Table 3.

ment status transition ($e_t = 1, e_{t+1} = 2$), I assume that the productivity of the worker declines by a fixed fraction δ_p, in order to capture earnings loss upon job loss. δ_p is calibrated using the size of average earnings loss reported by Farber (2011). In particular, I use the simple average across 1984-2010 for all workers, which is 10.96% decline in earnings.[6] Finally, in case a worker remains unemployed ($e_t = e_{t+1} = 2$) or a worker was unemployed and finds a job ($e_t = 2, e_{t+1} = 1$), I assume the individual labor productivity shock remains the same. In other words, the transition probability matrix for these cases is an identity matrix.

The parameter controlling the amount of liquidity available when a worker is hit by a wealthy hand-to-mouth shock, δ_a is set at 0.0477. This is obtained by computing the ratio of median credit card limit across all households and median total wealth. Following Kaplan et al. (2014), the credit card limit is defined as equivalent to one-month earnings. The definition of total wealth is described in Section 2.2. As for the type-dependent probability of the wealthy hand-to-mouth shock, I use the fraction of hand-to-mouth for four racial groups, adjusted by dividing by the fraction of non-poor hand-to-mouth. This is because poor hand-to-mouth workers remain poor hand-to-mouth even if they are hit by wealthy hand-to-mouth shock. The resulting probabilities, π_s^h, are shown in the last column of Table 5. It is about 0.2 for White (0.19) and Asian (0.21) workers, while it is above 0.3 for Hispanic (0.32) and Black (0.31) workers.

As for the production sector, the parameter controlling the investment adjustment cost is set at $\psi_i = 0$. The intention is to use this parameter to match the volatility of aggregate PCE, but it turns out that the volatility of aggregate PCE generated by the baseline model is close to the data with $\psi_i = 0$. The quarterly depreciation rate is set at 1.5%, following NIPA. The curvature parameter of the depreciation cost function is set at $\delta_1 = 1.5833$, which guarantees that the steady-state utilization rate is one. ϵ_p is set at 20, implying price mark-up of 5% (Bayer et al. (2019)). Capital share parameter of the production function θ is set at 0.30, which implies

[6] I take the numbers reported in Appendix Table 15. Specifically, for each p, I first compute $\log(p) - \delta_p$, and find grids $\log(p_i)$ and $\log(p_{i+1})$ between which $\log(p) - \delta_p$ falls into. Then I assign probabilities to the two grids in a proportional manner so that the average earnings loss is equal to δ_p.

that the resulting labor share (after taking into account the price mark-up and the profits of labor firms) is about 2/3. The fixed cost of production is set at $\psi_0 = 0.1474$, making sure that the steady-state profit (and dividends) is zero. The price adjustment cost parameter ψ_1 is set at 38.08, such that, when converted into Calvo framework, the parameter value implies the nominal price is adjusted every five quarters on average (Gornemann et al. (2021)). This is a common value in the New-Keynesian literature.

Many parameters related to labor markets are type-specific. Table 5 contains parameter values and calibration targets that are type specific. π_s is the proportion of each type, computed as share within labor force, from Current Population Survey (CPS), Annual Social and Economic Supplement. I take the average between 2003 and 2018. η_s is the average labor productivity for each type, obtained from the median usual weekly earnings for each type, reported by BLS. f_s and λ_s are quarterly job-finding rate and the quarterly separation rate for the four racial groups. These numbers are based on the monthly transition rates reported by Cajner et al. (2017). I convert the monthly transition rates into quarterly rates, and adjust proportionally so that the implied steady-state unemployment rates match the unemployment rate in the CPS. u_s/π_s is the unemployment rate, which is the number of unemployed workers of type-s divided by the total measure of type-s workers. v_s is the total number of vacancy posted for type-s workers. κ_s is the vacancy-posting cost for each type. Different values of κ for different types help matching the type-specific job-finding rate. Specifically, first I assume that the average vacancy posting cost ($\overline{\kappa}$) is 1.5 month equivalent of average wage ($= 0.5\overline{\kappa\eta}w$). Using the zero-profit condition for labor firms posting a vacancy to hire an average worker, and the average job-finding rate of 63.4% per quarter, I can back up the matching efficiency parameter $\mu = 0.7743$. Once μ is fixed, I can compute type-specific κ_s that is consistent with the type-specific job-finding rate f_s. As for the elasticity of the matching function, α, is typically estimated to be around 0.5 (Petrongolo and Pissarides (2001)), I calibrate α to be 0.681, such that the Black-White unemployment gap shrinks by 0.34pp in response to a 25bp accommodative monetary policy shock. This size of the response of the Black-White unemployment gap to a monetary policy shock is estimated by Bartscher et al. (2021) using the U.S. data. I will discuss the effects of a monetary policy shock in Section 6.2. The ad-hoc wage function is extended from the one used in Nakajima (2012b). In particular, $\omega_0 = 0.97$ reflects that profits for firms out of production is 3% of the total surplus. The sensitivity parameter of wage to changes in labor productivity is $\omega_1 = 0.449$, which is computed by Hagedorn and Manovskii (2008). The sensitivity parameter of wage to inflation (price changes) is set at $\omega_2 = -0.1326$, using the information provided by Gertler et al. (2008). In their estimated model with staggered nominal wage bargaining, the fraction 0.283 of firms re-optimize the nominal wage without restrictions, which means that the inflation rate does not affect the bargained wage in real terms. The nominal wage of the remaining (the fraction of 0.717) firms are not optimally adjusted. In particular, the elasticity of the nominal wage in terms of the inflation rate is estimated to be 0.815. In other words, the elasticity of real wage in terms of the inflation rate is -0.185. I do not model explicitly staggered nominal wage bargaining, but using these two pieces of information implies that the average elasticity of real wage to inflation is $\omega_2 = -0.185 \times 0.717 = -0.1326$.

In terms of the fiscal and monetary authority, the UI replacement rate and the upperbound of the UI benefits are average numbers across U.S. states.Specifically, the UI replacement rate is $\phi_0 = 0.461$ and the upperbound of the UI benefits is 0.512 of average earnings. As for the

monetary authority, interest rate smoothing parameter is set at $\rho_R = 0.80$, which is standard in literature. The response parameters to inflation gap and to output gap are set at $\phi_\pi = 1.5$ and $\phi_y = 0.125$, respectively, again following the standard specification of Taylor rule. Average inflation rate is set at $\overline{\pi} = 1.005$, implying 2% annual inflation target. Average nominal interest rate is $\overline{R} = 1.0138$, which is obtained from the average inflation rate and the steady-state real rate of return, which is endogenously determined. Standard deviation of monetary policy shock is set at $\sigma_s = 0.0025$. The persistence of the monetary policy shock is set at $\rho_s = 0.61$, following Kaplan et al. (2018).

There are three aggregate shocks in the model, namely total factor productivity (TFP) shock z_t, marginal efficiency to investment (MEI) shock b_t, and monetary policy shock s_t. The persistence and the standard deviation of the monetary policy shock are already discussed above. The persistence of the TFP shock is set at $\rho_z = 0.95$, which is standard in the literature. The persistence of the MEI shock is set at $\rho_b = 0.81$, following the estimated value of Justiniano et al. (2010). In calibrating the remaining two parameters — standard deviation of the TFP shock and the MEI shock, I use the standard deviation of output and the variance decomposition of output volatility in Justiniano et al. (2010). The standard deviation of detrended GDP in the U.S. data from 1980 to 2019 is 1.24%. According to the estimated model of Justiniano et al. (2010), 0.25 and 0.60 of the output variations in business cycle frequencies (between 6 and 32 quarters) are accounted by the TFP shock and the MEI shock, respectively.[7] Since I have only three aggregate shocks, and the parameters associated with the monetary policy shock are already calibrated using independent evidence, I calibrate the standard deviation of the TFP shock and that of the MEI shock such that (1) output volatility of the model matches the model counterpart, and (2) the ratio of fractions of the output variance accounted for by the two shock is $25/60$. $\sigma_z = 0.0031$ and $\sigma_b = 0.187$ satisfy the two targets simultaneously. The standard deviation of output in the model is 1.24%, and the model implies that 0.24, 0.16 and 0.58 of output fluctuations can be accounted for by the TFP shock, the monetary policy shock, and the MEI shock, respectively. The ratio between the number for the TFP shock and that of the MEI shock ($24/58$) is close to $25/60$, which is the ratio implied by Justiniano et al. (2010).

By imposing steady state conditions ($\mathbf{x}_t = \mathbf{x}_{t+1} = \overline{\mathbf{x}}$ and $\mathbf{y}_t = \mathbf{y}_{t+1} = \overline{\mathbf{y}}$), I can obtain steady-state conditions, which are used to compute steady-state values of aggregate variables. Steady-state values of the aggregate variables, together with how they are obtained, are summarized in Table B.1 in Appendix B.

5 Racial Inequality in the Model

The model exhibits racial inequality in terms of both income and wealth. Racial inequality of income is mostly exogenously set, capturing observed differences in average income and unemployment risks, as described in Section 4. On the other hand, inequality in wealth is endogenous. In this section, I show how distribution of wealth is different across racial groups. Table 6 summarizes mean and median wealth, and the fraction of hand-to-mouth households in the U.S. data (top panel) and in the model (bottom panel). The data are the same as those

[7] Contribution from other shocks are as follows: monetary policy shock = 0.04, government expenditure shock = 0.02, investment specific productivity shock = 0.00, price mark-up shock = 0.02, wage mark-up shock = 0.01, intertemporal preference shock = 0.05.

Table 6: Wealth Distribution for Four Racial Groups

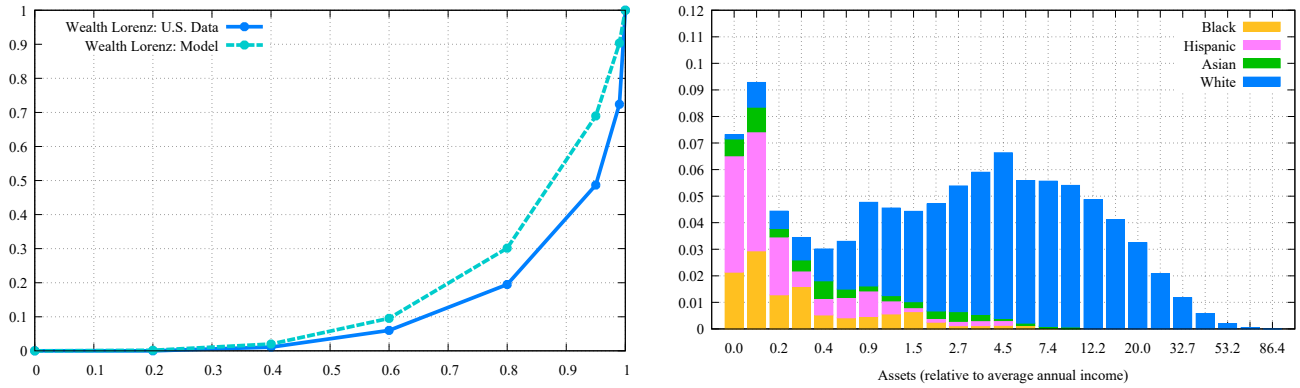
	Overall	White	Asian	Hispanic	Black
Data					
Mean Total Wealth	314,945	389,187	282,150	84,646	88,962
Relative to White	80.9	100.0	72.5	21.7	22.9
Median Total Wealth	75,475	104,510	77,530	9,291	17,938
Relative to White	72.2	100.0	74.2	8.9	17.2
Total Hand-to-Mouth	30.3	24.9	31.2	51.8	44.2
Poor Hand-to-Mouth	10.7	6.7	12.5	28.7	18.8
Wealthy Hand-to-Mouth	19.7	18.2	18.7	23.1	25.5
Model					
Mean Total Wealth	100.0	142.7	18.4	5.1	7.8
Relative to White	70.1	100.0	12.9	3.5	5.5
Median Total Wealth	40.7	72.8	5.5	0.9	2.0
Relative to White	55.9	100.0	7.6	1.2	2.8
Total Hand-to-Mouth	28.0	19.7	31.2	51.8	44.2
Poor Hand-to-Mouth	7.3	0.2	12.5	28.7	18.8
Wealthy Hand-to-Mouth	20.7	19.4	18.7	23.1	25.5

Note: Data are computed using the Survey of Consumer Finances, 2004. See the note for Table 3 for description of the data. In the model, mean and median wealth are normalized such that the overall mean wealth is 100.

in Table 3. The numbers for the model are taken from the steady-state of the baseline model. Mean and median total wealth in the model are normalized such that the overall mean total wealth is 100.

Let's start with the proportion of hand-to-mouth (bottom three rows of each panel). For non-White workers, the proportions of both poor and wealthy hand-to-mouth in the model perfectly match the data counterparts. This is by construction. I use the discount factor (β_s) to match the fraction of poor hand-to-mouth for each minority type, and set the probabilities of the wealthy hand-to-mouth shock for each minority type (π_s^h)to match the fractions of wealthy hand-to-mouth. For White workers, since I use their discount factor to match the economy-wide capital-to-output ratio, the model does not capture the fraction of poor-hand-to-mouth among White workers. Specifically, the fraction is 6.7% in the data but only 0.2% in the model. In the remainder of the paper, I often compare White workers and minority workers, but since the White workers in the model do not contain as many poor hand-to-mouth as in the data, the White workers in the model can be interpreted as middle-class and upper-class White workers. Besides, since White workers make up 2/3 of the labor force, the overall fraction of poor hand-to-mouth in the model (7.3%) is lower than the fraction in the data (10.7%). By construction, the overall fraction of wealthy hand-to-mouth in the model (20.7%) is close to the data (19.7%). Since 2/3 of total hand-to-mouth is wealthy hand-to-mouth, the overall fraction of hand-to-mouth in the model (28.0%) is close but slightly lower than the data (30.3%).

