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Essays on Heterogeneity in Macroeconomics and Labor Markets

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Thesis abstract

This thesis is composed of three independent chapters.
The first project studies how wealth can determine employment risk over the business cycle through labor market sorting. I find that workers with low liquid wealth face higher employment risk and propose a theory of wealth-sorting into risky jobs to rationalize it. I then integrate wealth-sorting in a quantitative model with aggregate risk to study its implications for wages and job transitions over the business cycle, as well as its consequence for long-term inequality. Key findings are that recessions depresses labor market outcomes relatively more for the poor; and that the interaction between employment risk and wealth accumulation generates a "poverty trap".
The second project empirically uncovers a novel transmission mechanism of monetary policy to individual labor income, working through the employers. Using matched employer-employee data from Germany, we show that firms differ in the degree of income insurance they provide to their workers. Our main finding is that wages of workers in large firms are relatively more sensitive to monetary policy shocks. This is particularly true for above-median workers and cannot be fully explained by a worker component or sorting. Moreover, monetary policy shocks exacerbate labor income inequality. The effect is relatively stronger in easings, driven by a large increase in wages for top earners.
The third project studies how monetary policy shapes the aggregate and distributional effects of an imported energy price shock. Based on the observed heterogeneity in consumption exposures to energy and household wealth, we build a quantitative small open-economy HANK model that matches salient features of the Euro Area data. We find that energy price shocks always reduce aggregate consumption, and households with little wealth are more adversely affected. Policy responses inducing strong increases in interest rates in response to inflation amplify the negative aggregate outcomes in the short-term, but lead to a faster recovery. However, low-wealth households are further adversely affected.

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Chapter 1

Wealth Sorting and Cyclical Employment Risk

Abstract

I present empirical evidence that U.S. workers with low liquid wealth face significantly higher cyclical employment risk. This finding cannot be fully explained by skills, socio-demographics, or past income. I propose a framework that generates a negative correlation between wealth and employment risk in equilibrium, through job sorting based on wealth. Job search provides an insurance mechanism for liquidity constrained and risk-averse unemployed workers. Asset-poor unemployed sort into relatively lower wage and lower security jobs, because these offer a relatively higher job finding probability. I build a quantitative model to study the implications of wealth sorting for wages and job transitions over the business cycle, as well as its consequence for long-term inequalities. A recessionary shock induces all unemployed to look for worse jobs – and this is more pronounced for poor workers. Moreover, the interaction between employment risk and wealth accumulation generates a "poverty trap".

JEL-Classification: E21, E24, E32.
Keywords: sorting, heterogeneous agents, business cycles.

1 Introduction

Wealth is closely linked to labor market outcomes for unemployed individuals, with financial distress often leading to worse employment prospects.[1] Understanding how wealth affects different labor market outcomes is important for deepening our understanding of economic inequalities and, in turn, for the design of labor market policies. Nevertheless, whether and how wealth might influence employment risk through the labor market remains largely unexplored – employment risk is generally assumed to be exogenous to an agent's wealth. The interaction between wealth and earnings risk is of particular interest from the perspective of the recent heterogeneous agent macroeconomic literature, given its potential implications for consumption risk.

In this paper, I empirically and theoretically examine the relationship between workers' wealth and their cyclical employment risk. I show that U.S. workers at the bottom of the liquid wealth distribution experience greater sensitivity of employment to changes in aggregate output. To explain this finding, I present a theory of wealth sorting that generates a negative correlation between liquid wealth and employment risk. Wealth sorting emerges from the presence of risk aversion and liquidity constraints, which incentivize asset-poor workers to look for jobs offering a high job finding probability – those that are more risky. I then build a quantitative model to study the implications of wealth sorting on wages and job transitions over the business cycle, as well as its consequence for long-term inequalities. The cost of starting an unemployment spell during a recession (relative to a normal time) amounts to 3% of lifetime consumption for the poorest and 1% for the richest workers.

I start by providing evidence that asset-poorer workers in the U.S. have employment probabilities that are more sensitive to aggregate fluctuations. Using the Panel Study of Income Dynamics (PSID), I compute the correlation between individual employment and changes in aggregate output, distinguishing workers based on their prior period liquid wealth holdings. I show that the negative correlation remains significant even after control-

[1] See e.g. Bloemen and Stancanelli, 2001. In the U.S., more than a quarter of working-age households do not have sufficient savings to cover their expenditures after a month of unemployment (Catherine et al., 2020).

ling for workers' fixed effects, skills, past income, and demographics. This paper focuses on this *residual* inequality, attributable to heterogeneous liquid wealth holdings. I find that asset-poorer workers not only face higher employment risk over the business cycle but also have a higher job loss probability in the cross-section. What matters is whether the worker is *liquid* wealth-poor in a certain period. I show that classifying agents according to their illiquid wealth or "permanent" wealth does not induce significant differences in employment elasticity. These findings support a theoretical link between heterogeneous employment risk and binding liquidity constraints. My empirical motivation closely aligns with Patterson (2023), who shows that workers with a high marginal propensity to consume (MPC) exhibit relatively greater employment elasticity to aggregate fluctuations. These empirical findings challenge models of job acceptance under risk aversion, which predict that poorer workers are relatively more likely to reject low-security jobs. A key contribution of this paper is to provide a theoretical explanation for the observed the negative correlation between liquid wealth and employment risk.

I then develop the simplest theoretical framework consistent with the empirical evidence above. Job search is directed, unlike in job acceptance models. Directed search introduces a trade-off between job-finding probability and job attributes, which is central to the sorting mechanism. I introduce two-sided heterogeneity on the labor market: workers differ in wealth, and jobs differ in their separation risk (security). As is common in directed search theory, the labor market is segmented in separated submarkets, each representing a subset of unemployed workers and firms with vacant jobs searching for each other. Time lasts for two periods. The aggregate state in the second period is uncertain, and heterogeneously affects jobs' separation risk. Firms post wages, and there is free entry for vacancy posting. Workers are risk-averse and can save at the (constant) risk-free interest rate, up to a borrowing constraint. Employed workers take a consumption-savings decision, while unemployed workers additionally need to search for a job.

In this economy, workers sort to different types of jobs based on their level of wealth. I provide sufficient conditions for having positive wealth sorting in equilibrium, i.e., for asset-poor workers to sort into low security jobs and wealthy workers to sort into high security jobs. Similarly to Eeckhout and Sepahsalari (2024), positive sorting comes from a *preference*

complementarity between asset-poor risk-averse workers and jobs that offer a high job finding probability. Differently from their paper, in my model with heterogeneous job security, agents additionally need to consider the job separation probability (security). If high matching probability jobs also feature lower security, the sorting motive is weakened as asset-poor value job security relatively more. I show that positive sorting may still happen in equilibrium, as long as the trade-off between matching probability and job attributes is "good enough". In particular, it must be that workers are compensated enough in terms of job finding probability when applying to low wage, low security jobs. This is governed by the matching function elasticity and holds true for a reasonable parametrization. Whether low security jobs are those associated with high matching probability is governed by the free entry condition and relates to the shape of the separation and vacancy cost functions. If the cost of an unfilled vacancy is relatively larger for higher type jobs, firms opening high type jobs post relatively higher wages to attract applicants. In the positive wealth sorting equilibrium, wages and job security are thus endogenously positively correlated, and workers with lower assets not only have less secure jobs but also lower wages.[2]
More generally, wealth sorting is positive if workers' need to self insure outweighs the utility costs of matching in low wage and low security jobs ("bad" jobs). Any force that either increases the need for insurance or decreases the costs of searching for bad jobs strengthens the motive for positive wealth sorting. Infinite horizon and aggregate uncertainty ambiguously affect both the need for insurance and the long-term utility costs of searching for bad jobs through various channels. Understanding how wealth sorting behaves in such a framework is therefore a quantitative question.

Next, I extend the simple model to an infinite horizon framework with aggregate uncertainty. I build a dynamic quantitative incomplete market heterogeneous agent model with wealth sorting to study the dynamics of wages, assets, and labor market flows over the business cycle. Relative to existing research, my model newly connects wealth heterogeneity

[2]Note that the mechanism I propose can be thought to work within skill groups, or in addition to how skills may affect cyclical employment risk. While these dimensions of worker heterogeneity are surely important determinants of labor market choices, they have been the focus of some other papers already (e.g., Kramer, 2022; Griffy, 2021; Acabbi et al., 2022). Whether there are some interaction effects between wealth and skill accumulation in the current context is beyond the scope of this paper.

with labor market sorting in an incomplete market setup. An interaction between the distributions of cyclical employment risk and wealth arises. Wealth influences job search decisions through the need for insurance, and job search decisions influence the workers' wealth through savings during the employment spell. My model therefore highlights an economic force that is present in models with incomplete markets and heterogeneous wealth and that operates on labor markets if one allows for sorting.

I show that the quantitative model is block recursive, i.e., that the individual value functions and market tightness in every submarket are independent of the distribution of workers over asset and employment states. This result allows me to solve for the full stochastic equilibrium in a relatively tractable way. I calibrate the model to the U.S. at a monthly frequency and assume firms with higher separation risk to be less productive. My calibration matches moments of the wealth distribution, as well as cross-sectional and cyclical job flows moments. In the steady state, relatively poorer workers look for relatively lower wage jobs and lower productivity jobs (with a larger separation risk). They use their labor market search as a way to smooth consumption. This mechanism is valid both across workers (low versus high assets) and also across aggregate productivity states. In bad times, asset-poor unemployed optimally decide to apply to even worse jobs to mitigate the decrease in job finding probability. As a consequence, sorting is relatively stronger in bad aggregate states, as measured by the larger correlation between individual wealth and separation risk, wages and job productivity. Moreover, the dispersion of wages and job productivity is relatively larger in bad aggregate states.

Finally, I use the quantitative model to study the effect of recessions and targeted transfers. I simulate a 1% negative aggregate productivity shock. First, I show that following a 1% negative aggregate productivity shock, the search of unemployed workers tilts towards worse jobs – average wages and productivity decrease by around 6%. This number hides substantial heterogeneity concentrated in the bottom 1% of the wealth distribution. In fact, these workers search for wages and job productivity around 1 percentage point lower than the richest 1%. This change in job search allows to greatly mitigate the drop in their consumption. Second, I study the effect of four types of targeted transfers implemented when the aggregate productivity shock hits. The first policy is a standard unemployment

benefit and targets all unemployed. I compare this to policies targeting the asset-poor, as well as policies targeting only the employed or unemployed asset-poor. By targeting the transfer to workers with on average lower assets, the aggregate consumption drop is mitigated. This is especially true for the transfers targeted at the unemployed. However, this distorts their job search –allowing them to look for better jobs, which depresses the following period's aggregate consumption through a relatively larger share of workers who remain unemployed (matching probabilities are lower for good jobs). This backlash effect on consumption does not happen when targeting the poorest employed workers. Lastly, I show that in the presence of aggregate risk and liquidity constraints, wealth sorting creates a "poverty trap". Asset-poor workers systematically face higher employment risk and struggle to escape their precarious state, as they are unable to save sufficiently during short and low-wage employment spells. Additionally, I show that starting an unemployment spell during a recession, as opposed to normal times, has long-lasting effects for all workers, though to a greater extent for the poorest. A job search during a recession leads to persistently lower wages and slower asset accumulation for years, especially so for the poorest workers. I quantify the lifetime cost of starting an unemployment spell during a recession (relative to a normal time) to represent 3% of lifetime consumption for the poorest, more than twice that of the wealthiest workers.

Related literature This paper relates to four strands of the literature. First, I contribute to the literature on sorting over the business cycle by studying *wealth* sorting. Lise and Robin (2017) study skill-sorting over the business cycles in a model with random search and alternating offers. Payne et al. (2024) instead develop a deep-learning algorithm to extend the class of random search models that can be solved with aggregate uncertainty. Acabbi et al. (2022) explore how sorting of heterogeneously skilled workers varies over the business cycle in a directed search framework. These papers do not model heterogeneity in wealth, which is my focus. I add to the understanding of how aggregate shocks affect sorting by studying the role of wealth heterogeneity for labor market transitions and wage dynamics over the business cycles. Moreover, in my model, sorting newly relates wealth to

cyclical employment risk.[3] Unlike these papers, job sorting in my model is driven purely by the need for insurance; I assume no production complementarity between wealthy workers and good jobs. My mechanism is not in conflict with alternative sorting theories but rather works within dimensions of heterogeneity such as skills. My paper builds on the directed search frameworks developed in Menzio and Shi (2010, 2011), and extends the proof for block recursivity to an environment with aggregate risk, worker wealth heterogeneity, and firm productivity heterogeneity.[4]

Second, my paper speaks to the literature on incomplete market models with wealth heterogeneity and labor market frictions. Relative to other frameworks (e.g., Krusell et al. 2010; Shao and Silos 2017 or Ravn and Sterk (2021)), my model implies a selection effect of negative aggregate shocks on individual probability to get unemployed through sorting. In particular, asset-poor workers are relatively more likely to become unemployed. While risk is usually modeled to be exogenous to wealth, my mechanism maps wealth into cyclical risk and cyclical risk to wealth.

The coexistence of low wage and low security jobs resembles Jarosch (2023), though emerging from a different mechanism. While he assumes a joint distribution consistent with his estimated data, in my model the fact that low security jobs offer low wages is endogenous and depends on primitives.

Third, my work relates to theoretical and empirical literature analyzing the role of wealth for labor market outcomes. The theoretical literature, going back to Danforth (1979), studies the effect of wealth on job search behavior and various outcomes. Acemoglu and Shimer (1999) show that risk-averse agents use the labor market as an insurance mechanism against consumption risk due to unemployment. Rendon (2006) and Chaumont and Shi (2022) study the relationship between job search, unemployment spells, and asset accumulation. Eeckhout and Sepahsalari (2024) introduce the notion of wealth sorting and show that workers' wealth determines their productivity through labor market sorting.

[3]Kramer (2022) jointly studies wealth heterogeneity and income risk, but through a different mechanism – he does not have sorting.

[4]Existing related papers have proved the existence of a block recursivity in similar environments: with skill-sorting and aggregate shocks (Acabbi et al., 2022); with a wealth distribution (Chaumont and Shi, 2022); with a wealth distribution, worker heterogeneity, and aggregate shocks (Birinci and See, 2023; Herkenhoff et al., 2024).

The mechanism at the heart of my paper builds on this line of research in the sense that wealthier individuals are more selective and are able to wait for better job offers. The novelty I propose is to explore a job search outcome that has not been explored yet (both empirically and theoretically), namely employment cyclical risk.[5] Importantly, I also introduce aggregate risk and study the effect of wealth over business cycles.

Many empirical papers explore related outcomes. Herkenhoff et al. (2024) estimate the role of credit constraints on unemployment duration, wages, and matched firm productivity. He and le Maire (2020) analyzes the effect of liquidity constraints on wages, human and physical capital accumulation in Denmark. Relatedly, Bednarzik et al. (2021) estimates the role of indebtedness on unemployment duration for U.S. households. Lammers (2014) analyzes the role of wealth on reservation wages and search effort using Dutch data. Chetty (2008); Card et al. (2007) and Fontaine et al. (2020) establish a negative relationship between liquidity and job-finding rates. My model is consistent with these results and additionally considers the effect of liquid wealth on workers' employment risk.

Fourth, understanding heterogeneous earnings cyclical risk across different dimensions of heterogeneity has been the focus of recent empirical studies.[6] I add to this literature by documenting a negative relationship between liquid wealth and employment cyclicality. In terms of empirics, my work is related to Patterson (2023) who studies the correlation between MPCs and earnings' elasticity to aggregate fluctuations. Differently from her, I focus on residual inequality – differences that are not explained by workers' characteristics beyond their liquid wealth.

The manuscript is organized as follows. Section 2 presents empirical findings on the correlation between cyclical employment and liquid wealth. Section 3 introduces a tractable

[5]Other strands of the literature explored different search outcomes; see e.g., Lentz and Tranaes (2005); Lise (2013) who studies how wealth affects search effort; or Griffy (2021) and Kaas et al. (2023) who study how wealth inequality affect workers' climbing of the job ladder.

[6]Guvenen et al. (2014) focuses on idiosyncratic labor income risk across the earning distribution; Hoynes et al. (2012) analyzes how recessions impacts labor income differently by demographic groups; Dany-Knedlik et al. (2021) document that lower and higher income individuals experience significantly larger fluctuations across the business cycle than middle-income individuals; and Cairó and Cajner (2018) find that less educated individuals in the U.S. have less stable jobs, which is due to a more frequent job loss. Carrillo-Tudela et al. (2022) study cyclical earnings through the lens of a job ladder model.

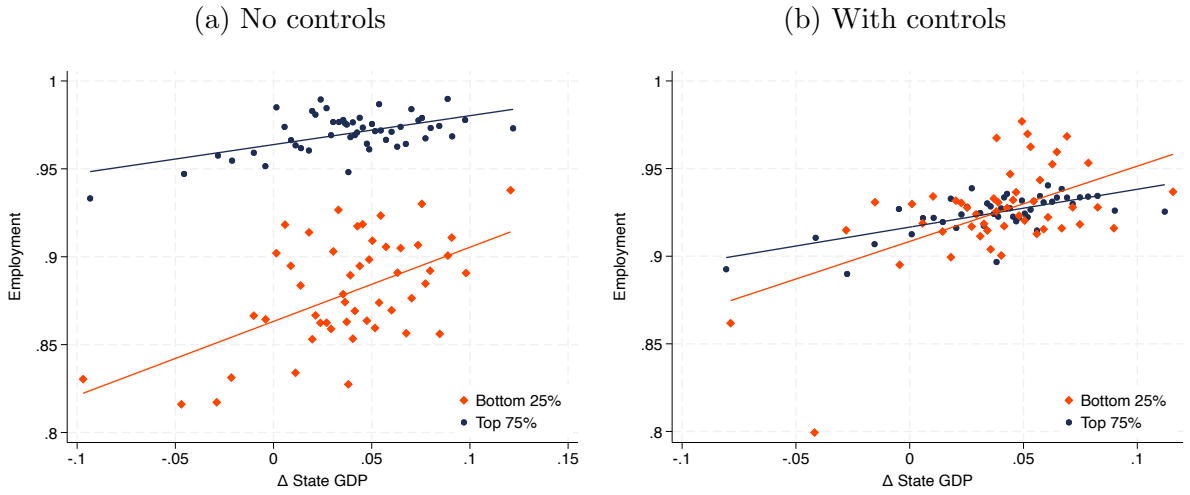
theoretical framework where workers with different levels of wealth bear heterogeneous employment risk. I provide conditions for the model to be consistent with the negative empirical correlation between wealth and cyclical risk. Section 2 outlines a parsimonious quantitative model and presents the equilibrium. Section 5 presents quantitative results on the short- and long-term effect of recessions, and implements different policy counterfactuals. Finally, Section 5 concludes.

2 Liquid wealth and employment in the data

The relationship between wealth and employment risk is a relevant moment in models with incomplete insurance, however it has received little attention in the literature. An exception is Patterson (2023), who shows that the earnings of high-MPC individuals are relatively more exposed to aggregate fluctuations. Figure 1.1 shows a similar correlation for individuals with low liquid wealth.[7] In particular, it plots the correlation between employment status and U.S. State real GDP growth, differentiating by liquid wealth holdings. The orange diamonds and lines represent workers who are in the bottom quartile of liquid wealth distribution – roughly corresponding to those with zero liquid wealth, and the blue dots and lines represent the rest of the workers.

[7]MPCs and liquid wealth are closely related concepts in incomplete market models. Typically, individuals closer to their borrowing constraints have a higher MPC. However, this relationship can vary depending on specific modeling assumptions, such as the presence of assets with different levels of liquidity. Additionally, in empirical data, MPC and wealth are distinct concepts: MPC must generally be estimated (unless derived from an experiment), whereas wealth is directly measured in many large-scale surveys.

Figure 1.1: Employment and aggregate output fluctuations by liquid wealth



Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Dots represent mean of x and y values within 50 equally populated bins. The $x-$ axis represents log changes in U.S. states real GDP; the $y-$axis is the mean employment status. The left panel plots the unconditional correlation, while the right panel controls for individual fixed effects, socio-demographics, a quadratic in age and past income. Liquid wealth is measured as the amount in the savings accounts and stocks holdings.

The correlation between GDP and employment is positive for all workers, but stronger so for workers with low assets. This holds both unconditionally (left panel) and after controlling for observable characteristics (right panel). These figures suggest that on average, asset-poor workers' employment moves more with aggregate fluctuations, everything else being equal. This correlation is consistent with Patterson (2023), and no existing theory can rationalize it.[8]

Asset-poor workers not only have more cyclical employment risk, but they also show a higher probability to change employment status in the cross-section (see Appendix Figure A1). In what follows, I examine the correlation between liquid wealth and cyclical employment in greater detail. My findings show that workers with low liquid wealth are statistically significantly more exposed to employment fluctuations during the business cycle. I then explain why existing models fail to rationalize this relationship.

[8]It is consistent to the extent that liquid wealth and MPC are negatively correlated. Computing the MPC as she does, I find that workers at the bottom of the liquid wealth distribution in my sample indeed have a higher MPC.

2.1 Data and empirical specification

The PSID is the world's longest ongoing longitudinal household panel dataset. The survey is conducted in the U.S. and on a biannual basis since 1999. From that year onward, collected information of interest on workers include socio-demographics, employment, and detailed financial situation. See Appendix A1 for more information about the data and cleaning.

While wealth is an endogenous variable correlated with education, productivity, and skills, among others, the focus of this paper is on *residual* inequality, i.e., inequality that is directly attributable to wealth. I estimate the correlation between employment elasticity to aggregate fluctuations and liquid wealth, accounting for both observed and unobserved differences between asset-poor and wealthy agents. The results should be interpreted as operating *within* specific groups, such as those defined by skill or education. My baseline specification is as follows.

$$e_{it} = \gamma_i + X'_{it}\beta + +\chi a_{it-1} \times \Delta \log Y_t + \nu_{it}, \tag{1.1}$$

where e_{it} is a dummy capturing the employment status of the worker (1 if employed, 0 if unemployed), γ_i is the worker fixed effect, a_{it-1} is a dummy equal to 1 if the individual is asset-poor; X_{it} are controls including time-by-state fixed effects and the asset-poor dummy; and Y_t is the U.S. States' real GDP.

The coefficient of interest is χ: a positive value means that the employment of asset-poor individuals is more exposed to changes in aggregate output relative to wealthy individuals. If there is no role for a residual effect of wealth on the correlation with cyclical employment, the coefficient should become insignificant as we control for dimensions of heterogeneity underlying the correlation.