Since I calibrate the model to replicate the high fractions of poor hand-to-mouth, the mean



(a) Wealth Lorenz: Data and Model

(b) Histogram of Wealth Distribution: Model

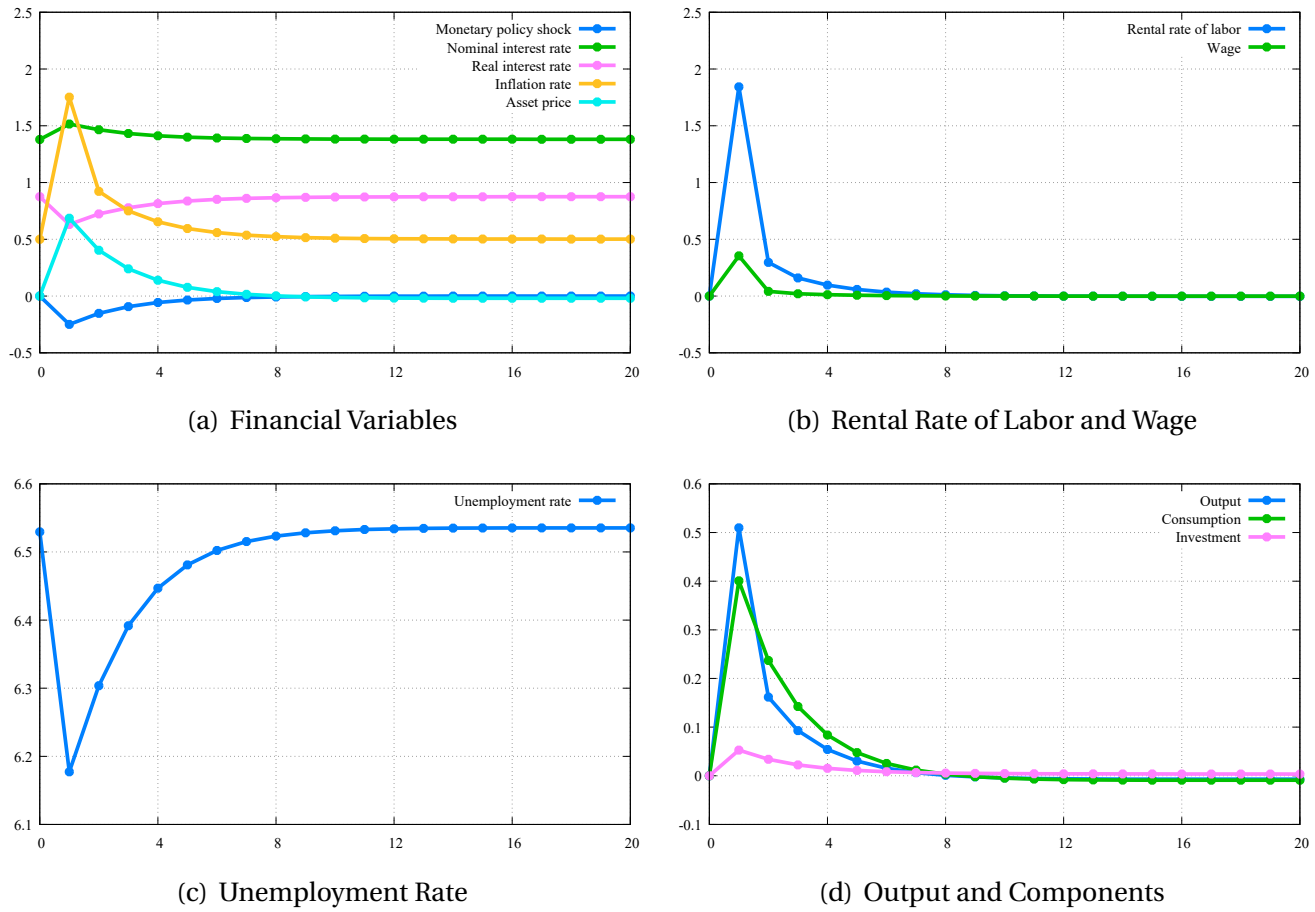
Figure 2: Wealth Distribution

and median wealth holding are not targeted. It turns out that the model generates far smaller total wealth holding by minority groups, which is shown in the first four rows in each panel of the table. In the data, mean total wealth holding by Asian, Hispanic, and Black households are 72.5%, 21.7%, and 22.9% of mean total wealth of White households, respectively. In terms of median total wealth, median total wealth of Asian households is 74.2% of median total wealth of White households, but the same ratio for Hispanic (8.9%) and Black (17.2%) households is significantly lower. The model replicates the property that minority groups hold less wealth than White workers, but the differences are extremely large compared with the data. Mean total wealth of Asian, Hispanic, and Black workers is 12.9%, 3.5%, and 5.5% of White workers, respectively. And median total wealth of Asian workers is only 7.6% of median wealth of White workers, compared with 74.2% in the data. For Hispanic workers, their median wealth is 1.2% of median wealth of White workers in the model, while the ratio is 8.9% in the data. For Black workers, their median total wealth is 2.8% of White's median wealth in the model, while their median wealth is 17.2% of White's median wealth in the data.

Panel (a) of Figure 2 compares the wealth Lorenz curves of the data and the model. Since the model is calibrated to generate a large fraction of workers without wealth, the model captures the property of the data that bottom 40% of wealth distribution hold virtually no wealth. However, the Lorenz curve in the model does not capture the extreme concentration of wealth in the data, which is represented by the extremely convex Lorenz curve. It is well known that the standard incomplete-market model has difficulty in replicating the extreme concentration of wealth observed in the U.S. data. Panel (b) shows a histogram of wealth for four racial groups in the model. There is large mass of Asian, Hispanic, and Black workers at the lower part of wealth distribution, while the top end of wealth distribution mostly contains White workers.

6 Monetary Transmission with Racial Inequality

This section studies how an accommodative monetary shock affects different racial groups differently. Section 6.1 looks at the response of macroeconomic aggregates, before Section 6.2 investigates how an accommodative monetary policy shock affects different racial groups dif-



(a) Financial Variables

(b) Rental Rate of Labor and Wage

(c) Unemployment Rate

(d) Output and Components

Figure 3: Effects of Monetary Policy Shock: Macro Aggregates

ferently. Section 6.3 shows the welfare effects.

6.1 Macroeconomic Effects

Figure 3 summarizes macroeconomic effects in response to a quarterly -25bp (-100bp annually) monetary policy shock. The macroeconomic effects are standard in the New-Keynesian model. Panel (a) contains financial variables. After the initial negative (accommodative) shock, monetary policy shock goes back gradually to the steady-state level of zero (dark blue line). Because of the nominal rigidity, real interest rate declines (pink line), although nominal interest rate goes up slightly (green line), because the inflation rate (yellow line) and output picks up (blue line in Panel (d)), and the nominal interest rate responds to the increase of both, following the Taylor rule. Asset price rises (light blue line), incorporating the increase in future dividends in the stimulated economy.A positive response by the asset price is consistent with empirical finding by Bartscher et al. (2021), but the magnitude is smaller than what they find. In the baseline model, the asset price rises by about 0.7% but the response is not persistent. On the other hand, Bartscher et al. (2021) find that stock prices rise by about 5%, and house prices gain by about 2%, to a monetary policy shock of the same magnitude.

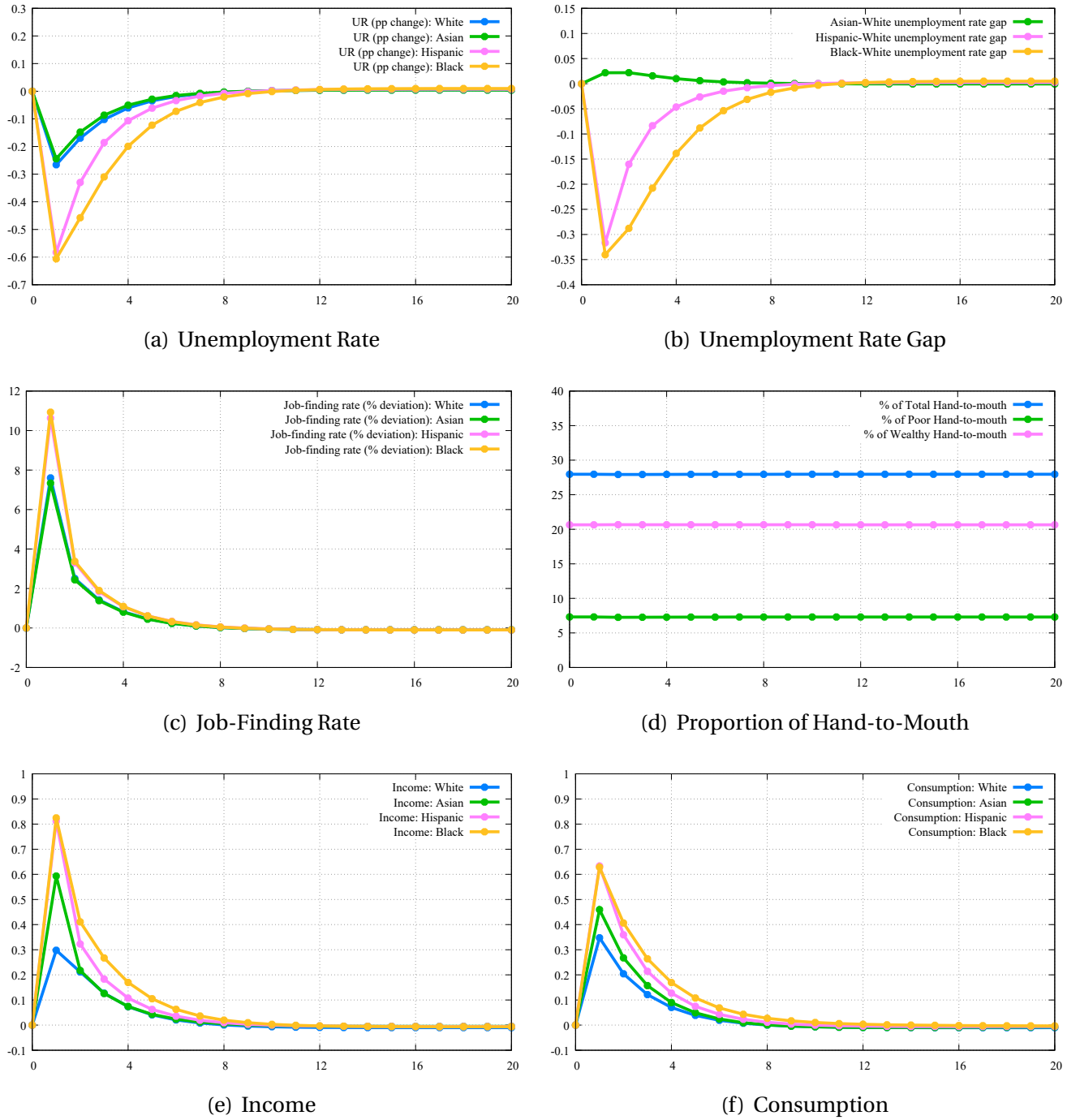
Panel (b) shows the response of the rental rate of labor (x_t) and wage rate (w_t). Since the aggregate demand increases in response to a lower real interest rate, demand for labor increases, which pushes up the rental rate of labor (blue line). As wage is assumed to respond less elastically to changes in the rental rate of labor, wage increases, but less than the rental rate (green line). As emphasized by Shimer (2005), since wage does not increase as much as the rental rate of labor, profits of labor firms increase more than the rental rate, which makes the number of vacancy postings respond strongly. Consequently, the unemployment rate declines sizably (Panel (c)).

Panel (d) shows output and its components. Output increases (blue line) as aggregate demand is stimulated, and both labor input (the unemployment rate goes down) and capital stock increase. Consumption increases for two reasons. First, there is a standard intertemporal substitution effect; a lower real interest rate lowers savings and brings forward consumption. Second, when a worker is hand-to-mouth, either because the worker has zero assets and thus is poor hand-to-mouth, or because the worker is hit by the wealthy hand-to-mouth shock and cannot use the whole savings for consumption even if the worker wants, a lower unemployment rate and a higher wage raise income, and thus consumption of the constrained worker. Investment also increases, adding capital stock supporting a higher path of output in the medium run.

6.2 Racial Differences of Monetary Transmission

Figure 4 shows how an accommodative monetary shock affects workers of different races differently. Panel (a) shows that the unemployment rate declines for all four racial groups, but the unemployment rate for Black and Hispanic workers declines more than that for White and Asian workers. Panel (b) shows the same thing differently. Panel (b) shows the unemployment rate gaps. For example, Black-White unemployment rate gap (yellow line) is the difference between the unemployment rate of Black workers and that of White workers, normalized such that the steady-state level is zero. Since the Black unemployment rate declines more than the White unemployment rate, the Black-White unemployment rate gap declines, by 0.34pp, on impact. As I discussed in the calibration section, Bartscher et al. (2021) estimate that, in the U.S., the Black-White unemployment rate gap shrinks by up to 0.34pp in response to a -25bp monetary policy shock. I use the elasticity of the matching function, α, to replicate the empirical response of the Black-White unemployment rate gap to an accommodative monetary policy shock. Panel (b) also show that the Hispanic-White unemployment rate gap responds to a similar magnitude as the Black-White unemployment rate gap, while Asian-White unemployment rate gap remains close to zero in response to an accommodative monetary shock, which implies that the responses of the unemployment rate are similar between White and Asian workers.