2.2 Asset-poor workers and cyclical employment

Table 1.1 presents baseline results. Columns (1) through (4) progressively saturate with fixed effects and controls. In Column (1), the estimates are displayed without the inclusion of controls or fixed effects. The first coefficient indicates a positive correlation between aggregate output and individual employment probability. Specifically, a 1% increase

Table 1.1: Liquid assets and individual employment elasticity to aggregate fluctuations

	(1)	(2)	(3)	(4)
$\Delta \log Y_t$	0.23***			
	(0.035)			
a_{it-1}	-0.15***	-0.011	-0.011	-0.011
	(0.0093)	(0.0076)	(0.0077)	(0.0073)
$a_{it-1} \times \Delta \log Y_t$	0.32***	0.27**	0.26**	0.27***
	(0.12)	(0.11)	(0.11)	(0.097)
FEs	No	Yes	Yes	Yes
Worker controls	No	No	Yes	Yes
Past income	No	No	No	Yes
R^2	0.050	0.45	0.45	0.45
N	35961	35961	35961	35961

Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Standard errors in parentheses; $^{*}p < 0.1$,$^{**}p < 0.05$,$^{***}p < 0.01$, clustered at the state level. The outcome variable is the employment status of the household head. Liquid wealth is measured as the checks and savings account. a_{it-1} is equal to one if the household's liquid wealth lies in the first quartile of that year's liquid wealth distribution. Fixed effects include workers, and year by state. Worker controls include a quadratic in age, and all the respective interactions with education, gender and race. Past income is the lagged labor income (if missing for the prior two years, it is the past income from the prior 4 years) and it is interacted with GDP.

in aggregate GDP is associated with a 0.23% higher probability of employment. The second coefficient shows that individuals in the lowest asset quartile are, on average, 0.15% less likely to be employed. More relevant to this paper, the estimates reveal that asset-poor individuals exhibit a greater exposure of labor income to aggregate fluctuations, as evidenced by the significantly positive coefficient on the interaction term. Introducing fixed effects and socio-demographic controls decreases the magnitude of coefficients, as it isolates the direct effect of being asset-poor on the sensitivity of employment to changes in aggregate output. The coefficient on the asset-poor dummy decreases in magnitude and becomes insignificant, suggesting that the conditional correlation effectively controls for the direct effect of wealth on the employment probability. To mitigate concerns that the skills are not controlled for by the fixed effects and education, Column (4) further controls for workers' past income interacted with real log GDP.[9] The interaction coefficient

[9]If the worker was unemployed in the previous period, the "past income" variable corresponds to the previous period's income. If the worker was unemployed in that previous period, she is dropped out of the sample. Past income may capture idiosyncratic productivity, helping to disentangle the distinct effects of income and wealth.

of interest is of 0.27%, and can be interpreted as the effect of *residual* wealth inequality on the elasticity of individual employment to aggregate output fluctuations.[10]
This residual inequality is present not only within skill groups, but also within occupation and industries. In Appendix Table A2 I further control for workers' occupation and industry interacted with GDP fluctuations. The baseline coefficient is slightly lower (also due to a smaller sample), but remains significantly different from zero. Consistently with the evidence that unequal employment risk is present within industries, occupations and skill groups, in my model I assume an ex-ante distribution of job separation risk. In that sense, the mechanism I propose can be thought to work within skill, occupation and industry groups.

Job loss and job finding I then explore whether the heterogeneous cyclicality across the liquid wealth distribution is driven by job loss or job finding. I change the baseline regression's dependent variable to represent either a transition from employment to unemployment (job loss dummy) or a transition from unemployment to employment (job finding dummy). Results suggest that job loss is the more relevant margin, both in terms of magnitude and significance – see Appendix Table A6. Nevertheless, in the cross-section both the job loss and job finding margins matter. Liquid wealth poor workers, on average, have more chance of finding a job and loosing their jobs. Moreover, the magnitudes are similar – see Appendix Table A5. The model that I present in the next section is consistent with these findings.

Sensitivity Low levels of liquid wealth are closely related to tight liquidity constraints in a standard model. Tight liquidity constraints are also the underlying reason that agents with low liquid wealth have, everything else being equal, higher MPCs. Therefore, the fact that the evidence above is consistent with Patterson (2023) suggests that it is the liquidity constraints that matter for the residual differential employment exposure to aggregate fluctuations. While I do not have a good measure of liquidity constraints in the PSID, below I show evidence that supports this hypothesis.

[10]The covariance implied by these coefficients is 0.049, which is in line with Patterson (2023)'s results. It can be computed as the interaction coefficient times the variance of a_{it}.

The wealth distribution exhibits a high concentration of observations at zero, with approximately 25% of individuals in the sample possessing no assets. In Appendix Figure A3, I compare different segments of the wealth distribution to higher wealth percentiles. The first data point illustrates the comparison of the bottom 20th percentile to the remaining distribution, followed by the comparison of the bottom 30th percentile, and so on. Coefficients are weakly decreasing up to the 80th percentile (with a magnitude of around one half of the baseline estimate). The fact that coefficients decrease with liquid wealth aligns with the idea that liquidity constraints underlie the baseline correlation, as the latter weakens when constraints become less binding. To distinguish the role of liquidity constraints from other mechanisms potentially linked to wealth holdings, I then run the baseline regression classifying agents according to their illiquid asset holdings. Appendix Table A3 shows results where I classify agents according to their illiquid wealth (instead of the baseline result that uses *liquid* wealth). Coefficients are smaller and not significant, indicating that illiquid wealth does not imply a differential employment elasticity to output fluctuations. In contrast, and supporting a role of liquidity constraints, I show that being hand-to-mouth is relevant; see Appendix Table A4.

Another question that may arise is whether the correlation is driven by some permanent component of wealth or because of different histories of shocks. First, although liquid wealth is auto-correlated at the individual level (around 0.9), the auto-correlation of the probability to be in the lowest quartile is smaller (around 0.5), suggesting that the baseline regression does not merely capture a permanent component of being asset-poor. To verify whether there is an important role of the permanent component of wealth that would not be captured by the individual fixed effects, Appendix Table A4 shows baseline results changing the "poor" dummy to represent workers that are in the lowest quartile of the permanent liquid wealth distribution. The coefficients are smaller and the standard errors larger, implying no significantly higher employment response to aggregate fluctuations for the "permanently poor" workers.

2.3 Employment risk and wealth in existing models

From the perspective of risk-averse agents, these findings are at odds with standard random search models. Intuitively, since asset-poor individuals are in a very concave part of their

utility function, they value low volatility relatively more. In a world where agents can accept job offers (à la McCall, 1970), this basic economic force induces them to trade low wages for income security. Instead, wealthy individuals do not mind risk as much and are willing to accept riskier but better paid jobs. To understand this, consider a McCall structure built on a simple consumption-saving problem under borrowing constraints. Assume that unemployed workers may receive job offers that differ in their cyclical risk and have to decide to accept or reject them. The equilibrium is such that asset-poor agents are less likely to accept risky jobs, as their reservation wage for these jobs is relatively higher. On average, this thus predicts that more risky jobs are populated with more wealthy agents.[11] The same intuition carries over to more complex models of wage compensation differentials. For example, in Pinheiro and Visschers (2015), the wage compensating differential for additional job loss risk is larger for those workers who have most to lose from job loss, in their case workers who are at the top of the job ladder. Applying the same logic to a model with liquidity constraints predicts that workers with little savings are less likely to accept highly risky jobs – the opposite of what I find in the data.

This paper provides a theoretical foundation for the higher employment elasticity of asset-poor individuals to aggregate output fluctuations. The key distinction from the models discussed above is that I allow workers to direct their labor market search. I focus on a labor supply mechanism because, from an employer's perspective, there is no reason to expect different hiring or firing behavior based on workers' liquid wealth, and because the latter is not even necessarily observable.

3 Wealth-sorting and elasticity of employment

In this section, I show how asset-poor workers can decide to sort into jobs with relatively larger separation risk. My model focuses on residual inequalities – those unexplained by workers' characteristics aside from wealth. When agents are risk-averse, liquidity constrained, and can direct their job search, they may use the labor market to insure

[11] The model and results are available upon request.

themselves by applying to jobs that offer a high matching probability.[12] But is it possible that poor workers apply to bad jobs even if this means bearing more cyclical employment risk? This feature directly conflicts with workers' need for insurance. I present the conditions under which sorting still happens because the insurance motive dominates the "bad" features of a job. In this model, as will become clear in the next section, exposure to cyclical risk is a by-product of workers' optimal labor market search. I start by laying down a two-period model that clarifies the trade-offs involved. For a more realistic and complete effect of wealth on sorting into jobs, Section 2 presents a quantitative model.

3.1 A two-period model

In this section, I present the simplest model conveying the core mechanism of the paper. In essence, I show that constrained risk-averse agents decide to apply to jobs with a higher probability of destruction if this allows them to increase the probability of matching.

Environment Time lasts two periods, i.e., $t = 1, 2$. Aggregate productivity z in the second period is uncertain. In particular, it may take two values, z^H and z^L, each materializing with respective probabilities p and $(1 - p)$.

The economy is populated with a continuum of heterogeneous workers and firms. Workers are risk-averse and differ in their asset holdings $a_t \in \mathcal{A} = [\underline{a}, \bar{a}] \subset \mathbb{R}_+$. Their period utility function $u(c)$ is increasing and concave ($u'(c) > 0$, $u''(c) < 0$ $\forall c \in \mathbb{R}_+$) and satisfies the Inada conditions. They face a liquidity constraint such that they cannot save less than $\underline{a}$. They discount the future at rate β, and the risk-free interest rate $R = 1 + r$ is determined by the world market and taken as given. Their labor market status is either employed or unemployed. When employed, workers earn a wage w and when unemployed they benefit from home production b.

Firms have one job, are risk neutral, and face the same discount rate as workers. As is common in the search literature, I refer to a job as a firm. Jobs are indexed by their (observable) type $x \in \mathcal{X} = [\underline{x}, \bar{x}] \subset \mathbb{R}_+$, and differ in their cyclical separation probability $\lambda(x, z)$. Let $|\lambda_x(x, z^H) - \lambda_x(x, z^L)| < 0$, such that low-type jobs are those carrying relatively

[12] See discussion of Acemoglu and Shimer 1999; Chaumont and Shi 2022 in the literature review.

more cyclical separation risk. The production technology is independent of job type; all jobs produce output $\bar{y}$ using labor as the only factor of production.[13] A final good competitive firm pools individual output and transforms it to the consumption good.

Labor markets Job search is directed, and the labor market is segmented in submarkets that do not compete directly with one another. Like is common in directed search theory, every submarket represents a subset of unemployed and firms with vacant jobs that are searching for each other. Submarkets are denoted by the firm type and the posted wage, (x, w) – different firms posting the same wage operate in different submarkets. There is free entry for vacancy posting; firms opening a vacancy pay a cost that depends on their type, $\varphi(x)$.[14] Each entrant firm posts a wage to be paid in the production stage upon matching. Unemployed workers choose to apply to (only) one submarket, and employed workers do not search on the job. The firm-to-worker ratio in each submarket is denoted by $\theta(x, w)$. For ease of notation, I hereafter drop the arguments and write θ to denote the tightness in a specific submarket. Matching is governed by a matching function that satisfies common assumptions (twice continuously differentiable, concave) and features constant returns to scale. The latter allows to write matching probability in every submarket as a function of tightness, $m(\theta)$, with $m'(\theta) > 0$ and $m''(\theta) < 0$. The probability of filling a vacancy is given by $q(\theta) = m(\theta)/\theta$, with $q'(\theta) < 0$. I assume a CES matching function, in the with the literature (see e.g., Menzio and Shi 2011).

Timing In $t = 1$, all agents start unemployed. Firms open vacancies and post wages. Workers apply to one job offer and take their consumption-savings decision. At the end of the period, the matching function determines the matching outcome in each open submarket. In the beginning of period 2, the aggregate productivity state materializes, and a lottery destroys some matches created in the end of period 1 according to the separation function $\lambda(x, z)$. If separated, workers remain unemployed and the job vacant (with zero value). Matched workers get their contract wage, and production takes place.

[13] I will relax this assumption in the quantitative model.

[14] This assumption is needed for the existence of an interior solution for sorting. Generally, one can think about it as assuming that there exist deep-pocketed entrepreneurs who can invest in the quality of their jobs, and higher type jobs require a higher investment (in the same spirit as Acabbi et al., 2022).

Value functions It is natural to write the value functions backwards. In the second (and last) period, the values of employment E and unemployment U are, (given that $a_3 = 0$), $E_2(a_2, w) = u(Ra_2 + w)$, and $U_2(a_2) = u(Ra_2 + b)$. For simplicity of exposure and without loss of generality, in what follows I set $b = 0$. The value of a filled job, given that wages and productivity are fixed, is simply $J(x, w) = \bar{y} - w$.

In period 1, the firm decides to open a vacancy in a certain market by posting a wage, according to the following value function.

$$V(x) = \max_{w} -\varphi(x) + \beta\Lambda(x)q(\theta)J(x, w),$$

where $\Lambda(x) = \mathbb{E}_z(1 - \lambda(x, z))$ is the expected retention rate. Given that in this model the aggregate state only affects separation probabilities and not the continuation value functions (J, E, U), what is relevant to agents is the *expected* retention, not its cyclicality.[15] Unemployed workers' problem is to save a_2 subject to the liquidity constraint $\underline{a}$, and to choose a submarket (x, w) to which to apply. Their value function writes

$$U_1(a_1) = \max_{a_2 \geq \underline{a}, (x,w)} u(Ra_1 - a_2) + \beta[m(\theta)\Lambda(x)E_2(a_2, w) + (1 - m(\theta)\Lambda(x))U_2(a_2)]$$

Relevant to the unemployed' labor market search is only the *expected* retention. A search in a high-type job x affects the continuation values through the retention rate $\Lambda(x)$ (exogenously), as well as through the matching probability $m(\theta)$ (endogenously). As will become clear below, if these forces move in opposite directions, the sign of sorting depends on which of the two prevails.

Free entry The measure of entrant firms is determined by competitive entry. This implies that in equilibrium, the value of open vacancies is zero, i.e., the cost of opening a vacancy is equal to the expected value of the job. Formally,

$$\varphi(x) \geq \beta\Lambda(x)q(\theta)J(x, w) \qquad \forall x \in \mathcal{X} \tag{1.2}$$

[15] One may also assume that the aggregate productivity affects continuation value functions. In this case, agents would care about expected continuation value instead of expected retention rate only. This mechanism is present in the quantitative model.

and $\theta(x,w) \geq 0$ with complementary slackness:

$$\theta(x,w) = \begin{cases} q^{-1}\left(\frac{\varphi(x)}{\beta\Lambda(x)J(x,w)}\right) & \text{if } \beta\Lambda(x)J(x,w) > \varphi(x) \\ 0 & \text{otherwise} \end{cases} \tag{1.3}$$

For a given job type x, the free-entry condition pins down the tightness as a function of wages in any submarket that is visited by a positive number of workers. It provides firms' indifference curves in the menu of market tightness and wages; posting a high wage has to be compensated with high job filling probability.

3.2 Equilibrium and positive wealth sorting

To solve for the equilibrium allocation, and as is usual in the directed search literature, I consider the unemployed optimal search and the firms' optimal posting strategy jointly. Effectively, unemployed workers take the firms' indifference condition as given. We can then analyze the problem as a maximization with non-linear Pareto frontier $U(a,x)$, which denotes the value to the worker with assets a when matched with job type x. Conditional on a search with job type x, the maximization problem of an unemployed writes

$$\begin{aligned} U(a_1,x) = \max_{a_2,\theta} \quad & u(c_1) + \beta\left[m(\theta)\Lambda(x)u\left(Ra_2+w\right) + (1-m(\theta)\Lambda(x))u(Ra_2)\right] \\ \text{s.t.} \quad & c_1 + a_2 = Ra_1 \\ & w = \bar{y} - \frac{\varphi(x)}{\beta q(\theta)\Lambda(x)} \end{aligned}$$

The first order conditions (FOC) with respect to a_2 and θ are, respectively:

$$-u'(c_1^*) + \beta R\left[m(\theta^*)\Lambda(x)u'\left(c_{e,2}^*\right) + (1-m(\theta^*)\Lambda(x))u'(c_{u,2}^*)\right] = 0 \tag{1.4}$$

$$\beta\Lambda(x)\left[m'(\theta^*)\left(u\left(c_{e,2}^*\right) - u(c_{u,2}^*)\right) + u'\left(c_{e,2}^*\right)\frac{\varphi(x)\theta^* q'(\theta^*)}{\beta q(\theta^*)\Lambda(x)}\right] = 0 \tag{1.5}$$

where $c_1^* = Ra_1 - a_2^*$, $c_{e,2}^* = Ra_2^* + \bar{y} - \frac{\varphi(x)}{\beta q(\theta^*)\Lambda(x)}$ and $c_{u,2}^* = Ra_2^*$.

The first condition is an Euler equation where $t = 2$'s consumption depends on the

probability of match and match outcome; the second condition pins down market tightness for a given type x.

The worker takes the firm payoff as given – like a menu of value functions for all possible θ, and chooses the firm type that maximizes her expected utility. From the first order condition, it must hold that $\frac{\partial U(a_1,x)}{\partial x} = 0$. The optimality condition for the choice of x can be written as

$$\frac{\Lambda'(x)}{\Lambda(x)} = \frac{-u'(c_{e,2^*})}{u(c^*_{e,2}) - u(c^*_{u,2})} \left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta^*)(\Lambda(x))^2} \right) \tag{1.6}$$

In equilibrium, Eq. (1.25) - (1.27) determine whether wealth sorting is positive or negative. I define wealth sorting to be positive whenever ex-ante wealthier agents apply to relatively higher type jobs – negative sorting would induce them to apply to relatively lower type jobs. Proposition 1 gives the sufficient conditions for the equilibrium of the two-period model to feature positive wealth sorting.

Proposition 1. *Wealth sorting is positive if*

$$\frac{u'(c_{e,2}) - u'(c_{u,2})}{u(c_{e,2}) - u(c_{u,2})} < \frac{u''(c_{e,2})}{u'(c_{e,2})} \tag{1.7}$$

$$\frac{\varphi'(x)}{\varphi(x)} > \frac{\Lambda'(x)}{\Lambda(x)}(1+\gamma) \tag{1.8}$$

Moreover, the equilibrium is unique.

Proof. See Appendix A2. □

Inequality (1.7) is satisfied for all utility functions featuring Decreasing Absolute Risk Aversion (DARA) (Eeckhout and Sepahsalari, 2024). In directed search models, workers choose which job offers to apply to by weighing the value of a job against the probability to get it (or the waiting time). When workers are ex-ante heterogeneous in their wealth levels, face liquidity constraints, and have a DARA utility, they value the matching probability

in a heterogeneous way. In particular, poor agents use the labor market as an insurance mechanism by applying to short queues with a high probability of matching as they desire to smooth consumption. Risk aversion is thus a key force in this model, as it makes workers relatively more sensitive to consumption smoothing. To gain further insights into the mechanism, I solve the model numerically and parametrize it such that equations (1.7) and (1.8) hold. Figure A5 presents the equilibrium under different calibrations of risk aversion. While the equilibrium is qualitatively similar, when agents are more risk-averse, they direct their search towards relatively worse jobs, ceteris paribus. This effect is strongest the lower the unemployed workers' wealth. Higher risk aversion implies a higher probability of match, and the difference is largest at the bottom of the wealth distribution.

While the first condition determines which types of workers look for high matching probability jobs, Eq. (1.8) instead governs which types of jobs are the ones associated with a higher effective probability of being employed. First, this condition guarantees that high-type firms are those posting higher wages in equilibrium, and therefore having the longest queues. To understand why it is the case, it is useful to think about the firm indifference curves in the menu of wages and tightness. From the free entry condition (1.2), it is easy to show that the rate of substitution between wages and tightness decreases with firm type whenever the following holds

$$\frac{\varphi'(x)}{\varphi(x)} > \frac{\Lambda'(x)}{\Lambda(x)} \tag{1.9}$$

Intuitively, φ determines firms ex-post profits and Λ the expected duration (and thus value) of a filled vacancy. When the marginal benefit from opening a higher type job outweighs the marginal decrease in job duration, then the search costs in terms of foregone production increase with firm type. Therefore, to accept a lower job filling probability, high type jobs need to be compensated by relatively lower wages compared to low type jobs.

Second, introducing job separations that are decreasing in firm's type directly decreases the insurance of searching for low type jobs. While Eq. (1.9) ensures that $q(\theta)$ is increasing with type x, in a positive wealth sorting equilibrium it must be that the *effective* probability to find a job $m(\theta)\Lambda(x)$ is decreasing in x. Eq. (1.8) ensures that this is the

case by correcting Eq. (1.9) for the different elasticity of the job finding and job filling probabilities. With CES matching function, this takes the form $(1+\gamma)$. Intuitively, the endogenous variable $q(\theta)$ must move enough so to counteract the exogenous force $\Lambda(x)$.

Relationship to exiting papers Besides a different notion of equilibrium, the key difference with Eeckhout and Sepahsalari (2024) is that I introduce a force that directly decreases the insurance motive of searching for low type jobs (the decreasing separation rate by job type). Through the free entry condition, I can moderate the conditions under which this force outbalances the endogenous force which is going through the market tightness. In the baseline model, if the separation function is such that the *expected* retention is equal across job types, i.e., $\Lambda'(x) = 0$, then, just like in Eeckhout and Sepahsalari (2024), Eq. (1.7) is a sufficient condition for positive wealth sorting. If cyclicality in the separation function impacts continuation values, as previously discussed, the condition is no longer sufficient, but positive wealth sorting may still obtain.
The coexistence of low wage and low security jobs is consistent with what Jarosch (2023) estimates in Germany. The dual labor market is also an example of the coexistence of low-wage, low-security jobs alongside high-wage, high-security jobs. More generally, the fact that low-paid jobs are relatively more likely to get destroyed is consistent with the theory of cleansing effects of recessions, if low wages reflect a lower firm productivity. Having heterogeneous firm productivity is irrelevant in the two-period model, but I will integrate it in the quantitative model.

Equilibrium allocation Positive wealth sorting implies that asset-poor agents self-select into high matching probability jobs as they smooth their consumption, consistently with empirical evidence.[16] Moreover, asset-poor workers' optimal search imply that upon matching, they get relatively lower wages and lower job security. Because of risk aversion and the liquidity constraint, workers' need to self insure outweighs the "costs" of matching

[16]E.g., Card et al. (2007); Chetty (2008); Lammers (2014); Herkenhoff et al. (2024); He and le Maire (2020); Fontaine et al. (2020); Bednarzik et al. (2021). See the literature review for more information.

in low wage and low security jobs. Any force that either increases the need for insurance (e.g., higher risk aversion, tighter liquidity constraints) or decreases the "cost" of searching for bad jobs (e.g., more homogeneous separation rates) strengthens the motive for positive wealth sorting.[17]

More generally, with an infinite horizon and aggregate risk, both the need for insurance and the "cost" of searching for bad jobs may increase. The former because in a recession it is overall more difficult to find a job, and the latter because bad jobs imply a higher chance of becoming unemployed, especially when it is more costly to do so (in bad times). In this two-period model, I assume that the aggregate state affects only the separation function and not the second period's values of consuming for employed and unemployed workers ($u\left(Ra_2 + w\right)$ and $u\left(Ra_2\right)$ are independent of z). Effectively, agents thus factor in the *expected* separation risk, and not directly its cyclicality. However, sorting in an infinite horizon model does depend on the cyclicality, through the continuation values of employment and unemployment. To illustrate how cyclicality matters for sorting, one straightforward extension is to allow the continuation value of employment to depend on the aggregate state so as to reduce the insurance that working provides. In particular, it is easy to assume that the value of working is lower in bad states and higher in good states, relative to the benchmark model. In this case, Eq. (1.7) is no longer sufficient to ensure positive wealth sorting, even when (1.8) holds. Instead, the condition need for positive sorting is more stringent, as it must hold in expectations (see Appendix A8 for more details). This illustrative model is useful to understand that both the cross-sectional and cyclical risk heterogeneity matter for sorting, and both dimensions make *positive* sorting more difficult to obtain.