Why does the unemployment rate respond differently for difference races? And why does the Black-White unemployment rate gap shrink in response to an accommodative monetary policy shock? Since the job separation rate is type-specific but exogenously fixed, different responses of the unemployment rate for workers of different racial groups come from different responses of the job-finding rate. This is shown in Panel (c) of Figure 4. In response to a -25bp monetary policy shock, the job-finding rate for Black (yellow line) and Hispanic (pink line) workers increases about 11%, while the job-finding rate for White (blue line) and Asian



(a) Unemployment Rate

(b) Unemployment Rate Gap

(c) Job-Finding Rate

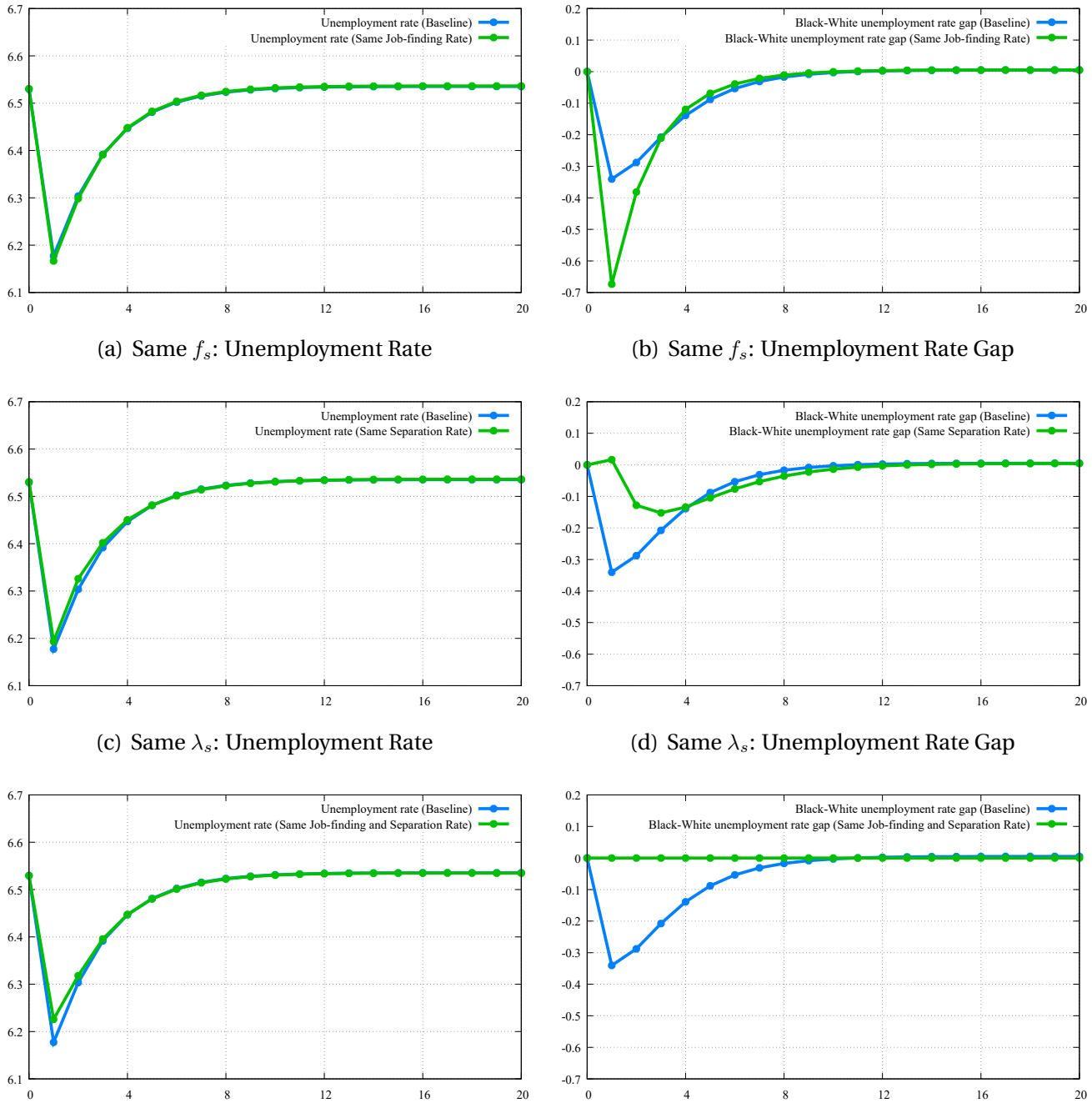
(d) Proportion of Hand-to-Mouth

(e) Income

(f) Consumption

Figure 4: Effects of Monetary Policy Shock: Racial Inequality

(green line) workers increases by less than 8%. These differences in the response of the job-finding rate yield the different responses of the unemployment rate. Why does the job-finding rate for Black and Hispanic workers rise more than that of White and Asian workers? In order to answer the question, I create and study three alternative model economies. The results of these alternative models are shown in Figure 5. In the first alternative model, I assume that the



(a) Same f_s: Unemployment Rate

(b) Same f_s: Unemployment Rate Gap

(c) Same λ_s: Unemployment Rate

(d) Same λ_s: Unemployment Rate Gap

(e) Same f_s and λ_s: Unemployment Rate

(f) Same f_s and λ_s: Unemployment Rate Gap

Figure 5: Decomposing Racial Differences in Labor Market Dynamics

job-finding rate is the same for all racial groups, and the common job-finding rate is set at the overall average job-finding rate in the baseline model.[8] Then, I adjust the race-specific separation rate so that the unemployment rate for each racial group is the same as in the baseline

[8] More precisely, I adjust κ_s for each s so that the targeted job-finding rate is achieved.

model. By construction, racial differences in the separation rate are larger in this alternative model. In this alternative model, the common job-finding rate is 63.4%. The separation rate is 3.6% for White workers, 3.3% for Asian workers, 5.7% for Hispanic workers, and 8.3% for Black workers. In the second alternative model, I do the opposite. I assume that the separation rate is the same for all races, which is fixed at the overall average separation rate in the baseline model. Then, I adjust the race-specific job-finding rate to make sure that the unemployment rate for each race is the same as in the baseline model. Specifically, in this alternative model, the common separation rate is 4.4%, and the job-finding rate is 77.0% for White workers, 86.1% for Asian workers, 49.4% for Hispanic workers, and 34.0% for Black workers. In the third, alternative model, I fix both the job-finding rate and the separation rate for four racial groups as equal to their respective overall average in the baseline model. Notice that the unemployment rate is equal to the overall unemployment rate in the baseline model for all racial groups in this alternative model, by construction.

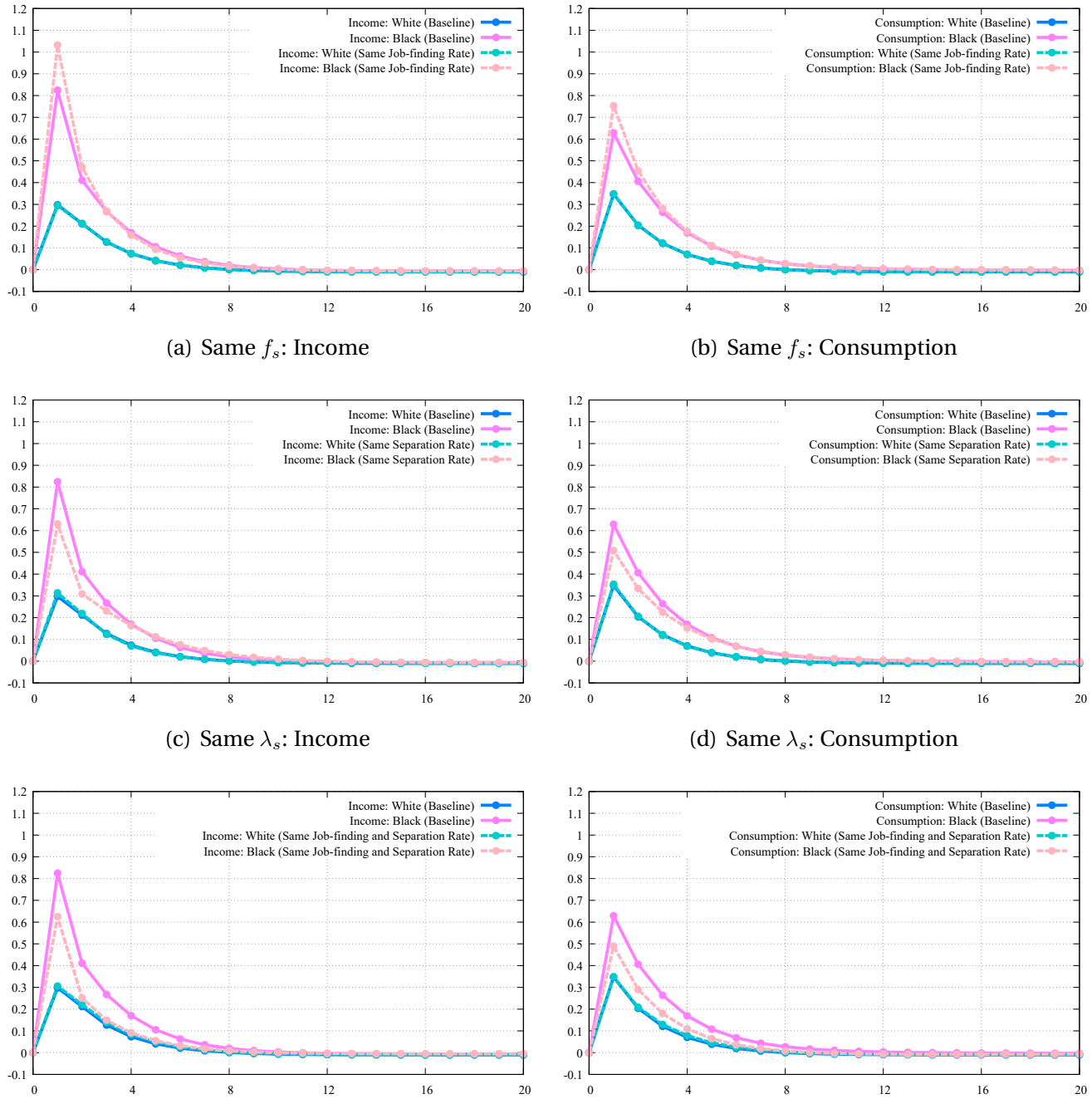
The overall unemployment rate in response to the -25bp accommodative monetary policy shock is shown in Panel (a) (the model with the same job-finding rate), (c) (the model with the same separation rate), and (e) (the model with the same job-finding and separation rate) of Figure 5. The Black-White unemployment rate gap in response to the -25bp accommodative monetary policy shock is shown in Panel (b) (same job-finding rate), Panel (d) (same separation rate), and Panel (e) (same job-finding and separation rate). In all panels, the responses of the alternative models are shown in green. The responses of the baseline model are also shown, in blue, for comparison. According to the Panels (a), (c), and (e), we can see that the response of the overall unemployment rate is similar in the alternative models to the response in the baseline model, with a slightly weaker impulse response in the unemployment rate in the model in which both the job-finding rate and the separation rate are set the same across all racial groups. However, in Panels (b) and (d), we can see that the Black-White unemployment rate gap responds more strongly in the model with the same job-finding rate (Panel (b)), and more weakly in the model with the same separation rate (Panel (d)). Put differently, according to Panel (b), a higher separation rate for Black workers than White workers generates stronger response of the Black unemployment rate than the White one, and thus the strong response of the Black-White unemployment rate gap, in response to the accommodative monetary policy shock. The intuition is the following. For Black workers, for whom the separation rate is high, a temporary increase in the rental rate of labor (which is induced by the accommodative monetary policy shock) affects the value of the labor firm matched with a Black worker more strongly, since labor productivity is higher for a larger proportion of expected duration of the match. Therefore, more vacancies are posted in the labor market for Black workers than that for White workers, and the Black-White unemployment rate gap shrinks. On the other hand, in Panel (d), the unemployment rate gap does not shrink on impact, because a match with a Black worker and a match with a White worker are affected by a temporary increase in the rental rate of labor similarly, even though the job-finding rate for White workers is higher, and thus the job-finding rate responds similarly. The unemployment rate gap shrinks from the second period on after the monetary policy shock because the same percentage point decline in the unemployment rate between White and Black workers means that the unemployment rate for White workers declines more. In the next period, the number of workers searching for a job among White workers are smaller, which makes the job-finding rate lower for White workers

compared with that for Black workers. Finally, Panel (f) shows that, when both the job-finding rate and the separation rate are the same across all racial groups, Black-White unemployment rate gap does not respond to an accommodative monetary policy shock; the unemployment rate of all racial groups exhibits the same impulse response dynamics.

Panel (d) of Figure 4 shows how the fraction of total, poor, and wealthy hand-to-mouth workers changes in response to the accommodative monetary shock. The fractions do not respond in the sizable manner. Panel (e) shows how average income for four racial groups changes in response to the accommodative monetary policy shock.[9] Panel (f) shows the response of average consumption. Panel (e) shows that Black and Hispanic average income increase more than Asian average income, and Asian income increases more than White average income. Since changes in wage w_t and dividends d_t affect workers of all races in the same way, the different response of average income must come from the differences in income composition across racial groups, and the different response of the unemployment rate across racial groups. Since the Black and Hispanic unemployment rate declines the most, and employed workers earn more than what unemployed workers receive (UI benefits), their average income increases the most among racial groups. Specifically, Black average income increases by 0.82% on impact, while the White average income increases only by 0.30%. In other words, the average income among Black workers increases about 2.8 times more than that of White workers. Panel (f) shows the same ordering for consumption. For example, Black average consumption increases more (0.63%) than that of White workers (0.35%), but the difference is smaller than that of income. This is because of consumption smoothing. Black workers spread the additional income gain over long period of time, to achieve inter-temporal consumption smoothing.

Figure 6 show how average income and consumption for Black and White workers respond differently to an accommodative monetary policy shock, in the baseline model and three alternative models discussed above. Panels (a), (c), and (e) show how average income for Black and White responds differently, while Panels (b), (d), and (f) are associated with average consumption of Black and White workers. As discussed above, the unemployment rate for Black workers declines more, compared with White workers, in the alternative model with the same job-finding rate (Panels (a) and (b)). Therefore, average income of Black workers increases more in the alternative model, compared with White workers (Panel (a)). Again, consumption response is muted compared with income response, but average consumption among Black workers increases more in the alternative model with the same job-finding rate than in the baseline model (Panel (b)). The opposite happens in the alternative model with the same separation rate (Panels (c) and (d)). Since the Black-White unemployment rate gap shrinks less than in the baseline model, average income of Black workers responds less strongly in the alternative model (Panel (c)). Black average consumption also increases less in response to the accommodative monetary policy shock in the alternative model than in the baseline model (Panel (d)). When Black and White workers face the same unemployment risk (Panels (e) and (f)), Black average income and consumption respond more weakly than in the baseline model, but Black average income and consumption still increase more than White counterparts. These are not due to the larger decline in the unemployment rate among Black workers. The response of average income of Black workers is stronger than that for White workers be-

[9] Income does not include capital gain, i.e., change in p_t^a.