The quantitative model fully accounts for these additional channels and allows studying the effects of positive wealth sorting on the dynamics of wages and employment over the business cycle.

[17] Kaplan and Violante (2022) highlight the empirical and quantitative relevance of the so-called "wealthy hand-to-mouth" – workers with low liquidity but a significant amount of illiquid wealth (e.g., in housing). In this project, I abstract from illiquid assets for tractability reasons. However, my mechanism in theory would also be relevant for wealthy hand-to-mouth, as long as it is less costly for them to adapt their labor market search than transfer their illiquid asset.

4 Quantitative model

In this section, I embed the mechanisms outlined in the preceding section into a quantitative model featuring aggregate uncertainty.

Environment Time is discrete, and the economy is infinitely lived. As in the two-period model, the economy is populated by a continuum of risk-averse agents with asset holdings $a_t \in \mathcal{A} = [\underline{a}, \bar{a}] \subset \mathbb{R}_+$, and a continuum of risk neutral one-employee firms, with (observable) productivity $x \in \mathcal{X} = [\underline{x}, \bar{x}] \subset \mathbb{R}_+$. Agents have a period utility function $u(\cdot)$, which is increasing ($u'(\cdot) > 0$) and concave ($u''(\cdot) < 0$). They discount the future at rate β, they can save at the risk-free interest rate $R = 1 + r$ and can borrow up to a constraint $\underline{a}$. The interest rate is determined by the world market and taken as given. Firms have the same discount factor as workers.

When they work, employed agents earn a fixed wage $w \in \mathcal{W}$ which is match-specific. When unemployed, they earn unemployment benefits b_t which are financed by proportional wage taxes τ collected by the government.

Aggregate productivity $z \in \mathcal{Z}$ evolves according to a Markov transition probability $\pi(z_t, z_{t+1})$. Firms produce output $f(x_t, z_t)$ using labor as the only factor of production, and a final good competitive firm pools individual output and transforms it to a consumption good. The aggregate state of the economy, including the distribution of workers and the aggregate productivity state, is denoted with Γ.

Labor markets Job search is directed, and there is a separate submarket for each productivity and wage so that they do not compete directly with one another. There is free entry in every submarket and firms have to pay a vacancy cost $\varphi(x_t, z_t)$. I allow the entry cost to vary with type and aggregate productivity for the calibration. Each entrant firm posts wages w promised to the workers upon match formation and for the entire duration of the match. Firms have limited commitment in the sense that they can fire workers if the value of a filled job becomes negative.[18] Unemployed workers choose to

[18]This assumption is not material to the results. However, it allows to bound the expected surplus function from below, to allow firms to open vacancies even if in expectations they generate negative value. In the calibrated model, job destruction coming from this assumption is immaterial.

apply to (only) one submarket $(x_{t+1}, w_{t+1}; \Gamma_t)$, and workers do not search on the job.[19] The firm-to-worker ratio in each submarket is denoted $\theta_t(x_{t+1}, w_{t+1}; \Gamma_t)$.[20] Matching is governed by a matching function $m(\theta_t)$ that is twice continuously differentiable, strictly increasing, strictly concave, and such that $m(0) = 0,\ m'(0) < \infty$. The probability of filling a vacancy is given by $q(\theta_t) = m(\theta_t)/\theta_t$, with $q'(\theta_t) < 0$. Matches are exogenously separated with a probability that is decreasing in the firm type and function of the aggregate state of the economy, i.e., $\lambda(x_t, z_t), \lambda_x < 0, \lambda_z < 0$.

Timing Within a period, there are the following four phases. (i) the aggregate shock materializes and some existing matches get endogenously destroyed, others get exogenously destroyed; (ii) firms with type x decide whether to open a vacancy, in which case they post wages; (iii) unemployed workers apply to a job offer and take their consumption-savings decision, employed workers choose optimal savings; (iv) agents potentially match on the labor market (the matching function determines the outcome) and production takes place. Matches become productive next period – if they do not get destroyed before production.

4.1 Value functions

Unemployed workers choose in which market to apply (summarized by the contract pair (x_t, w_t)) and solve a standard consumption saving problem

$$U(a_t; \Gamma_t) = \max_{a_{t+1}, (x_t, w_t)} u(c_{u,t}) + \beta \mathbb{E}_t \left[m(\theta_t) E(a_{t+1}, x_t, w_t; \Gamma_{t+1}) + (1 - m(\theta_t)) U(a_{t+1}; \Gamma_{t+1}) \right]$$
$$\text{s.t.} \quad c_{u,t} + a_{t+1} = R a_t + b_t, \qquad a_{t+1} \geq \underline{a} \tag{1.10}$$

Employed workers with wage w_t simply choose savings

$$E(a_t, x_t, w_t; \Gamma_t) = \max_{a_{t+1}} \quad u(c_{e,t}) + \beta \mathbb{E}_t \left[\lambda(x_t, z_t) U(a_{t+1}; \Gamma_{t+1}) + (1 - \lambda(x_t, z_t)) E(a_{t+1}, x_t, w_t; \Gamma_{t+1}) \right]$$
$$\text{s.t.} \quad c_{e,t} + a_{t+1} = R a_t + (1 - \tau) w_t, \qquad a_{t+1} \geq \underline{a} \tag{1.11}$$

[19] These assumptions are crucial for the tractability of the model, in particular for it to be block recursive. See proposition 2 and Appendix A3 for further details.

[20] For notational simplicity and in an abuse of notation, I hereon write θ_t to denote the tightness in a specific submarket.

, where τ are (exogenous) taxes.

The value of posting a vacancy in a specific submarket with productivity x is

$$V(x_t, \Gamma_t) = \max_{w_t} \quad -\varphi(x_t, z_t) + \beta \mathbb{E}_t \left[q(\theta_t) J(x_t, w_t; \Gamma_{t+1}) + (1 - q(\theta_t)) V(x_{t+1}; \Gamma_{t+1}) \right] \tag{1.12}$$

The value of a filled job in submarket (x_t, w_t) is

$$\begin{aligned} J(x_t, w_t; \Gamma_t) = \max\{0; \\ f(x_t, z_t) - w_t + \beta \mathbb{E}_t \left[\lambda(x_t, z_t) V(x_{t+1}; \Gamma_{t+1}) + (1 - \lambda(x_t, z_t)) J(x_t, w_t; \Gamma_{t+1}) \right] \} \end{aligned} \tag{1.13}$$

Note that both firm productivity and wages are fixed over the employment duration. The max operator comes from limited commitment by firms. At the beginning of the period, the aggregate productivity materializes, and existing matches may be subject to destruction. If firms exit the market, they send their workers to unemployment and get payoff 0. This ensures that firms do not refrain from opening vacancies even if the expected value is negative.

Free entry Free entry drives the value of posting a vacancy to zero. The expected value of the job is then equal to the fixed cost of opening a vacancy, i.e.,

$$\beta \mathbb{E}_t \left[q(\theta_t) J(x_t, w_t; \Gamma_{t+1}) \right] = \varphi(x_t)$$

Which pins down the market tightness for markets that are visited by unemployed workers. The concept follows the notion of subgame perfect equilibrium. For unvisited markets, the market tightness is equal to zero. Given the functional assumptions stated above, it holds

$$\theta_t(x_t, w_t; \Gamma_t) = \begin{cases} q^{-1}\left(\frac{\varphi(x_t)}{\beta \mathbb{E}_t [J(x_t, w_t; \Gamma_{t+1})]} \right) & \text{if } \beta \mathbb{E}_t \left[J(x_t, w_t; \Gamma_{t+1}) \right] > \varphi(x_t) \\ 0 & \text{otherwise} \end{cases} \tag{1.14}$$

Government In an extension of the model, I introduce a government to fund the unemployment benefits. The government pools income taxes and redistributes them to the

unemployed. I do not assume a balanced budget in every state, but that in the stochastic steady state it holds that

$$\mathbb{E}_z \int^{\Psi^e} \tau w = \mathbb{E}_z \int^{\Psi^u} b \tag{1.15}$$

, where Ψ^e denotes the stationary distribution of employed workers and Ψ^u that of unemployed workers. This condition implies a balanced budget in expectations. On the one hand, this avoids having a cyclical unemployment benefit or tax. On the other hand, it is also relevant for block recursivity, as will become clear in the next section.

4.2 Equilibrium characterization

Definition 1. *Let $\Gamma = \Omega \times \Psi \times \mathcal{Z}$. A recursive equilibrium for the baseline economy consists of a set of value functions for workers $U : \mathcal{A} \times \Gamma \to \mathbb{R}$ and $E : \mathcal{A} \times \mathcal{W} \times \Gamma \to \mathbb{R}$; a value function for entrant firms $J : \mathcal{X} \times \mathcal{W} \times \Gamma \to \mathbb{R}$; a set of policy functions c_u, c_e, x, w; a market tightness function $\theta : \mathcal{X} \times \mathcal{W} \times \Gamma \to \mathbb{R}_+$; a destruction productivity function $\ell : \mathcal{X} \times \mathcal{W} \times \Gamma \to \{0, 1\}$; such that:*

[i)]

1. *U and E satisfy, respectively, Eq.* (1.10) *and* (1.11)*, taking taxes τ as given. c_u and $c_{e,x}$ are the associated policy functions.*

2. *V and J satisfy, respectively, Eq.* (1.12) *and* (1.13)*, and w is the associated policy function.*

3. *Market tightness satisfies* (1.14)*, for all submarkets (x, w, Γ).*

4. *Γ satisfies the policy and contract policy functions, as well as the exogenous low of motion for aggregate productivity, which evolves according to a Markov chain with transition probability $\Xi(z_t, z_{t+1})$.*

Under some restrictive assumptions, the model admits a *block* recursive equilibrium.

Definition 2. *A Block Recursive Equilibrium (BRE) is a recursive equilibrium in which the functions $\{\theta, E, U, J, \ell\}$ only depend on the aggregate state of the economy Γ through the aggregate state of productivity z.*

In general, BRE obtains as long as workers' policy and value functions are independent of the distribution of workers across employment states (Menzio and Shi, 2010). Under some additional assumptions, this is true even when the asset distribution is a state variable of the steady state and in the presence of sorting.

Proposition 2. *The baseline quantitative model is block recursive.*

Proof. See Appendix A3. □

The combination of separated submarkets and the free entry condition is central to the existence of a BRE. To get some intuition of why the equilibrium is BR, assume that J depends on Γ solely through the aggregate component of productivity z. Importantly, I assume that firms do not observe workers' wealth when posting job contracts. Then, free entry implies that θ is also independent of Ψ (see Eq. 1.14). In fact, free entry determines the number of vacancies in each submarkets, independently of the distribution of workers across the employment distribution. The support of market tightness, i.e., the open markets in equilibrium, is function of the distribution of workers across employment and asset states, but is immaterial for workers' value functions. The unemployed workers' jobs search problem is thus also independent of Γ, as it merely depends on exogenous parameters and the job finding probability (function of market tightness θ). It follows that the values of search and unemployment also only depend on z. Directed search is a crucial assumption here, as if it were undirected, the worker would need to evaluate the whole distribution of open vacancies. As for the consumption-savings decision of both employed and unemployed workers, it is independent of Γ given that we assume the interest rate r to be exogenous to their savings decision. Therefore, the workers value functions and policy functions are independent of Γ. We can then prove that the mapping is a contraction, therefore that the solution is such that the equilibrium is block recursive.

Block recursivity implies that one can solve for the equilibrium of the model without keeping track of the distribution of agents over asset or employment states. It therefore offers a relatively tractable way to solve a fully stochastic dynamic equilibrium. I solve the model numerically with a nested algorithm and using policy and value function iteration; see Appendix A6 for more details.

The extended model with a government taxing the working population to finance unemployment benefits is still BR. The assumption of having a tax rate balancing the stationary distribution and not the period distribution is key. In particular, the tax rate is fixed and can be treated as a parameter by agents. Numerically, I solve the model for a guess of τ, verify the government balance constraint, and adapt the initial guess of τ accordingly, until the constraint is met.

4.3 Calibration and steady state

I calibrate the model at a monthly frequency for the United States. Functional forms are listed in Appendix Table A7, externally calibrated parameters in Table 1.2 and internally calibrated parameters in Table 1.3. The utility and matching functions are taken from standards in the literature. I assume a CRRA utility function with an intertemporal elasticity of substitution σ equal to 2. I follow Menzio and Shi (2011) and choose a standard CES matching function. I set the interest rate to target a 2 percent annualized real rate in steady state. I follow the standard and set the borrowing constraint to $\underline{a} = 0$. Important for the mechanism is that the borrowing constraint exists, not necessarily that it is binding. In fact, because of unemployment benefits, unemployed workers never consume zero. As explained below in more detail, what matters ultimately is the liquidity when unemployed, which is the sum of assets and benefits. I calibrate the discount factor β to target an average annual MPC consistent with the literature.[21] Given my focus on *residual* inequality, the model is in nature parsimonious. My calibration exercise focuses on calibrating the dispersion and cyclicality of matching and separation rates. I thus assume a separation function that depends both on the firm type and on aggregate productivity, following Birinci and See (2023). $\bar{\lambda}$ is the average separation rate, which I choose to target the average EU rates; η^{λ_z} captures the cyclicality of the job destruction rate; and η^{λ_y} captures the dispersion of the job destruction rate across firms. Similarly, I choose the vacancy cost function to have the same functional form and calibrate parameters $(\bar{\varphi}, \eta^{\varphi_y}, \eta^{\varphi_z})$ to match, respectively, the average matching probability, the cross-sectional dispersion in matching by assets, and the cyclicality of matching.

[21] The corresponding annual MPC is 0.46, computed as $mpc_a = 1 - (1 - mpc_m)^{12}$.

Unemployment benefits are important in this model, as they affect the utility cost for unemployed workers to be at the borrowing constraint. A generous unemployment benefit makes it generally less costly to be in that state, thereby decreasing the urgency for these workers to find a job. I set b to target a replacement rate of 40% for the lowest paid jobs.[22] I target γ to match an average elasticity of the matching function to tightness of 0.5, in line with the literature (see e.g., Chaumont and Shi, 2022). The average vacancy cost is tightly connected to the average matching rate, which I target to 25%. The average separation rate is targeted to replicate the monthly E-U flow of 1.7%. I calibrate the dispersion of vacancy cost by firm type to match the standard deviation of residual wages observed in the data (in progress). In particular, "total" residual wage dispersion is on average 0.46-0.56 (Morin, 2019), while "matching" dispersion is on average between 0.25 and 0.3 (Cannon and Mustre-del Rio, 2017). I match the standard deviation of matching and separations using the cyclicality of vacancy cost and separation rate, respectively.

Table 1.2: External calibration

Parameter	Definition	Value	Parameter	Definition	Value
Households			*Productivity*		
r	interest rate	0.0016	ρ_z	TFP, persistence	0.918
σ	risk aversion	2.0	σ_z	TFP, standard deviation	0.004
$\underline{a}$	borrowing limit	0.0			

[22]Unemployment benefits in this model are meant to capture only the pecuniary value of benefits.

Table 1.3: Internal calibration

Param	Definition	Value	Target moment	Model	Data
β	discount factor	0.990	average MPC	0.039	0.03-0.056 (Literature)
b	unemployment benefits	3.1	replacement rate	0.321	40% (Shimer, 2005)
γ	matching elasticity	0.38	elasticity of m to θ	0.50	[0.27-0.5] (Literature)
	Separation rate				
$\bar{\lambda}$	average separation rate	0.03	average λ	0.016	1.7% (Eeckhout and Sepahsalari, 2024)
η^{λ_x}	- dispersion by firm	-0.24	dispersion λ	0.0124	0.012 (CPS)
η^{λ_z}	- cyclicality	30.00	std. λ	0.0024	0.002 (CPS, std. EU rate)
	Vacancy cost				
$\bar{\varphi}$	average vacancy cost	1.00	average $m(\theta)$	0.172	25% (Eeckhout and Sepahsalari, 2024)
η^{φ_x}	- dispersion by firm	1.00	dispersion $m(\theta)$	0.117	0.063 (CPS)
η^{φ_z}	- cyclicality	65.00	std. $m(\theta)$	0.0100	0.069 (CPS, std. UE rate)

The model replicates well the median income to asset ratio, as I compute in the PSID – using the variables described in Appendix A1.

Table 1.4: Non targeted moments

Moment	Model	Data
unemployment rate	0.085	6% (FRED)
std. unemployment rate	0.014	0.0165
avg (w/a)	0.256	53% (PSID)
sd(w)	0.333	0.3 (residual wage dispersion, Morin 2019)

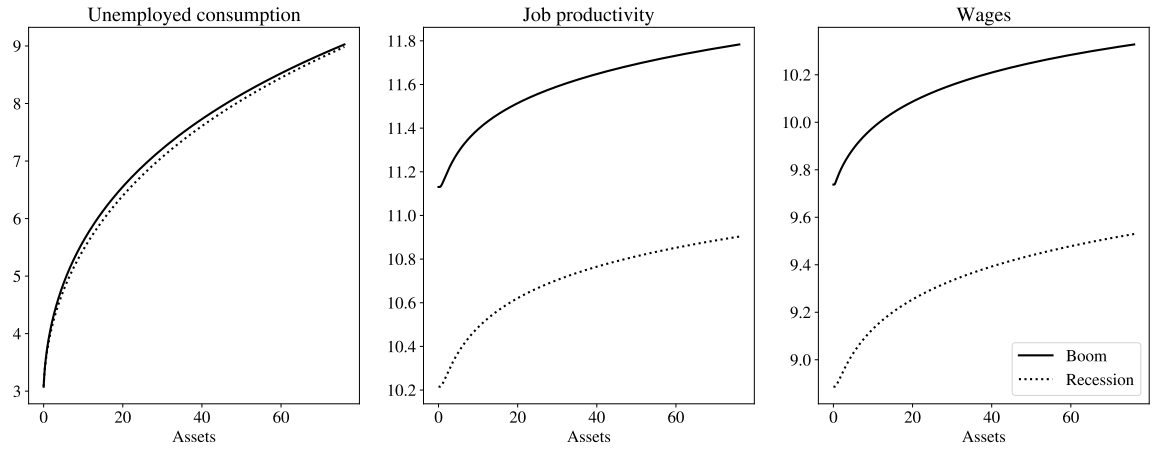
4.4 Consumption and job search policy functions

Figure 1.2 illustrates the consumption and job search behavior of unemployed workers as a function of their asset holdings. The consumption policy function follows a standard pattern (left panel). The middle and right panels, respectively, plot the choice of wages and firm type as a function of assets. As shown by the monotonically increasing lines, the equilibrium exhibits positive wealth sorting, i.e., wealthier individuals apply to higher-productivity jobs that also offer higher-wage ("good" jobs), while poorer workers target lower-productivity jobs that offer lower-wage ("bad" jobs). The driving mechanism is the shorter queue length in bad jobs, which implies a higher probability of match in those submarkets. Since asset poor individuals are at risk of becoming hand-to-mouth

and thereby off their Euler equation, they prefer to search in submarkets that offer a relatively higher probability of match. Instead, wealthy unemployed workers are far from the borrowing constraint and prefer to target a relatively high wage, thereby accepting a longer waiting time. The solid and dotted lines plot the policy functions under different states of aggregate productivity. Low aggregate productivity states mute the job creation motive. Together with the increased probability of separations (by assumption), this implies a slacker labor market and therefore an overall lower matching probability. If unemployed were to keep their job search unchanged, the lower tightness would induce them to decrease their consumption today. Agents thus balance consumption smoothing against job search and future income prospects. When aggregate productivity is low, unemployed workers shift their search towards "worse" jobs (lower wages and lower productivity jobs) in an effort to smooth their consumption. In the presence of incomplete markets, the labor market thus provides some insurance to unemployed workers – in the spirit of Acemoglu and Shimer (1999), at the same time implying a cyclicality of wages and employment risk. Wages decrease relatively more than productivity in bad times.

Appendix Figure A7 shows the consumption policy function for employed workers in different submarkets. Unsurprisingly, those employed in bad jobs consume less as they earn lower wages and face a higher separation probability.

Figure 1.2: Unemployed workers policy functions

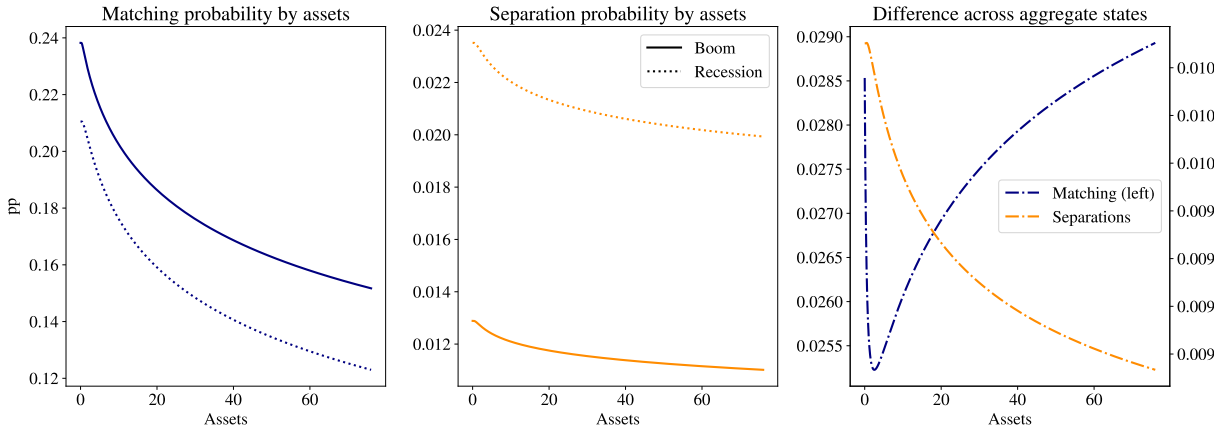


Note: The solid (dotted) lines represent unemployed workers' smoothed policy functions when the aggregate state is good (bad).

The left panel of Figure 1.3 plots the matching probabilities by assets, which reflects

the choice of submarkets. By directing their search towards bad jobs, poor workers have around 20% probability of exiting their precarious unemployment state (versus around 15% for the wealthiest). Wealthier workers are willing to wait longer (direct their search towards markets featuring low probability of matches) to get good jobs. Although unemployed shift their search towards relatively lower productivity jobs in bad times, the matching probability of all unemployed remains lower than in good times – consistently with empirical evidence on the pro-cyclicality of market tightness. Given the assumption of decreasing job separation by firm productivity, positive wealth sorting implies a higher probability of separation for poorer employed workers, especially in times of low aggregate productivity (middle panel). The right panel plots the difference of the matching and separation probabilities across good and bad times. When moving from a boom to a recession, matching and separation probabilities of poor agents increase relatively more than for the wealthy. This can be seen as a theoretical counterfactual of the empirical evidence presented in Section 2.