(a) Same f_s: Income

(b) Same f_s: Consumption

(c) Same λ_s: Income

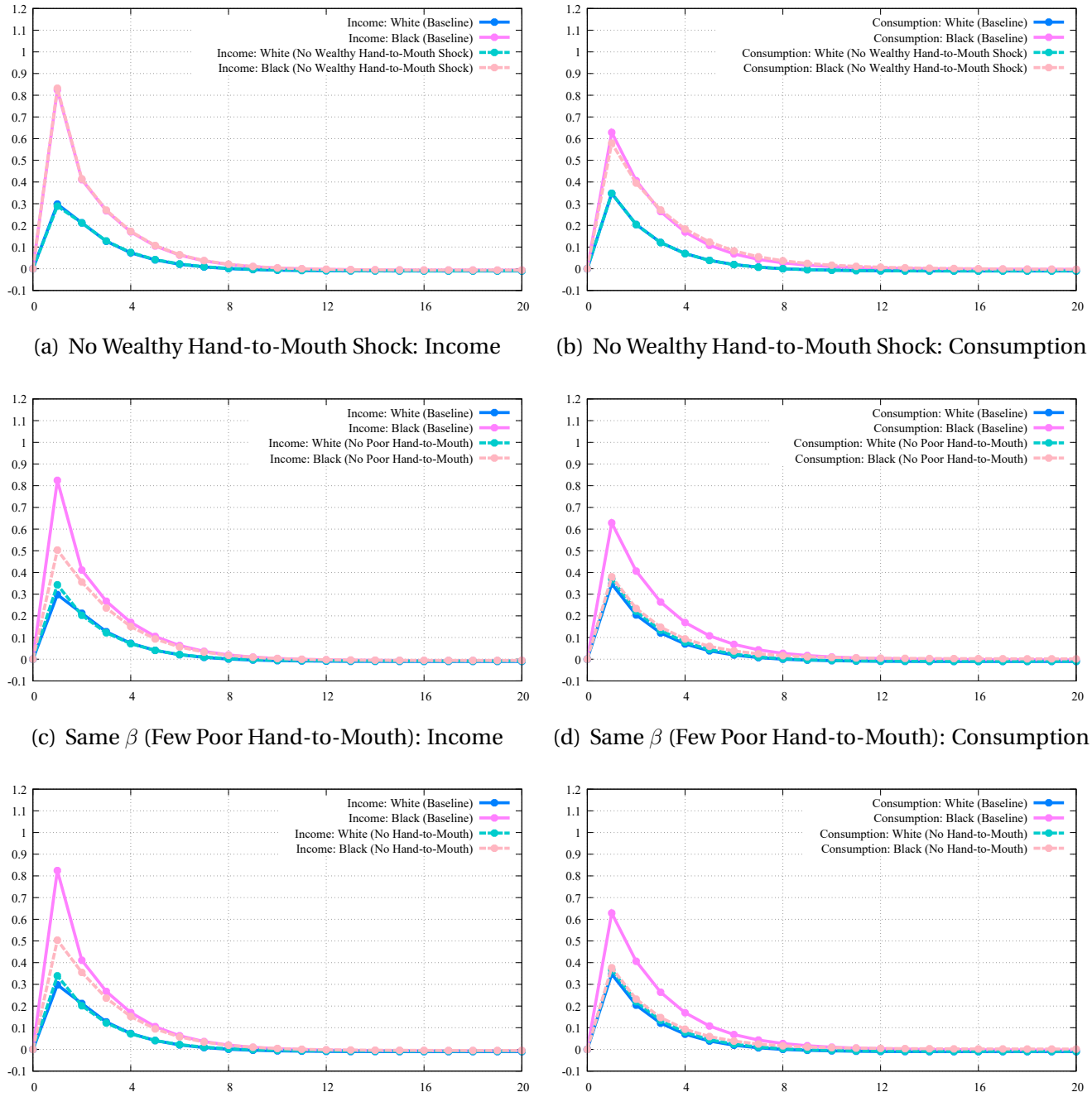
(d) Same λ_s: Consumption

(e) Same f_s and λ_s: Income

(f) Same f_s and λ_s: Consumption

Figure 6: Labor Market Dynamics and Consumption for Black and White

cause of income composition. Since Black workers rely more on labor income than financial income compared with White workers, even the same change in the unemployment rate and wage has a larger impact to total income of Black workers than White workers, who rely more on financial income, which responds more weakly. Moreover, the differences in the response of average consumption are also due to different fractions of hand-to-mouth. Since more Black



(a) No Wealthy Hand-to-Mouth Shock: Income

(b) No Wealthy Hand-to-Mouth Shock: Consumption

(c) Same β (Few Poor Hand-to-Mouth): Income

(d) Same β (Few Poor Hand-to-Mouth): Consumption

(e) No Hand-to-Mouth: Income

(f) No Hand-to-Mouth: Consumption

Figure 7: Hand-to-Mouth and Consumption for Black and White

workers are hand-to-mouth, either wealthy one or poor one, changes in income more directly affect consumption for Black workers.

Figure 7 shows how two types of hand-to-mouth (poor and wealthy) introduced to the model generate racial differences in income and consumption response to an accommodative mone-

tary policy shock. Specifically, I construct three alternative model economies. In the first (Panels (a) and (b)), I turn off the wealthy hand-to-mouth shock, but leave poor hand-to-mouth as in the baseline model. In the second alternative model (Panels (c) and (d)), β_s is set the same for all racial groups, and the common β_s is calibrated such that the capital-output ratio is three in the steady state. In other words, the discount factor for racial minorities are not separately calibrated to generate a larger fraction of hand-to-mouth workers. Although there are still a small proportion of poor hand-to-mouth workers in each racial group (0.3%), this model can be considered as the one in which there are virtually no poor hand-to-mouth workers among any racial group. The third alternative model (Panels (e) and (f)) combines the two features, and basically can be considered as the model without wealthy or poor hand-to-mouth. For each model, the left panel compares average income of White and Black workers, while the right panel compares average consumption of the two. The results for the alternative models are shown in light-colored broken line, while average income or consumption in the baseline model is shown in darker-colored solid line. Panels (a) and (b) show that, turning off wealthy hand-to-mouth does not change average income or wealth of White or Black workers in a sizable manner. The only small discernible difference is that the response of average consumption of Black workers to an accommodative monetary shock declines slightly. This is because a larger fraction of wealthy hand-to-mouth workers among Blacks makes the consumption response in the baseline model larger. Panel (c) shows that average income of Black workers responds to an accommodative monetary shock less strongly if there are no poor hand-to-mouth. This is because of the income composition effect; when β is not calibrated to be lower for minority groups, they hold more assets in general, and the positive effects to *labor income* from the rate cut (through a lower unemployment rate and a higher wage) have smaller impact to *total income*, which also includes *financial income*. Besides, panel (d) shows that, if there are virtually no poor hand-to-mouth workers among Blacks, the response of average consumption among Black workers become almost identical to that of White workers. In other words, having a significantly more poor hand-to-mouth among Black workers is crucial in generating a significantly stronger consumption response of Black workers compared with White ones. Not surprisingly, Panels (e) and (f) show that, if both wealthy and poor hand-to-mouth are eliminated from the baseline model, the stronger response of average consumption among Black workers than White ones, to an accommodative monetary shock, almost disappears.

6.3 Welfare Effects of an Accommodative Monetary Policy Shock

This section investigates welfare consequences of a -25bp monetary policy shock for different racial groups. Table 7 summarizes the results. Specifically, the table compares welfare effects between the baseline model and six alternative models which are already analyzed above. The first three alternative models are used to investigate the importance of racial heterogeneity in labor market risks. In the first alternative model, I set the job-finding rate the same across all racial groups, and re-calibrate the type-dependent separation rate so that the unemployment rate for each racial group is the same as in the baseline. In the second alternative model, I set the separation rate the same for all racial groups, and re-calibrate the type-dependent job-finding rate. In the third model, I set both the job-finding rate and the separation rate the same across all racial groups. The remaining three alternative models are associated with hand-to-mouth. In the first of the three, I turn off wealthy hand-to-mouth shock. In the second, I set

Table 7: Heterogeneous Welfare Effects of Accommodative Monetary Shock

	Overall	White	Asian	Hispanic	Black
% Change in Consumption					
Baseline Model	0.401	0.347	0.460	0.633	0.629
Model with Same f_s	0.405	0.347	0.447	0.602	0.753
Model with Same λ_s	0.391	0.353	0.503	0.522	0.508
Model with Same f_s and λ_s	0.383	0.348	0.486	0.500	0.489
Model without Wealthy Hand-to-Mouth	0.395	0.347	0.427	0.629	0.579
Model without Poor Hand-to-Mouth	0.368	0.367	0.366	0.372	0.368
Model without Hand-to-Mouth	0.371	0.370	0.370	0.375	0.380
% Change in Welfare (in CEV)					
Baseline	0.043	0.015	0.108	0.292	0.313
Model with Same f_s	0.045	0.014	0.098	0.283	0.384
Model with Same λ_s	0.037	0.015	0.121	0.234	0.225
Model with Same f_s and λ_s	0.034	0.016	0.140	0.202	0.165
Model without Wealthy Hand-to-Mouth	0.043	0.016	0.074	0.184	0.182
Model without Poor Hand-to-Mouth	0.026	0.021	0.020	0.031	0.039
Model without Hand-to-Mouth	0.023	0.020	0.019	0.027	0.033

Note: In response to -25bp monetary policy shock. "% Change in Consumption" shows the largest response of average consumption, which happens in the first period after the shock in all models.

the discount factor the same across all racial groups, which implies that minority groups do not have a large number of poor hand-to-mouth. This is used to investigate the importance of poor hand-to-mouth. Finally, in the last model, both wealthy and poor hand-to-mouth are eliminated from the model. The top panel of Table 7 shows the maximum consumption response in percent to the accommodative monetary policy shock. Note that the maximum response occurs in the first period right after the shock in all experiments. The second panel shows the welfare effects of the accommodative monetary shock, in consumption equivalence variations (CEV).

In the baseline model (first row in each panel), overall average consumption rises by 0.40% right after a -25bp monetary policy shock, and workers on average gain equivalent of 0.04% of consumption every period. White workers enjoy a smaller welfare gain. As shown in the previous section, average consumption of White workers increases by 0.35%, and their welfare gain is 0.015% of flow consumption. On the other hand, minority workers gain significantly more. Average consumption of Black workers rises by 0.63% at peak, and their welfare gain is 0.313%, 21 times larger than that of White workers. Hispanic workers' average consumption increases by 0.63% as well, and their welfare gain is 0.29%, almost 20 times the welfare gain of White workers. Average consumption of Asian workers increases 0.46%, and their welfare gain is 0.11%. Since labor market risks of Asian workers are similar to White workers, but their discount factor is set to match the fraction of poor hand-to-mouth, while the discount factor of White workers is not used to match the fraction of poor hand-to-mouth, the difference in the welfare gains between Asian and White workers suggests that poor hand-to-mouth is

important in the determination of the welfare gains.

How important are racial differences in labor market risks? The second to fourth rows in each panel provide answers to this question. If the job-finding rate is fixed (second row), consumption response of Black workers is higher, at 0.75%, compared with 0.63% in the baseline model. This is consistent with the stronger response of Black-White unemployment rate gap in the model. As White workers' unemployment rate response does not change in this alternative model, consumption response of White workers remains the same. Consequently, while the welfare effect for White workers is virtually the same, the welfare effect of a rate cut for Black workers increases even more, from 0.31% to 0.38%. In the model with the common job-finding rate, the welfare gain among Black workers is 27 times larger than White workers. Consumption response and the welfare gain from the rate cut among Asian and Hispanic workers do not change significantly from the baseline model. If, instead, the separation rate is fixed the same, and the job-finding rate is re-calibrated, the Black-White unemployment rate gap responds less strongly than in the baseline model. Consistently, the consumption response of Black workers is smaller, at 0.51%. The welfare gain by Black workers also shrinks, from 0.31% of flow consumption in the baseline model to 0.23%. However, Black workers still gain 15 times more than White workers from the rate cut. Consumption response of Hispanic workers also gets weaker, from 0.63% in the baseline model to 0.52% in the model with the common separation rate. Welfare gain for Hispanic workers also gets smaller, from 0.29% in the baseline to 0.23%. If both the job-finding rate and the separation rate are both set the same, the consumption response of Black workers (0.49%) becomes even close to that of White workers (0.35%). The welfare gain of Black workers from the accommodative monetary policy shock shrinks by almost half, to 0.17%. The race-specific productivity (η_s) is still in the model, but it turns out that it does not make a big difference in terms of welfare effects, and the results associated with the effects of η_s are omitted. Consumption response of Hispanic workers also weakens, to 0.50%, and the welfare gain also shrinks, to 0.20%. For Asian workers, both consumption response (from 0.46% to 0.49%) and the welfare gain (from 0.11% to 0.14%) increase, because the labor market risks for Asian workers gets larger when both the job-finding rate and the separation rate are set to their overall average values. In sum, even if labor market risks are set the same across racial groups, Black and Hispanic workers enjoy a significantly larger welfare gain from a rate cut because a larger fraction of them are hand-to-mouth, and thus benefit more from improved labor market conditions thanks to an accommodative monetary policy shock.