Figure 1.3: Matching and separation probabilities



Note: All lines are smoothed. The right panel plots the difference between the solid and dotted lines of the left and middle panels.

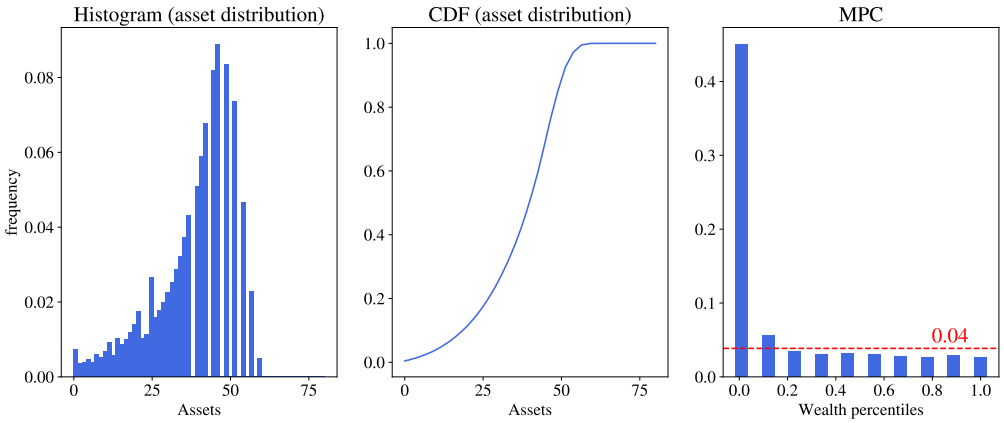
Appendix Figure A8 plots the value of filled vacancies ordered by the markets populated by workers with increasing assets. Jobs employing poor workers are also the ones that have the lowest value. This arises endogenously monitored by the calibration of the entry

cost function of the firms.[23]

4.5 Stationary distribution

The (stochastic) steady state of the model supports a stationary distribution of agents of states. Figure 1.4 plots the distribution of agents over assets, as well as the cumulative distribution function (CDF). While the majority of agents have substantial savings, a non-negligible share of the population holds zero assets. On the right panel, I plot the marginal propensity to consume (MPC) by wealth percentiles. The fact that the lowest percentiles exhibit an MPC close to 1 indicates tight liquidity constraints, which in turn are associated with a strong incentive to look for high matching probability jobs.

Figure 1.4: Steady state distribution of agents over assets



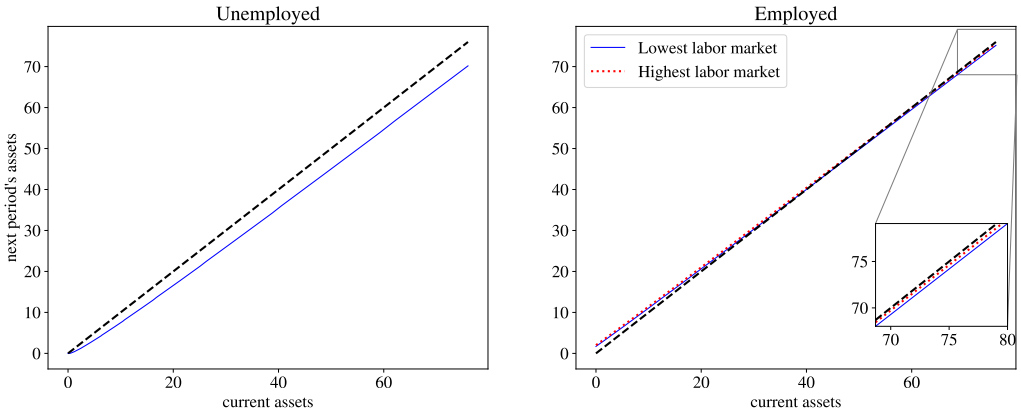
Note: The left and middle panels show the stationary asset distribution. On the right panel, the vertical bars show the marginal propensity to consume (MPC) of workers in different wealth percentiles, and the red dashed line represents the aggregate monthly MPC.

In equilibrium, workers with higher levels of assets are more likely to earn higher wages and have relatively more secure jobs. This dynamic could, in theory, set off a path of explosive asset accumulation, undermining the existence of a stationary equilibrium.

[23]This result suggests the possibility of endogenizing the separation function λ within the framework. Suppose firms face the same separation risk, and endogenous job destruction is introduced through a productivity threshold for labor market entry. Firms at the productivity margin are vulnerable to aggregate shocks, with those at the threshold being destroyed following a negative shock. Since ex-post profits increase with productivity, this mechanism implies a higher layoff risk for lower-productivity workers. Only that in that case it would come from a firm endogenous exit and not the separation function.

However, stabilizing forces are sufficient to sustain a stationary equilibrium under the baseline calibration. Specifically, the asset policy function is not diverging even in the highest asset and labor market states, as illustrated in Figure 1.5.

Figure 1.5: Workers' asset accumulation



Note: The 45° line is represented in dashed black. On the right panel, the two lines represent the asset accumulation decisions of workers in the lowest and highest labor market, i.e., those with lowest (highest) wages and productivity.

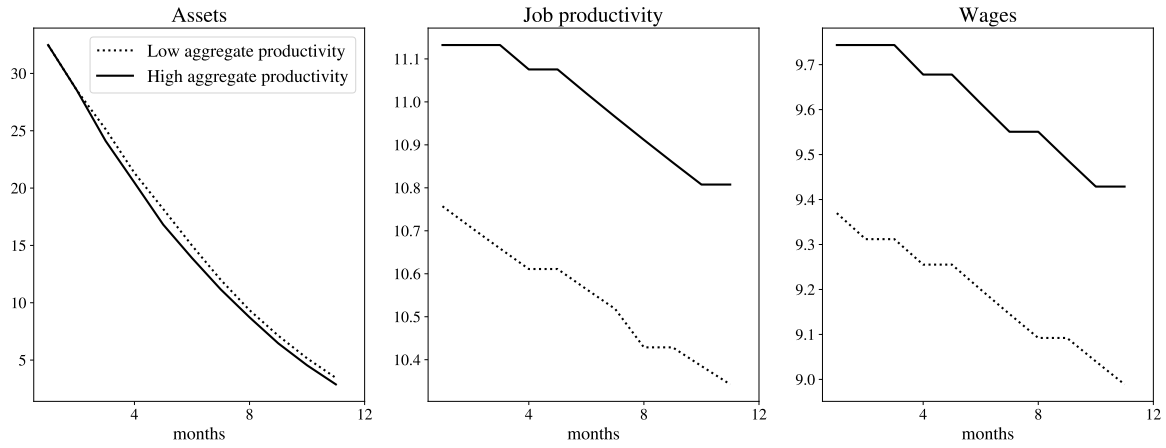
First, all workers face a positive probability of job separation, with separation rates that do not exhibit large cross-sectional variation. Second, workers deplete their assets during periods of unemployment, especially if they enter unemployment with higher initial assets. Figure 1.6 plots the behavior of an unemployed worker holding the mean level of steady state assets, as she continues not to be selected by the matching function (she is unlucky and remains unemployed period after period). The left panel shows the worker's assets over time, while the middle and right panels illustrate her labor market search behavior. The dotted (solid) line represents the worker's choices if the aggregate state is low (high) throughout.

Workers with higher assets direct their search towards good jobs, which implies longer average unemployment duration due the relatively low matching probability associated to these jobs. Consequently, these workers experience longer unemployment spells in which they deplete their asset holdings. Moreover, they do so at a faster pace the higher the initial assets , as visible from the decreasing slope in absolute terms in the left panel. Therefore, although workers with higher assets face a relatively lower probability of job separation, when they become unemployed they deplete their assets faster and for a longer expected

period. Furthermore, within individual workers, negative duration dependence in asset levels drives a shift in search behavior over time, towards lower wages and lower security jobs. In fact, as unemployment lengthens, asset holdings decline, increasing the relative preference for higher-matching probability jobs. This within-worker duration dependence contrasts with the positive duration dependence observed *across* workers, where higher-wage jobs correlate with longer unemployment spells.[24] Therefore, initially wealthier workers may ultimately accept the worst jobs if they experience extended unemployment. This outcome occurs after 12 months of unemployment for an average-wealth worker under baseline calibration.

The aggregate state influences the rate of asset depletion and the job search behavior. In low aggregate productivity states, workers exhibit a stronger precautionary savings motive, which slightly moderates the rate of asset depletion.

Figure 1.6: Average outcomes for cohort starting with the same level of assets

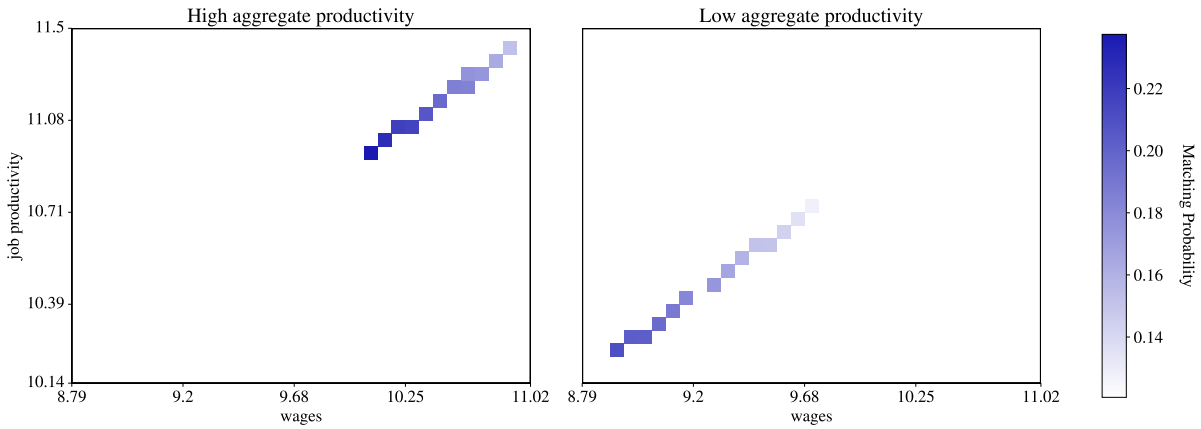


4.6 Wealth sorting over the business cycle

Figure 1.7 plots the distribution of labor markets that are open in equilibrium, in low and high aggregate productivity states. The color bars show the probability of match, $m(\theta)$. Because of both the muted job creation motive and the need for insurance, recessions are times when labor markets feature worse jobs (wages and job productivity are lower).

[24]This is a common feature of directed search models.