The last three alternative models (fifth to seventh rows) are used to investigate how hand-to-mouth affects the racial differences in the welfare effect of the accommodative monetary policy shock. Without the wealthy hand-to-mouth shock (fifth row), response of consumption to a rate cut becomes smaller for all minority workers. Consumption increase by 0.58% among Black workers, instead of 0.63% in the baseline. Consumption response gets small for Asian workers, from 0.46% to 0.42%, but the consumption response is virtually unchanged among Hispanic workers. The welfare gain from the accommodative monetary shock also shrinks for minority workers, but the size of the decline seems larger than implied by changes in consumption response. For Black workers, the welfare gain shrinks from 0.31% of flow consumption to 0.18%. For Hispanic workers, the gain declines from 0.29% to 0.18%.. For Asian workers, the welfare gains decreases from 0.11% to 0.07%. The role of poor hand-to-mouth is more important for welfare (sixth row). Consumption response to a rate cut declines from 0.63% to

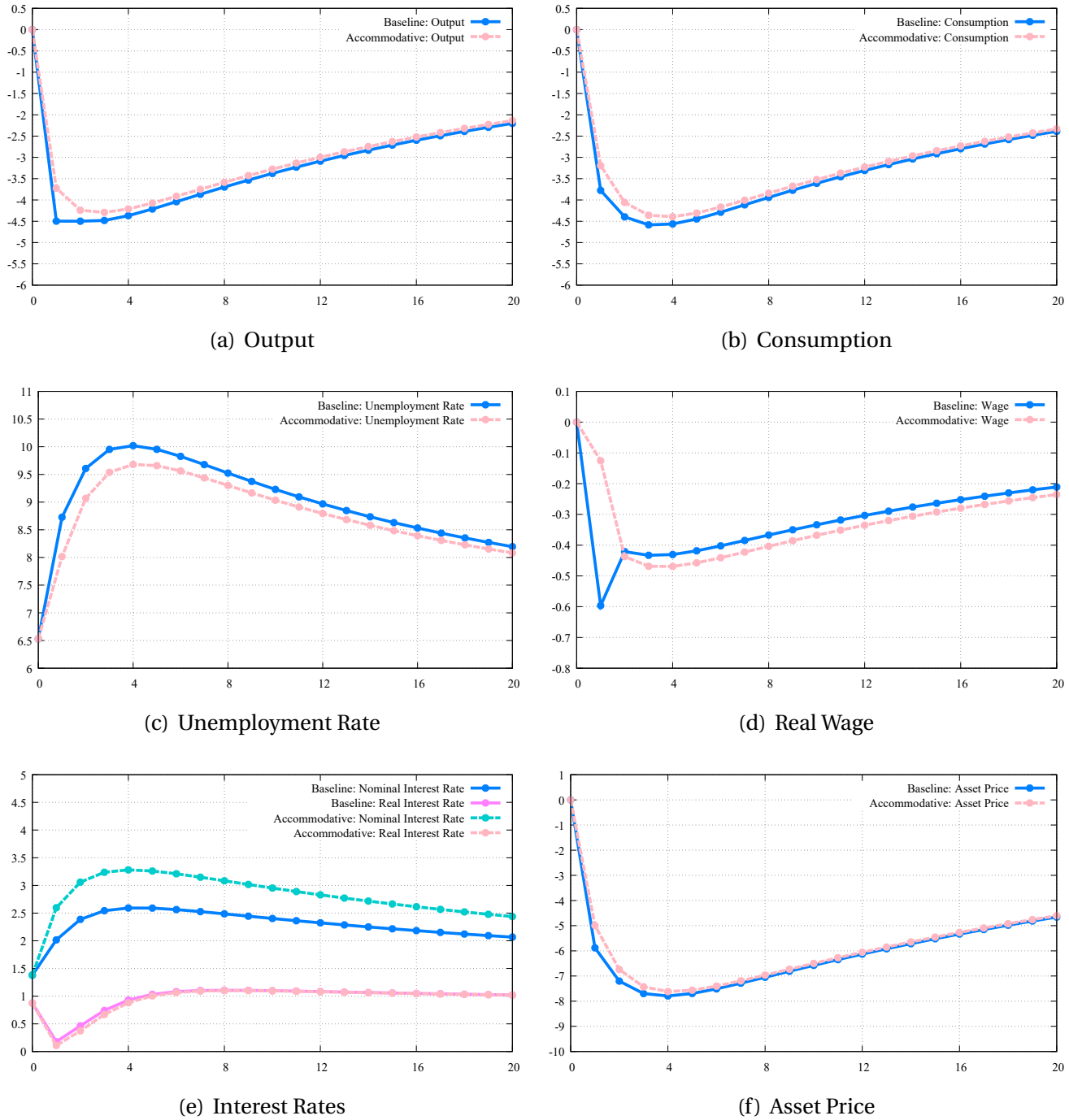
0.37% among Black and Hispanic workers. Consumption gain among Asian workers decreases from 0.46% to 0.37%. Consistent with the significantly smaller gain in consumption, the size of the welfare gain shrinks significantly for minority groups. For Black workers, the welfare gain from the rate cut drops to 1/8, from 0.31% to 0.04%. For Hispanic workers, the welfare gain in the model without poor hand-to-mouth is 0.03%, about 1/10 of 0.29% in the baseline model. For Asian workers, the welfare gain shrinks from 0.11% to 0.02%. These numbers confirm that the strong welfare effects for minority racial groups from an accommodative monetary policy shock crucially depends on the larger poor hand-to-mouth among them. If both wealthy and poor hand-to-mouth are turned off, consumption response to the rate cut for minority groups is similar to the model without poor hand-to-mouth, but the welfare gains get even smaller with both types of hand-to-mouth turned off. For Black workers, the welfare gain from the rate cut becomes 0.03%, which is close to 1/10 of the welfare gain in the baseline model. For Hispanic workers, the welfare gain drops to 0.03%, which is almost 1/11 of the welfare gain in the baseline model. Welfare gain among Asian workers also drops, from 0.11% to 0.02%. Overall, the welfare gain from the -25bp monetary policy shock declines from 0.04% in the baseline model to 0.02% in the model without wealthy and poor hand-to-mouth. Notice that, without wealthy and poor hand-to-mouth, minority workers gain more than White workers from the rate cut. Black and Hispanic workers gain 0.03% while White workers gain 0.02%. This is because minority workers, especially Hispanic and Black workers, gain from the accommodative monetary policy shock partly because they gain more from the mitigation of higher labor market risks that they are facing.

7 Recession, Monetary Policy Rule, and Racial Inequality

This section investigates the role of monetary policy in affecting different racial groups in the face of a large recession. For transparency, I assume that a large unexpected negative shock to TFP causes a recession, and the size of the TFP shock is calibrated such that the overall unemployment rate reaches 10% at its peak in the baseline model, which is what happened to the unemployment rate during the Great Recession. This approach yields the TFP shock of -3.2%. I will compare the results of the baseline model in the face of this "Great Recession" and those of an alternative model in which the Taylor response parameter to output is twice as large ($\phi_y = 0.250$) as the baseline ($\phi_y = 0.125$). I call this monetary policy regime as accommodative or dovish monetary policy rule. The main goal of this section is to unveil how workers of different races are differently affected by these monetary policy rules during the Great Recession in the model.

7.1 Aggregate Dynamics and Monetary Policy Rule

Figure 8 shows aggregate dynamics of the baseline model economy upon a large (-3.2%) negative TFP shock (the Great Recession shock). Each panel shows both the dynamics of the baseline model with $\phi_y = 0.125$ and the dynamics of the model in which the monetary authority follows a more accommodative ($\phi_y = 0.250$) monetary policy rule. According to the baseline model (shown in solid line), output declines by 4.5%, and aggregate consumption drops by 3.8% upon impact (Panels (a) and (b)). The overall unemployment rate gradually goes up, to reach 10.0% in the fifth quarter after the shock (Panel (c)). Real wage declines by



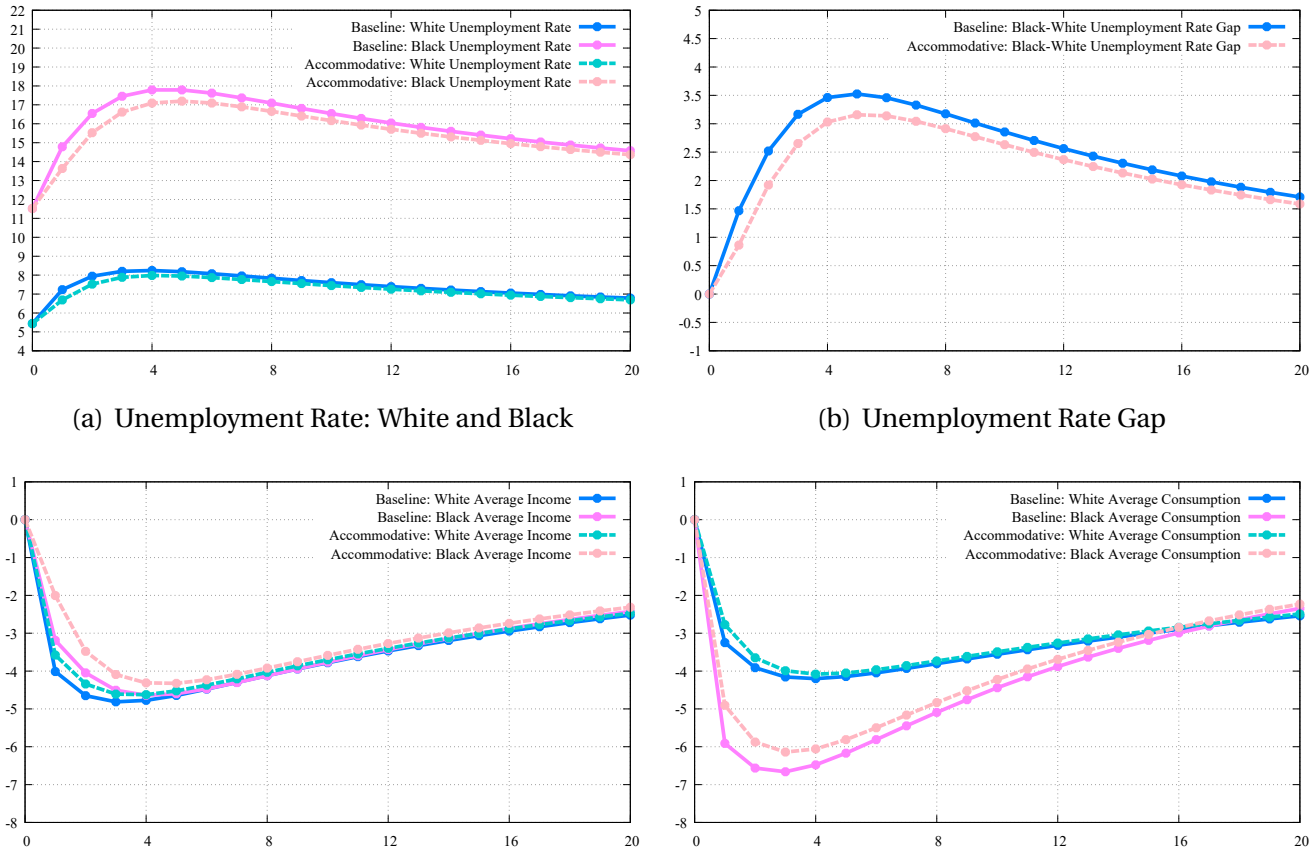
(a) Output (b) Consumption

(c) Unemployment Rate (d) Real Wage

(e) Interest Rates (f) Asset Price

Figure 8: Aggregate Implications of Different Monetary Policy Rules during Recession

0.6% (Panel (d)). Both works to lower labor income during this Great Recession scenario. In the financial market, although nominal interest rate goes up, in response to inflation, but real interest rate, which is the key for macroeconomic effects, declines, from 0.9% to 0.02% upon impact, before gradually reverting. As firms' profits decline in the near future, the asset price drops, by 5.9% upon impact, and by 7.8% at its trough.



(a) Unemployment Rate: White and Black

(b) Unemployment Rate Gap

(c) Average Income: White and Black

(d) Average Consumption: White and Black

Figure 9: Racial Implications of Different Monetary Policy Rules during Recession

Not surprisingly, under a more accommodative monetary policy rule (shown in broken line), the economy is stimulated and the severity of the recession caused by a large negative TFP shock is mitigated. The nominal interest rate is lower than in the baseline, which induces a lower path of real interest rate (Panel (e)). Consequently, the same negative TFP shock creates a smaller decline of overall economic activity. Output declines by 3.7% instead of 4.5% on impact (Panel (a)), and consumption declines by 4.1% instead of 4.4% (Panel (b)). The overall unemployment rate rises, but less so, and reaches 9.7% at its peak, a 0.3pp lower than in the baseline (Panel (c)). The initial drop in wages are significantly mitigated under the accommodative monetary policy rule (Panel (d)). The asset price declines, but less so (Panel (f)). The asset price declines by 5.0% on impact, and by 7.6% at its trough.

7.2 Racial Differences during Recession

This section looks at how accommodative monetary policy in a recession benefits workers of different races differently. Figure 9 shows how Black and White workers are affected by the recession under different monetary policy rules, in terms of the unemployment rate (Panels (a) and (b)), average income (Panel (c)), and average consumption (Panel (d)). There are three

Table 8: Welfare Loss from Recession under Alternative Monetary Policy Rules

	Overall	White	Asian	Hispanic	Black
Baseline Model					
Baseline Monetary Policy	–2.38	–2.02	–3.39	–5.19	–5.76
Accommodative Monetary Policy	–2.24	–1.94	–3.11	–4.61	–5.16
Model with the Same Job-Finding and Separation Rate					
Baseline Monetary Policy	–2.38	–2.17	–3.98	–3.97	–3.97
Accommodative Monetary Policy	–2.25	–2.08	–3.63	–3.57	–3.61
Model with No Hand-to-Mouth					
Baseline Monetary Policy	–2.19	–1.97	–1.90	–2.39	–2.85
Accommodative Monetary Policy	–2.08	–1.87	–1.81	–2.26	–2.68

Note: A 3.2% negative TFP shock is assumed to cause a recession with a similar magnitude as the Great Recession. The welfare numbers are in percentage consumption equivalence variation (CEV in %), relative to the steady-state welfare.

takeaways. First, more accommodative monetary policy rule not only makes the unemployment rate rise less in a recession, but make the Black unemployment rate rise less relative to the White one (Panel (a)). When the overall unemployment rate hits its peak at 10.0% in the baseline model, the Black unemployment rate is 17.8%, and White unemployment rate is 8.2%. Under the more accommodative monetary policy rule, the overall unemployment rate rises to 9.7%, 0.3pp lower than under the baseline monetary policy rule. Under the same policy rule, the Black unemployment rate peaks at 17.1%, or 0.7pp lower, while the white unemployment rate peaks at 8.0%, which is 0.2pp lower. Panel (b) shows how the Black-White unemployment rate gap moves in a recession under two monetary policy rules. Under the baseline monetary policy rule, the unemployment rate gap rises by 3.5pp, while it rise only by 3.1pp under the more accommodative monetary policy rule. Second, both White and Black workers benefit from the more accommodative monetary policy during a recession as their average income declines less, the difference is larger for Black workers (Panel (c)). Average income of White workers drops by as much as 4.81% during the recession under the baseline monetary policy rule, but 4.62% under the accommodative monetary policy rule, a 0.19pp difference. For Black workers, their average income drops by 4.64% under the baseline monetary policy, but only by 4.32% under the accommodative monetary policy rule, a 0.32pp difference. Third, similar to average income, Black workers benefit more from the more accommodative monetary policy rule in terms of their average consumption, compared with White workers. Average consumption of Black workers declines by 6.14% under the accommodative monetary policy rule, which is 0.52pp smaller than under the baseline monetary policy rule (6.66%). Meanwhile, average consumption of White workers drops by 4.20% in the baseline model and by 4.08% under the accommodative monetary policy rule, a smaller (0.12pp) decline compared with Black workers.

7.3 Welfare Implications

Finally, this section studies the diverse welfare effects of an accommodative monetary policy rule for different racial groups. Table 8 summarizes the results. The first two rows compare the welfare effects, measured in percentage change in consumption equivalent variations compared with the steady-state welfare, of a recession caused by 3.2% drop in TFP (the "Great Recession" shock), in the baseline model with $\phi_y = 0.125$ and in an alternative model with $\phi_y = 0.250$. The next two rows show the same for the model in which the job-finding rate and the separation rate are set the same for all racial groups. The proportion of hand-to-mouth for each racial group is the same as in the baseline model. The last two rows show the same for a model without poor or wealthy hand-to-mouth. Differences in labor market risks across racial groups remain the same.

There are four takeaways from Table 8. First, minority groups, especially Black and Hispanic workers, suffer significantly more from the Great Recession shock. White workers on average suffer 2.0% equivalent of flow consumption (first row), while Asian (3.4%), Hispanic (5.2%) and Black (5.8%) workers suffer more. Second, the larger welfare loss for minority groups is caused by the combination of higher labor market risks that they are facing, in the case of Hispanic and Black workers, and larger proportions of poor and wealthy hand-to-mouth workers. When the labor market risks are set the same across racial groups, the welfare loss by Hispanic (4.0%) and Black (4.0%) workers decline from the baseline model (third row). If hand-to-mouth is turned off, the welfare loss becomes even smaller, at 1.9% for Asians, 2.4% for Hispanics, and 2.9% for Black workers (fifth row). Third, all racial groups benefit from the more accommodative monetary policy rule mitigating the negative effects of the Great Recession shock, but the mitigation is greater for minority groups. In the baseline model, Black workers' welfare loss from the Great Recession shock shrinks from 5.8% to 5.2% and Hispanic workers' welfare loss declines from 5.2% to 4.6% under the more accommodative monetary policy (second row), while White workers' welfare loss shrinks less, from 2.0% to 1.9%. Fourth, both larger labor market risks and larger proportions of hand-to-mouth among Black and Hispanic workers make the welfare gains (smaller welfare loss) from the more accommodative monetary policy, but hand-to-mouth seems more important in creating larger welfare gains for minority groups from a more accommodative monetary policy rule. When labor market risks are set the same across racial groups (fourth row), welfare loss of White workers from the Great Recession shock shrinks by 0.09pp under the more accommodative monetary policy rule, compared with 0.08pp in the baseline. For Black workers, the welfare loss shrinks by 0.36pp (from 3.97% to 3.61%) in the alternative mode, compared with 0.60pp in the baseline model. If hand-to-mouth is turned off, again, the welfare loss for White workers shrink similarly with the more accommodative monetary policy (0.10pp), but the Black workers' welfare loss shrinks significantly less, by 0.17pp (from 2.85% to 2.67%).

8 Racial Inequality over the Business Cycle

This section studies how different monetary policy rules affect workers of different racial groups over the normal business cycle, unlike a large recession which is studied in the previous section. I start by looking at aggregate dynamics (Section 8.1). Then I look at how business cycles

Table 9: Comparison of Business Cycle Statistics: U.S. Data and Baseline Model

	U.S. Data			Baseline Model		
	S.D.(%)	Rel S.D.	Corr(Y)	S.D.(%)	Rel S.D.	Corr(Y)
Output	1.232	1.000	1.000	1.240	1.000	1.000
Consumption	0.951	0.772	0.863	0.969	0.781	0.866
Investment	6.029	4.892	0.900	2.673	2.156	0.762
Utilization	2.801	2.273	0.824	2.283	1.840	0.727
Real wage	0.596	0.484	–0.333	0.427	0.344	0.751
Inflation	0.319	0.259	0.314	1.279	1.032	0.311
UR (Overall)	10.756	8.729	–0.870	11.916	9.608	–0.539
UR (White)	11.246	9.126	–0.872	11.274	9.089	–0.544
UR (Hispanic)	11.825	9.596	–0.801	13.938	11.238	–0.541
UR (Black)	9.552	7.752	–0.773	12.071	9.733	–0.518

Note: All U.S. data are quarterly, from 1980:1 to 2019:4. Output is real GDP, consumption is real PCE, and investment is real gross private domestic investment, all of which are from the BEA. Inflation is headline PCE inflation rate from the BEA. Utilization is capacity utilization of all industries, from the FRB. Real wage is real median usual weekly earnings, from the BLS. UR is the unemployment rate, also from the BLS. All series of the data and the model are in log and detrended using the Hodrick-Prescott filter with the smoothing parameter of 1600.

are different across racial groups (Section 8.2). Finally, I investigate heterogeneous effects of different monetary policy rules across racial groups (Section 8.3). In a future version, I want to include welfare analysis, but so far I cannot think of a way to compute welfare under different monetary policy rules. Even with many and long simulations, the welfare numbers exhibit variances which are too high.

8.1 Aggregate Business Cycle Dynamics

Table 9 compares business cycle statistics between the U.S. economy (1980:1-2019:4) and the baseline model economy. The volatility of output in the model is close to the data counterpart by assumption; I use the standard deviation of two aggregate shocks (σ_z and σ_b) such that the volatility of output in the baseline model is close to the data, and the relative importance of the TFP shock and the MEI shock is close to what Justiniano et al. (2010) obtain with their estimated DSGE model. Specifically, in the baseline model, 24.3%, 16.0%, and 58.5% of output volatility is created by the TFP shock, the monetary policy shock, and the MEI shock, respectively. The volatility of aggregate consumption expenditures and its correlation with output are close to the data. I could use a quadratic investment adjustment cost to adjust investment (and thus consumption) volatility, but it turns out that the baseline model yields consumption volatility close to the data without it. Investment in the baseline model is less volatile (S.D. of 2.7%) than the data (6.0%). This is common when aggregate demand consist only of consumption and gross investment, and there is no inventory adjustments, government expenditures or imports and exports. The utilization rate in the model is slightly less volatile (2.3%) than in the data (2.8%). Real wage in the baseline model is as volatile as in the data. However, while

real wage is procyclical in the model (correlation with output of 0.75), it is countercyclical in the data (–0.33). This might be because I use real usual weekly earnings as the measure of real wage, or because the nominal wage rigidity in the model is not as strong as in the data. Inflation rate in the model (S.D. of 1.3%) is too volatile compared with the data (0.3%), although the model matches the weak procyclicality of the inflation rate in the data. Its correlation with output is 0.3% both in the data and in the baseline model.

The last four rows of Table 9 contains the overall unemployment rate, and the unemployment rate for White, Hispanic, and Black workers. As discussed in Section 2.1, the time series for the Asian unemployment rate is too short not to be biased by a small number of recent and deep recessions. As for the overall unemployment rate, the volatility in the model (11.3%) is slightly higher than the data (10.8%), but the model captures the fact that the unemployment rate is extremely volatile compared with output. Moreover, although the correlation between output and the unemployment rate in the model (–0.54) is slightly weaker than in the data (–0.87), the model captures the observed strong countercyclicality of the unemployment rate. Notice that the cyclical properties of the unemployment rate are not directly targeted when the model is calibrated. Three key parameters that are important in generating the large volatility of the unemployment rate are the parameter that guarantees small profits for labor firms (ω_0), the parameter that yields real wage rigidity (ω_1), and the parameter that controls the elasticity of vacancy posting (α). The first two parameters are calibrated to match the small profits of firms and the real wage elasticity, as in Hagedorn and Manovskii (2008), while the last parameter is calibrated to match the empirical response of the Black-White unemployment rate gap to a monetary policy shock (Bartscher et al. (2021)). This approach guarantees that the unemployment rate is generally volatile, but the fact that the volatility of the unemployment rate in the baseline model is close to the data is a success. Notice that, in the data, the unemployment rate volatility for all racial groups is bout 10 times larger than output volatility. This is because the unemployment rate is logged, and thus the volatility is relative to the level of the unemployment rate. In the baseline model, the unemployment rate for all racial groups is also almost 10 times larger than output volatility.

8.2 Business Cycle and Racial Inequality

Table 10 compares cyclical properties of the unemployment rate, average income, and average consumption of four racial groups, plus output, in the baseline model (first two columns), the model in which all racial groups face the same labor income risks (middle two columns), and the model without wealthy or poor hand-to-mouth (last two columns). There are four key takeaways. First, if there is no wealthy or poor hand-to-mouth, output volatility declines, from 1.24% in the baseline model to 1.14% (8.2% decline). As is known in the literature, hand-to-mouth is associated with a high marginal propensity to consume (MPC). Therefore, if there are no hand-to-mouth workers, the aggregate MPC is lower, and thus aggregate demand and output turn out to be less volatile. Second, the volatility of average income and average consumption for Hispanic and Black workers is lower if both the job-finding rate and the separation rate are set the same across racial groups. For Black workers, volatility of average income declines from 1.42% to 1.01%, and their average consumption volatility declines from 1.68% to 1.28%. For Hispanic workers, their average income volatility declines from 1.28% to 1.01%, and their

Table 10: Comparison of Business Cycle Statistics: Three Models

	Baseline		Same f_s and λ_s		No Hand-to-Mouth	
	S.D.(%)	Corr.	S.D.(%)	Corr.	S.D.(%)	Corr.
Output	1.240	1.000	1.227	1.000	1.139	1.000
UR (Overall)	11.916	–0.539	10.852	–0.544	11.331	–0.538
UR (White)	11.274	–0.544	10.852	–0.544	10.815	–0.543
UR (Asian)	11.296	–0.548	10.852	–0.544	10.861	–0.548
UR (Hispanic)	13.938	–0.541	10.852	–0.544	13.109	–0.536
UR (Black)	12.071	–0.518	10.852	–0.544	11.339	–0.514
Income (Overall)	0.969	0.866	0.952	0.858	0.871	0.822
Income (White)	0.951	0.778	0.988	0.778	0.824	0.809
Income (Asian)	0.937	0.962	1.030	0.962	0.802	0.807
Income (Hispanic)	1.278	0.959	1.005	0.958	1.019	0.866
Income (Black)	1.420	0.956	1.005	0.960	1.170	0.848
Consumption (Overall)	0.969	0.866	0.952	0.858	0.871	0.822
Consumption (White)	0.842	0.775	0.873	0.785	0.855	0.814
Consumption (Asian)	1.380	0.957	1.485	0.960	0.844	0.806
Consumption (Hispanic)	1.544	0.977	1.197	0.958	0.913	0.840
Consumption (Black)	1.679	0.960	1.282	0.955	0.987	0.866

Note: All series are in log and detrended using the Hodrick-Prescott filter with the smoothing parameter of 1600. The columns "S.D.(%)" contain the standard deviation in percent. The columns "Corr." contain the contemporaneous correlation with output.

consumption volatility goes down from 1.54%% to 1.20%. Not surprisingly, larger volatility of the unemployment rate for Hispanic and Black workers is responsible for the high volatility of their average income. And there are many hand-to-mouth workers among these racial minority groups, a lower income volatility yields a lower consumption volatility. Third, if there are no hand-to-mouth workers among minority groups, volatility of average income of all racial groups goes down, but average consumption volatility goes down significantly more. For Black workers, the volatility of average income goes down from 1.42% to 1.17%, but that of average consumption drops from 1.68% to 0.99%. For Hispanic workers, average income volatility decreases from 1.28% to 1.02%, but their average consumption volatility drops from 1.54% to 0.91%. Their average income volatility decreases because minority workers end up holding more assets, and enjoy higher financial income, which is more stable than labor income over the business cycle. On the other hand, their consumption volatility drops significantly because less of them are liquidity-constrained due to being either poor or wealthy hand-to-mouth.

8.3 Monetary Policy Rule and Racial Inequality

Table 11 compares volatility of variables of interest under the baseline monetary policy rule with $\phi_y = 0.125$ and the accommodative monetary policy rule with $\phi_y = 0.250$. The former is labeled as "Base" while the latter is labeled as "Dove" in the table. The columns labeled as $\Delta\%$ show percentage change in volatility between the two monetary policy rules. The table

Table 11: Cyclical Properties under Baseline and Accommodative Monetary Policy Rule

	Baseline			Same f_s and λ_s			No Hand-to-Mouth		
	Base	Dove	$\Delta\%$	Base	Dove	$\Delta\%$	Base	Dove	$\Delta\%$
Output	1.240	1.139	–8.2	1.227	1.127	–8.1	1.139	1.051	–7.7
UR (Overall)	11.916	10.723	–10.0	10.852	9.779	–9.9	11.331	10.261	–9.4
UR (White)	11.274	10.150	–10.0	10.852	9.779	–9.9	10.815	9.794	–9.4
UR (Asian)	11.296	10.161	–10.1	10.852	9.779	–9.9	10.861	9.827	–9.5
UR (Hispanic)	13.938	12.502	–10.3	10.852	9.779	–9.9	13.109	11.841	–9.7
UR (Black)	12.071	10.894	–9.8	10.852	9.779	–9.9	11.339	10.301	–9.2
Incm (Overall)	0.969	0.921	–4.9	0.952	0.907	–4.7	0.871	0.841	–3.5
Incm (White)	0.951	0.919	–3.4	0.988	0.953	–3.5	0.824	0.798	–3.1
Incm (Asian)	0.937	0.850	–9.2	1.030	0.936	–9.1	0.802	0.778	–3.0
Incm (Hispanic)	1.278	1.153	–9.8	1.005	0.911	–9.3	1.019	0.973	–4.5
Incm (Black)	1.420	1.289	–9.2	1.005	0.913	–9.2	1.170	1.112	–5.0
Cons (Overall)	0.969	0.921	–4.9	0.952	0.907	–4.7	0.871	0.841	–3.5
Cons (White)	0.842	0.820	–2.6	0.873	0.847	–2.9	0.855	0.827	–3.3
Cons (Asian)	1.380	1.269	–8.1	1.485	1.362	–8.3	0.844	0.818	–3.1
Cons (Hispanic)	1.544	1.401	–9.2	1.197	1.096	–8.4	0.913	0.876	–4.0
Cons (Black)	1.679	1.530	–8.9	1.282	1.178	–8.1	0.987	0.939	–4.8

Note: All series are in log and detrended using the Hodrick-Prescott filter with the smoothing parameter of 1600. "Base" columns contain volatility in percent under the baseline monetary policy rule ($\phi_y = 0.125$), while "Dove" columns contain volatility in percent under the accommodative monetary policy rule ($\phi_y = 0.250$). "$\Delta\%$" columns contain percentage change in volatility under the two monetary policy rules.

shows the comparison of volatility for three model economies: the baseline model (the first two columns), the model in which the job-finding rate and the separation rate are set the same across all racial groups (middle two columns), and the model without poor or wealthy hand-to-mouth (the last two columns). The numbers under the "Base" monetary policy rule are the same as those in Table 10.

Let me make five remarks. First, in all three model economies, under the accommodative monetary policy rule, volatility of output declines by about 8%, and volatility of the unemployment rate drops about 10%, but the size of the decline is slightly smaller in the model without hand-to-mouth. Output volatility drops by 8.2% in the baseline model under the accommodative monetary policy, but by 7.7% in the model without hand-to-mouth. This is because of the amplification of aggregate demand by hand-to-mouth. Second, in both the baseline model and the model without racial heterogeneity in labor market risks, the size of the decline in consumption volatility is smaller than the size of decline in income volatility for all racial groups. This is because workers use saving to smooth consumption even under the baseline monetary policy rule. Third, in both the baseline model and the model without racial heterogeneity in labor market risks, volatility of income and consumption for four racial groups declines similarly. The volatility of the overall average income declines by about 5%, and the volatility of income

among White workers decreases by about 3.5%. On the other hand, volatility of average income for all minority groups declines more than 9%. The difference in the response between the White and all minority groups suggest that how much the income volatility drops depend on the income composition; White workers experience a smaller decline in income volatility because they have more assets, and financial income associated with assets is less sensitive to the change in the monetary policy rule. In terms of the average consumption volatility, the overall consumption volatility declines about 5%, and the consumption volatility for White workers decreases by less than 3%, while the average consumption volatility declines more than 8% for all minority groups, in both model economies. Fourth, the changes in income volatility for four racial groups are different in the model with no hand-to-mouth workers. The income volatility for Hispanic (–4.5%) and Black (–5.0%) workers in the model without hand-to-mouth decline much less than in the baseline model, in which their average income volatility declines more than 9%. Again, this can be understood by income composition. In the economy without hand-to-mouth, minority workers hold more assets, and thus a larger fraction of their income is from financial income, which is less sensitive to the monetary policy rule. That's why the change in the monetary policy rule affects income volatility of minority workers less than in the baseline model. Finally, in the model without hand-to-mouth, consumption volatility for racial minorities declines less than in the baseline model. The average consumption volatility for Black workers declines by 4.8% and it declines 4.0% for Hispanic workers in the model without hand-to-mouth, compared with 8.9% for Black workers and 9.2% for Hispanic workers in the baseline model. There are two reasons. First, income is less volatile because of the difference in income composition I just discussed above. Second, workers in all racial minorities have more assets in the model without hand-to-mouth, and can use the assets to smooth consumption regardless of how accommodative monetary policy is. In other words, liquidity constraint is crucial in determining the consumption dynamics of racial minorities over the business cycle.

9 Earnings Loss upon Job Loss and Monetary Policy

One of the features of the model is that a worker which loses its job and becomes unemployed suffers a lower earnings in the future. This is motivated by the literature of earnings loss of displaced workers (Jacobson et al. (1993), Davis and Wachter (2011), Farber (2011)). The size of the earnings loss in the model is calibrated to be 10.96%, following Farber (2011). When earnings loss upon job loss is built into the model, accommodative monetary policy becomes more beneficial for minority workers which are more likely to lose a job and suffer the earnings loss. How important is this channel? In order to answer this question, I created an alternative model in which the channel of earnings loss upon job loss is turned off. Specifically, I set $\delta_p = 0$, leaving all other elements of the baseline model the same. Table 12 summarizes the results. The top half of the table contains results of the baseline model, which are discussed in the previous three sections. The bottom half of the table contains the same set of statistics in the alternative model without earnings loss.

The first two rows for each model show consumption and welfare effects of a -25bp accommodative monetary policy shock. Surprisingly, the consumption response to an accommodative monetary shock is larger in the model without earnings loss upon job loss, although an ac-

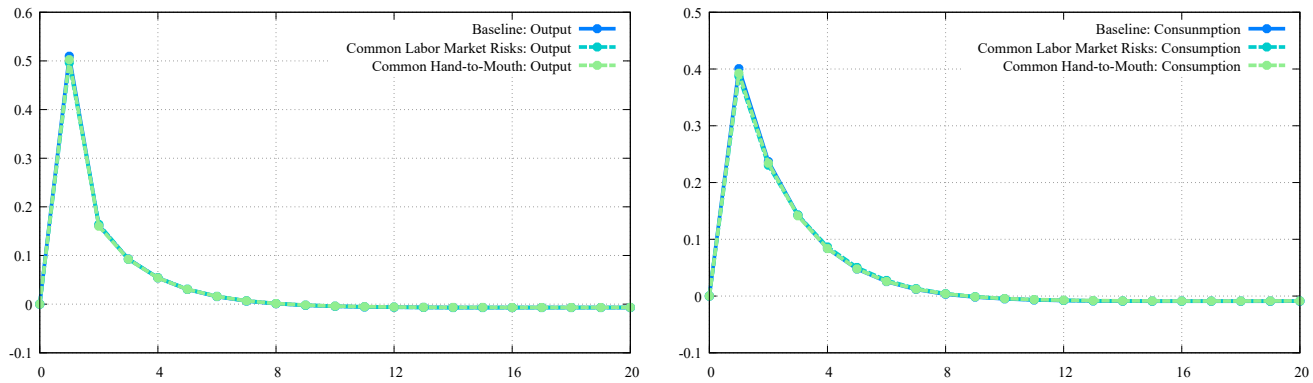
Table 12: Earnings Loss upon Job Loss and Effects of Monetary Policy

	Overall	White	Asian	Hispanic	Black
Baseline Model					
$\Delta\%$ in Cons after -25bp MP Shock	0.401	0.347	0.460	0.633	0.629
$\Delta\%$ in Welfare after -25bp MP Shock	0.043	0.015	0.108	0.292	0.313
$\Delta\%$ in Welfare of GR Shock under Baseline MP	–2.38	–2.02	–3.39	–5.19	–5.76
$\Delta\%$ in Welfare of GR Shock under Dovish MP	–2.24	–1.94	–3.11	–4.61	–5.16
$\Delta\%$ in S.D. of Avg Incm under Dovish MP	–4.91	–3.39	–9.24	–9.82	–9.24
$\Delta\%$ in S.D. of Avg Cons under Dovish MP	–4.91	–2.61	–8.06	–9.24	–8.90
Model without Earnings Loss upon Job Loss					
$\Delta\%$ in Cons after -25bp MP Shock	0.422	0.360	0.475	0.665	0.664
$\Delta\%$ in Welfare after -25bp MP Shock	0.039	0.014	0.093	0.259	0.276
$\Delta\%$ in Welfare of GR Shock under Baseline MP	–2.25	–1.94	–3.13	–4.71	–5.39
$\Delta\%$ in Welfare of GR Shock under $\phi_y = 0.250$	–2.12	–1.86	–2.87	–4.19	–4.82
$\Delta\%$ in S.D. of Avg Incm under Dovish MP	–5.24	–3.55	–9.39	–10.07	–9.50
$\Delta\%$ in S.D. of Avg Cons under Dovish MP	–5.24	–2.85	–8.12	–9.57	–9.18

Note: In the baseline model, a worker suffers a loss of productivity by $\delta_p = 10.96\%$ upon job loss, following Farber (2011). In the model shown in the second half of the table, δ_p is set 0%. "$\Delta\%$ Change in Cons" denotes the largest response of average consumption, which happens in the first period after the shock in all models. "$\Delta\%$ in Welfare" shows changes in welfare after the accommodative monetary shock, converted into CEV. "GR Shock" denotes a large negative TFP shock that mimics the Great Recession in magnitude. See Section 7 for more details. "Dovish MP" denotes the alternative monetary policy with $\phi_y = 0.250$ instead of its baseline value of $\phi_y = 0.125$. "S.D. of Avg Incm" and "S.D. of Avg Cons" are computed using simulations using the calibrated aggregate shocks. See Section 8 for more details.

commodative monetary policy shock lowers the risk of unemployment and the risk of earnings loss in the baseline model. However, as expected, the welfare gain from an accommodative monetary policy shock is smaller in the alternative model, exactly because there is no channel of lowering the probability of earnings loss upon job loss when the monetary authority lowers the policy rate. Not surprisingly, the difference in welfare gains is larger among Black (welfare gains decline from 0.31% to 0.28%) and Hispanic (2.9% to 2.6%) workers than with White workers (0.015% to 0.014%). In other words, an accommodative monetary policy shock is more beneficial for racial minorities as they are more likely to suffer from earnings loss upon job loss.

The third and fourth lines for each model in the table compare the welfare loss from a severe recession mimicking the Great Recession, under the baseline monetary policy rule ($\phi_y = 0.250$) and under a more accommodative monetary policy rule ($\phi_y = 0.250$). First, it is easy to see that the welfare loss for all racial groups are larger in the baseline model, as the earnings loss channel makes the recession more painful for the unemployed. Second, the differences in welfare under the two monetary policies are slightly smaller in the model without the earnings loss upon job loss. For example, the welfare loss shrinks by 0.60% for Black workers in the baseline model, but shrinks 0.57% in the model without the earnings loss. The overall welfare effects shrinks by 0.14% in the baseline model, and 0.13% in the alternative model without earnings loss. The differences are small partly because these numbers are average across all



(a) Output (b) Consumption

Figure 10: Racial Differences and Monetary Transmission

workers, majority of whom are employed, even among Blacks and Hispanics.

Finally, the last two rows for each model show that, under the more accommodative monetary policy rule, average income and average consumption volatility declines in both the baseline model and the model without the earnings loss. And the size of the decline is larger among Black and Hispanic workers, who face a larger unemployment risk and are more likely to be hand-to-mouth. Somewhat surprisingly, the size of decline in both average income and average consumption volatility is larger in the model without the earnings loss. There are less precautionary savings in the model without the earnings loss (β_s are calibrated to be higher), which makes income and consumption of workers to respond more to business cycles, and makes the effect of accommodative monetary policy rule stronger in lowering volatility over the business cycle.

10 Racial Differences and Monetary Transmission

Another interesting question one could ask is what are the implications of introducing racial inequality to monetary transmission. Figure 10 shows how impulse response of output (Panel (a)) and consumption (Panel (b)) are different between the baseline model, the model in which labor market characteristics are set the same across all racial groups, and the model in which all minority groups have the same hand-to-mouth characteristics. As we can see, the impulse responses are weaker in the two alternative models compared with the baseline model, but the differences are tiny. On the one hand, the existence of the subset of workers who both face higher labor market risks and are more likely to be liquidity constrained could make monetary transmission stronger. That's what we see in Figure 10. However, on the other hand, these workers are minority (small proportion), and have lower levels of income and consumption, which implies that their effects to aggregate dynamics are limited. Indeed, if the model is calibrated such that there are more hand-to-mouth among White workers, racial differences might dampen monetary transmission, as White workers who are majority face a smaller labor market risk. This discussion is reminiscent of the one inKrusell and Smith (1998). Implications of heterogeneity to aggregate dynamics are limited and the famous "approximate aggregation"

holds if workers which tend to be close to liquidity constraint and thus exhibit a higher MPC have lower income and consumption, and thus will not affect aggregate dynamics significantly.

11 Conclusion

This paper builds a heterogeneous-agent New-Keynesian (HANK) model with racial inequality in terms of labor market characteristics and wealth, and studies how monetary policy affects workers of difference races differently. Series of experiments highlight that the combination of a higher unemployment rate and a higher proportion of hand-to-mouth among Black and Hispanic workers is the key in shaping their larger welfare gains from accommodative monetary policy. Specifically, the welfare gain by Black workers from a rate cut is more than 20 times larger than that of White workers, and income and consumption volatility of Black workers declines three times more than that of White workers under a more accommodative monetary policy rule.

Going forward, I think this paper is the first step to understand how different racial groups are affected differently by monetary policy, and there are many other dimensions of racial differences that can be investigated in future research. Let me list five. First, as Bartscher et al. (2021) emphasize, White households invest more to assets whose prices increase more in response to an accommodative monetary policy shock. Although it is reasonable to think that welfare of White workers might not be significantly affected by temporary changes in asset prices, this channel could at least weaken the argument that Black and Hispanic workers benefit more from accommodative monetary policy. It is interesting to incorporate this channel into the model for formal comparison. Second, more broadly, introducing housing into the model is an interesting avenue to proceed, as housing is the most important assets for majority of households, and there is a large racial difference in terms of the homeownership rate, as shown. Third, an interesting dimension of racial differences that is not in the current paper is the difference in consumption basket, and thus difference in the inflation rates that different racial groups face. This is emphasized by Lee et al. (2021). Fourth, racial inequality in terms of access to credit is also considered an important issue. This could be an important extension as access to credit, which is abstracted from the current paper, affects the ability to smooth consumption over time. Finally, it is known that there are more singles and single parents among Black households, which could weaken their ability to absorb shocks to income. This could also be an important channel that affects the racial differences in terms of the efficacy of monetary policy.

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Appendix

A Equations Characterizing the Equilibrium

In this appendix, I organize the equations characterizing the equilibrium of the model so that the model can be solved with the first-order (linear) perturbation method developed by Schmitt-Grohé and Uribe (2009). In particular, we need to organize the equations characterizing the solution of the model in the following manner:

$$\mathbb{E}_t \mathbf{f}(\mathbf{x}_t, \mathbf{x}_{t+1}, \mathbf{y}_t, \mathbf{y}_{t+1}) = 0 \tag{A.1}$$

where $\mathbf{x}_t$ is a size-n_x vector of state variables in period t, meaning that $\mathbf{x}_t$ are predetermined at the beginning of period t. $\mathbf{y}_t$ is a size-n_y vector of control variables, which are not determined at the beginning of period t, but determined before period $t+1$. Denote $n = n_x + n_y$. $\mathbf{f}$ is a function that characterizes the equilibrium, and has to be a function which takes $2n$ variables ($\mathbf{x}_t$, $\mathbf{x}_{t+1}$, $\mathbf{y}_t$, and $\mathbf{y}_{t+1}$) and maps into n conditions.

What should be $\mathbf{x}_t$ and $\mathbf{y}_t$ in the model developed in this paper? Let's start with $\mathbf{x}_t$. First, shocks z_t, b_t, and s_t are included. Second, other variables predetermined at the beginning of period t are k_t, i_{t-1}, and R_{t-1}. Finally, type distribution of heterogeneous workers m_t is a part of $\mathbf{x}_t$. How do we store the type distribution? I use the simplest method and store the distribution of asset holding by n_a-grid histograms. This is also used by the bare-bone version of the algorithm proposed by Reiter (2009). A type distribution can be stored by a vector of length $n_s \times n_p \times n_e \times n_a$. Notice that, since the wealthy hand-to-mouth shock, h, is i.i.d., there is no need to keep track of the type distribution in terms of h, allowing to reduce the dimension of the type distribution. Moreover, the probability measure at one of the asset grids (I use the lowest grid point) for each of type-s is not necessary since this can be backed up using the measure of type-s workers (which is fixed). In the end, $\mathbf{x}_t$ is a vector of length $n_x = 6 + n_s \times n_p \times n_e \times n_a - n_s$.

Let's move on to $\mathbf{y}_t$. Aggregate variables that are not predetermined are the following $16+3\times n_s$: y_t, c_t, i_t, ℓ_t, n_t, p^a_t, d_t, mc_t, τ_t, δ_t, x_t, w_t, r_t, r^k_t, p^i_t, π_t, $u_{s,t}$, $v_{s,t}$, and $f_{s,t}$. Moreover, the optimal saving decision by heterogeneous workers and the value of labor firms are a part of $\mathbf{y}_t$. Using the same grids as those for storing the distribution of assets, the optimal saving decision can be stored by $n_s \times n_p \times n_e \times n_a \times n_h$ points. Notice that we need to store the optimal decision rule for each realization of the wealthy hand-to-mouth shock h. The value of labor firms can be stored by $n_s \times n_p$ points. In sum, $\mathbf{y}_t$ is a vector of length $n_y = 16 + 3 \times n_s + n_s \times n_p \times n_e \times n_a \times n_h + n_s \times n_p$.

The $n = n_x + n_y = 22 + 3 \times n_s + n_s \times n_p \times n_e \times n_a - n_s + n_s \times n_p \times n_e \times n_a \times n_h + n_s \times n_p$ equations included in $\mathbf{f}(.)$ are as follows:

$$\log z_{t+1} = \rho_z \log z_t + \epsilon^z_{t+1} \tag{A.2}$$

$$\log b_{t+1} = \rho_b \log b_t + \epsilon^b_{t+1} \tag{A.3}$$

$$\log s_{t+1} = \rho_s \log s_t + \epsilon^s_{t+1} \tag{A.4}$$

$$k_{t+1} = (1-\delta_t)k_t + i_t b_t \tag{A.5}$$

$$\ell_t = \int \mathbb{1}_{e=1} p \eta_s \, d\, m_{t+1} \tag{A.6}$$

$$i_{(t-1)+1} = i_t \tag{A.7}$$

$$\log R_t = (1-\rho_R)\log \overline{R} + \rho_R \log R_{t-1} + (1-\rho_R)[\phi_\pi(\log \pi_t - \log \overline{\pi}) + \phi_y(\log y_t - \log \overline{y})] + \log s_t \quad \text{(A.8)}$$

$$\tau_t \int \mathbb{1}_{e=1} w_t p \eta_s \, d\, m_{t+1} = \int \mathbb{1}_{e=0} \min(\phi_0 w_t p \eta_s, \phi_1 \overline{w\eta}_s) \, d\, m_{t+1} \quad \text{(A.9)}$$

$$y_t = c_t + i_t + b_t i_t \frac{\psi_i}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2 + \sum_s \kappa_s v_{s,t} + \frac{\psi_1}{2}(\pi_t - \overline{\pi})^2 y_t + \psi_0 \quad \text{(A.10)}$$

$$\overline{a} = \int a \, d\, m_{t+1} \quad \text{(A.11)}$$

$$c_t = d_t + w_t \ell_t \quad \text{(A.12)}$$

$$w_t = \omega_0 \overline{x} + \omega_1(\log x_t - \log \overline{x}) \quad \text{(A.13)}$$

$$b_t p_t^i = 1 + \frac{b_t \psi_i}{2}\left[3\frac{i_t^2}{i_{t-1}^2} - 4\frac{i_t}{i_{t-1}} + 1\right] - \mathbb{E}_t \frac{b_{t+1}\psi_i}{1+r_{t+1}} \frac{i_{t+1}^2}{i_t^2}\left[\frac{i_{t+1}}{i_t} - 1\right] \quad \text{(A.14)}$$

$$1 + r_{t+1} = \frac{p_{t+1}^a + d_{t+1}}{p_t^a} \quad \text{(A.15)}$$

$$y_t = z_t (k_t n_t)^\theta \ell_t^{1-\theta} \quad \text{(A.16)}$$

$$r_t^k = mc_t z_t \theta (k_t n_t)^{\theta-1} \ell_t^{1-\theta} \quad \text{(A.17)}$$

$$x_t = mc_t z_t (1-\theta)(k_t n_t)^\theta \ell_t^{-\theta} \quad \text{(A.18)}$$

$$[y_t - \psi_1(\pi_t - \overline{\pi}) y_t \pi_t + (mc_t - 1)\epsilon_p y_t] + \mathbb{E}_t \frac{1}{1+r_{t+1}}[\psi_1(\pi_{t+1} - \overline{\pi}) y_{t+1}\pi_{t+1}] = 0 \quad \text{(A.19)}$$

$$\delta_t = \delta_0 n_t^{\delta_1} \quad \text{(A.20)}$$

$$r_t^k = p_t^i \delta_0 \delta_1 n_t^{\delta_1 - 1} \quad \text{(A.21)}$$

$$R_t = \mathbb{E}_t \pi_{t+1}(1 + r_{t+1}) \quad \text{(A.22)}$$

$$p_t^i = \mathbb{E}_t \frac{1}{1+r_{t+1}}\left[r_{t+1}^k n_{t+1} + (1 - \delta_0 n_{t+1}^{\delta_1}) p_{t+1}^i\right] \quad \text{(A.23)}$$

The following gives $n_s \times n_p \times n_e \times n_a \times n_h$ equations characterizing the optimal saving decision.

$$a_{t+1} = \begin{cases} \max\{(p_t^a + d_t)a_t + (1-\tau_t)w_t p_t \eta_s - \left[\beta_s \mathbb{E}_t (1+r_{t+1}) c_{t+1}^{-\sigma}\right]^{-1/\sigma}, \underline{a}_t\} & \text{if } e_t = 1 \\ \max\{(p_t^a + d_t)a_t + \min(\phi_0 w_t p_t \eta_s, \phi_1 \overline{w\eta}_s) - \left[\beta_s \mathbb{E}_t (1+r_{t+1}) c_{t+1}^{-\sigma}\right]^{-1/\sigma}, \underline{a}_t\} & \text{if } e_t = 2 \end{cases} \quad \text{(A.24)}$$

where

$$\underline{a}_t = \begin{cases} 0 & \text{if } h_t = 1 \\ (1-\delta_a)a_t & \text{if } h_t = 2 \end{cases} \quad \text{(A.25)}$$

Using the type distribution at the beginning of period t, m_t, optimal decision rules, and transition probabilities of shocks, the type distribution can be updated to $\hat{m}_{t+1}$. Since m_{t+1} is a part of $\mathbf{x}_{t+1}$, we have:

$$m_{t+1} = \hat{m}_{t+1} \quad \text{(A.26)}$$

This gives $n_s \times n_p \times n_e \times n_a$ conditions. But n_s conditions can be dropped since it can be backed up by the fixed measure of each s-type. $u_{s,t}$, $v_{s,t}$, and $f_{s,t}$ are characterized by the following equations for each s:

$$u_{\bar{s},t} = \int \mathbb{1}_{e=2} \mathbb{1}_{s=\bar{s}} d\, m_t \tag{A.27}$$

$$\kappa_s = \mu v_{s,t}^{\alpha-1} u_{s,t}^{1-\alpha} \sum_p \pi_{p|s,e=2} J_{s,p,t} \tag{A.28}$$

$$f_{s,t} = \mu v_{s,t}^{\alpha} u_{s,t}^{-\alpha} \tag{A.29}$$

Finally, the following recursive definition of the firm's value gives $n_s \times n_p$ equations.

$$J_{s,p,t} = (x_t - w_t) p \eta_s + \mathbb{E}_t \frac{1-\lambda_s}{1+r_{t+1}} \sum_{p'} \pi_{p'|p,e,e'} J_{s,p',t+1} \tag{A.30}$$

B Equations Characterizing the Steady State

By imposing steady-state conditions to equations characterizing the equilibrium, steady-state variables can be characterized. They are summarized in Table B.1. I eliminate time scripts to denote variables in the steady state.

C Note on the Definition of Hand-to-Mouth

This Appendix summarizes the definition of poor and wealthy hand-to-mouth, following Kaplan et al. (2014). According to their definition, a household is poor hand-to-mouth if one of the following two holds:

$$a \leq 0 \quad \text{and} \quad 0 \leq m \leq \frac{y}{2} \tag{C.31}$$

$$a \leq 0 \quad \text{and} \quad m < 0 \quad \text{and} \quad m \leq -\underline{m} + \frac{y}{2} \tag{C.32}$$

The first case is when a household has a positive liquid asset position. a and m are household's illiquid and liquid wealth holding, respectively, and y is household's income in pay period. y is divided by half because y could be received anytime during the period. $a < 0$ rarely happens in the data. It happens only if a house price decline makes the home equity negative. The second case is when a household has a negative liquid asset position. Then a household is assumed to be able to borrow up to $-\underline{m}$. If the liquid asset position is less than the borrowing limit plus half of income in pay period, the household is considered liquidity constrained as the household is too close to the borrowing limit.

Similarly, a household is a wealthy hand-to-mouth if one of the following two holds:

$$a > 0 \quad \text{and} \quad 0 \leq m \leq \frac{y}{2} \tag{C.33}$$

Table B.1: Steady-State Values and Conditions

Variable	Value	Condition
z	1.0000	From law of motion
b	1.0000	From law of motion
s	1.0000	From law of motion
k	35.3731	$= (k/y\, zn^{\theta})^{1/(1-\theta)}\ell$
ℓ	1.0162	$= \int \mathbb{1}_{e=1} p\eta_s \, d\, m$
i	0.5306	$= \delta k$
R	1.0138	$= \pi(1+r)$
y	2.9478	$= z(kn)^{\theta}\ell^{1-\theta}$
c	2.2214	$= d + w\ell$
n	1.0000	By assumption
p^a	36.5612	$= d/r$
d	0.3199	$= rk - \sum_s \kappa_s v_s$
mc	0.9500	$= 1 - \frac{1}{\epsilon_p}$
τ	0.0205	From the government budget constraint
δ	0.0150	$= \delta_0$
x	1.9290	$= mc(1-\theta)z(kn)^{\theta}\ell^{-\theta}$
w	1.8711	$= \omega_0 x$
r	0.0088	$= r_k - \delta$
r^k	0.0238	$= mc\theta z(kn)^{\theta-1}\ell^{1-\theta}$
p^i	1.0000	From the first order condition of investment firms
π	1.0050	$= \overline{\pi}$
f_s	Table 5	From Cajner et al. (2017)
u_s	Table 5	$= \lambda_s/(f_s + \lambda_s)$
v_s	Table 5	$= (f_s/\mu)^{1/(\alpha-1)}u_s$

Note: Quarterly frequency.

$$a > 0 \quad \text{and} \quad m < 0 \quad \text{and} \quad m \leq -\underline{m} + \frac{y}{2} \tag{C.34}$$

Total hand-to-mouth is the sum of poor hand-to-mouth and wealthy hand-to-mouth. Kaplan et al. (2014) set y to be two-week of earnings, based on the pay frequency in CEX from 1990 to 2010. According to their calculation, during the period, 32% of respondents are paid weekly, 52% are paid bi-weekly, and the rest are paid at a lower frequency. In terms of $\underline{m}$, Kaplan et al. (2014) set the borrowing limit as one-month equivalent of non-financial income as their baseline case. They also try alternative case with one-year equivalent of non-financial income and self-reported borrowing limit in the Survey of Consumer Finances (SCF). According to their calculation (Table 3 of their paper), between 1989 and 2010 in SCF, 31.2% of households are hand-to-mouth. Among those, about 1/3 (12.1% of total) are poor hand-to-mouth, and 2/3 (19.2% of total) are wealthy hand-to-mouth.

In the model constructed in the paper, since there is no liquid debt, only the first condition for both poor and wealthy hand-to-mouth is used. In order to be consistent with the defini-

tion of poor hand-to-mouth of Kaplan et al. (2014), I set the second grid (first grid represents zero assets) to be equal to two-week equivalent of earnings. By doing it, the threshold on average between the first grid (zero assets) and the second grid is half of two-week equivalent of earnings. In other words, the first grid captures those with equal or less than half of two-week equivalent of earnings on average, which is consistent with the definition of poor hand-to-mouth in Kaplan et al. (2014). When I calculate the fraction of hand-to-mouth for each racial group, shown in Table 3, I use the same definition.

As for the wealthy hand-to-mouth, I assume that there is an i.i.d. shock with probability π_h^s. With probability $1 - \pi_h^s$, a worker of type-s is not hit by the wealthy hand-to-mouth shock, and their liquidity constraint is the standard one ($a_{t+1} \geq 0$). With probability π_h^s, a worker is hit by the wealthy hand-to-mouth shock, and the liquidity constraint becomes $a_{t+1} \geq (1 - \delta_a)a_t$. δ_a is calibrated to be median credit card limit divided by median total wealth. In the SCF, credit card limit for each household is defined as equivalent to one-month of earnings, following Kaplan et al. (2014). I assume that δ_a is common across all racial groups. The i.i.d. probability of wealthy hand-to-mouth shock, π_h^s, is calibrated such that the proportion of wealthy hand-to-mouth ($a > 0$ and hit by the shock) is equal to the data for each type-s. The fraction of wealthy hand-to-mouth for each racial group is reported in Table 3.

The assumption that households with positive amount of illiquid asset can use the value of illiquid asset up to the amount of median credit card limit can be considered tight, as households probably could use the value of illiquid asset as well in case they need more liquidity. However, notice that, even with the liquidity constraint for wealthy hand-to-mouth which can be considered tight, the role of wealthy hand-to-mouth shock is limited in model experiments.