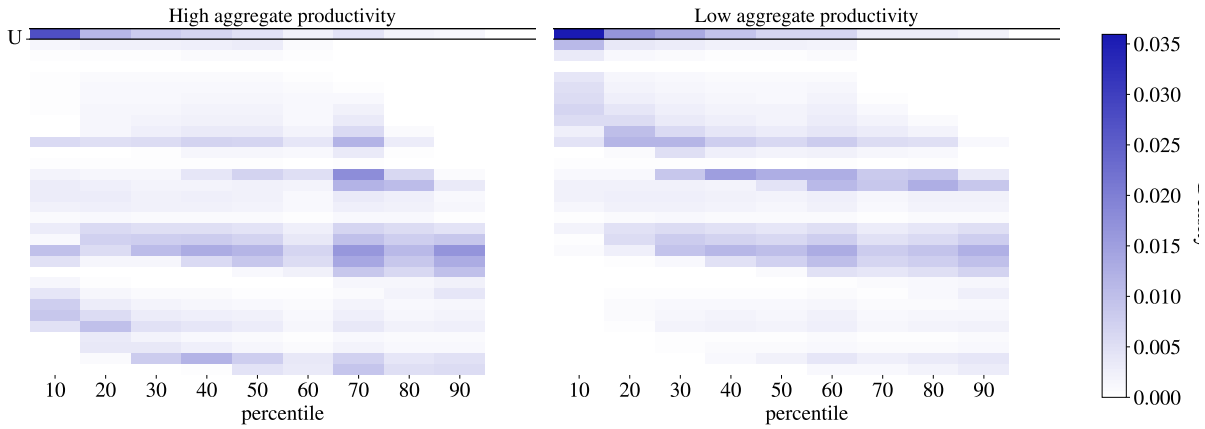
Figure 1.7: Distribution of open labor markets



Note: The left panel shows the distribution of open labor markets (indexed by job productivity x and wages w), under in the "recession" state, while the right panel shows that of the "boom" state. The intensity of coloring represents the matching probability in each open equilibrium labor market – darker color being associated with higher matching probability.

Moreover, the distribution of agents over labor markets also changes with aggregate productivity, as illustrated in Figure 1.8. The first row shows the unemployed, and the rest show the open labor markets ordered in ascending order (the rows at the top are bad jobs, and quality improves as we read rows more to the bottom). Two features are worth mentioning. First, as expected, recessions are times with relatively more unemployed. Second, the distribution is more scattered during booms than in recessions. Looking in the top left corner, we see an increased density of agents that are poor and working in low-quality jobs. At the same time, workers at the top of the asset distribution are less likely to work in these low paid, low security jobs. The density becomes more concentrated on the diagonal, which also means that sorting is stronger in recessions.

Figure 1.8: Steady state distribution of agents over assets



Note: The $x-$axis represents deciles of the asset distributions. The $y-$axis represents workers' labor market status; the first row is the unemployment status, while the other rows represent open labor markets (in ascending order, i.e., the bottom rows are higher productivity and wages jobs relative to the first rows). The intensity of coloring represents the density of agents in each asset bin and labor market state.

Table 1.5: Sorting in booms and recessions

Moment	Aggregate productivity		Difference
	low	*high*	
$\text{corr}(a_i, w_i)$	0.9373	0.9112	0.0261
$\text{corr}(a_i, x_i)$	0.9445	0.9298	0.0147
$\text{corr}(a_i, \Lambda_i)$	0.9382	0.9221	0.0161
$\text{sd}(w_i)$	0.1657	0.1413	0.0245
$\text{sd}(x_i)$	0.1826	0.1617	0.0210

Table 1.5 quantifies the dynamics of wealth sorting during booms and recessions. The strength of sorting can be evaluated by the relative correlation in good and bad aggregate states. As we can read from the positive differences, sorting is stronger in bad aggregate states. This is true by all measures of sorting (assets with wages, productivity, and retention rates). The correlation difference is relatively larger for wages, which is the margin that workers use more to insure their consumption. Moreover, the dispersion of wages and firm productivity is slightly higher in bad aggregate states.

5 Effects of recessions and targeted transfers

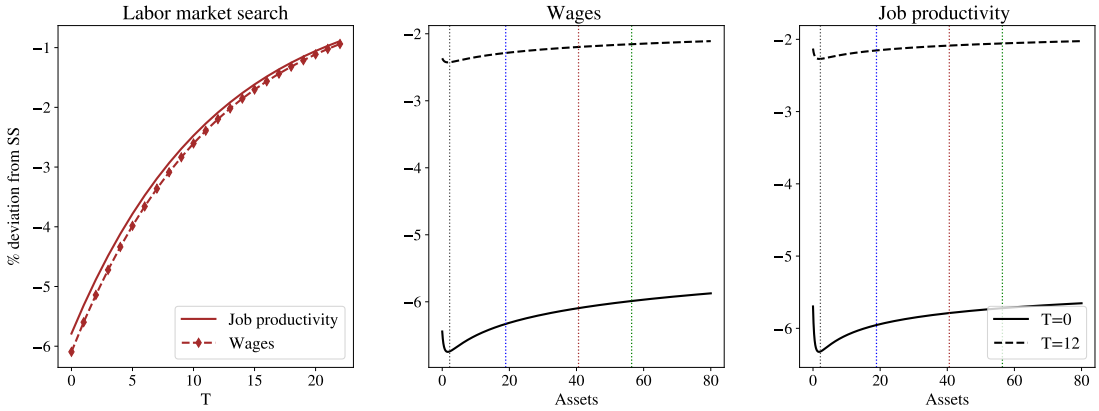
In this section, I first present the impulse response functions (IRFs) to a negative aggregate productivity shocks. I show that unemployed workers primarily adjust their job search behavior rather than their consumption, particularly among the asset-poor. A policy that provides an unexpected one-off transfer is most effective in boosting consumption if it targets the poorest unemployed workers. I then show that wealth sorting has implications for long-run inequalities, as it generates a "poverty trap".

5.1 Short-term responses to a recessionary shock

I simulate the effect of a recession on consumption and job search, both at the individual level and on aggregate. I assume that aggregate productivity follows an AR(1) process such that $z_t = \rho_z z_{t-1} + (1-\rho_z)z^{ss} + \epsilon_t$, where $\epsilon_t \sim \mathcal{N}(0,1)$; and implement a 1% negative aggregate productivity shock.

Figure 1.9 plots the job search response. On the left panel, we see that following a negative aggregate productivity shock, the median job search decreases both in terms of wages and job productivity. Wages and productivity decrease by around 6% on impact. This aggregate response hides important heterogeneity, as shown in the middle and right panels (for wages and productivity, respectively). The vertical lines in the middle and right panels flag percentiles of the distribution (1st, 10th, 50th and 99th percentiles, from left to right). The bottom 1% of the distribution decreases their search by relatively more, and the difference between the bottom and top 1% is of around 1% of wages, and 0.5% of productivity. After a year, the unemployed search shifts up (dashed lines) and also becomes more homogeneous across the wealth distribution. When aggregate productivity is at its lowest, its effect on the search of unemployed workers is thus the largest both in terms of magnitude and heterogeneity across workers.

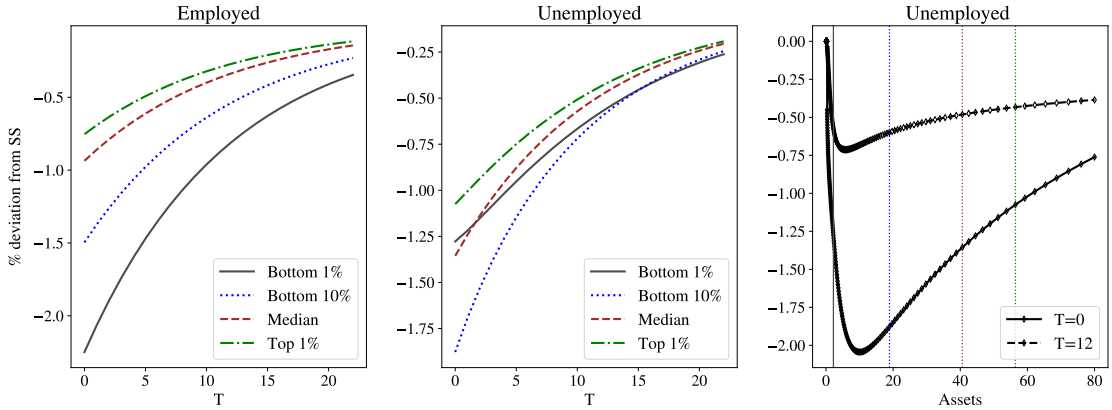
Figure 1.9: Unemployed workers' job search



Note: All panels plot the IRFs to a 1% negative aggregate productivity shock. On the left panel, the two lines correspond to the labor market search of the median unemployed worker. The vertical lines correspond, from left to right, to the bottom 1%, 10%, the median, and the top 1% of the wealth distribution.

The reason why the poorest unemployed adapt their search more can be seen in Figure 1.10 (right panel)– it allows mitigating the drop in their consumption. The left panel of Figure 1.10 instead plots the consumption response for employed workers. Consistently with more standard models, the poorest agents decrease their consumption by relatively more. In the middle panel, we see that besides for the poorest who are hand-to-mouth, the unemployed workers' consumption behavior mirrors that of the employed.

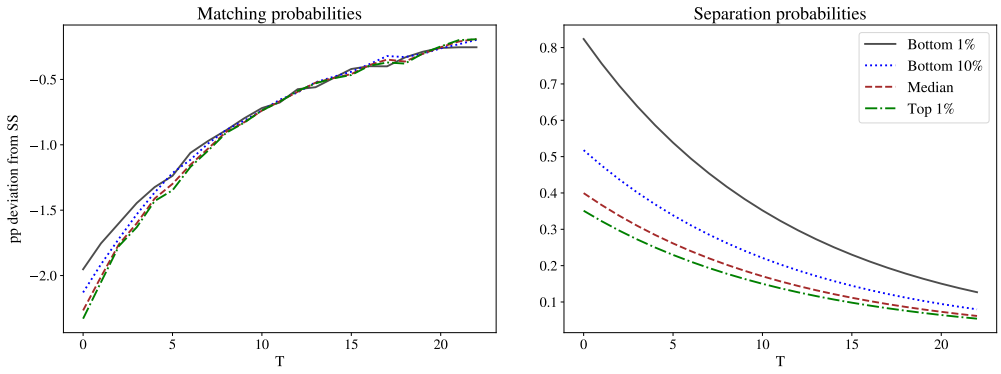
Figure 1.10: Workers' consumption response



Note: All panels plot the IRFs to a 1% negative aggregate productivity shock. On the left panel, lines correspond to workers working in the same submarket but holding different wealth. The vertical lines correspond, from left to right, to the bottom 1%, 10%, the median, and the top 1% of the wealth distribution.

Positive wealth sorting implies a difference matching and separation probability across the wealth distribution. As shows in Figure 1.11, on average, matching decreases and separations increase. Effects are heterogeneous across the wealth distribution. The change in job search of bottom 1% unemployed allows them to mitigate the drop in their matching probability, and they experience the lowest decrease.

Figure 1.11: Matching and separation probability by asset



Note: All panels plot the IRFs to a 1% negative aggregate productivity shock. The different lines represent percentiles of the wealth distribution

However, the heterogeneous effect are stronger in the separation probabilities. On impact, the separation for the poorest 1% is twice as larger relative to the median worker. This difference stays present throughout the shock – which is not the case for the matching probability. Therefore, recessions heterogeneously affect workers mostly through an increase separation probability, and through the consumption response. Positive wealth sorting may thereby serve as a microfoundation of the empirically observed higher employment elasticity of asset-poor to aggregate output fluctuations.

5.2 Targeted transfers and aggregate consumption response

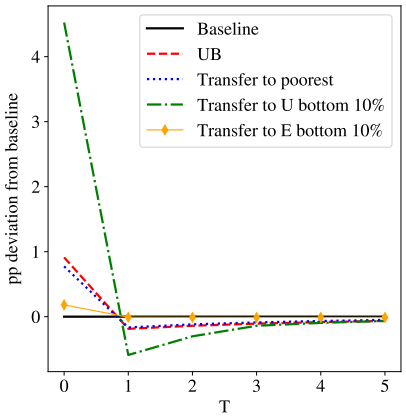
I study the effect of four types of targeted transfers implemented when the aggregate productivity shock hits for aggregate consumption response. Figure 1.12 plots the differential consumption response under policy counterfactuals. In the baseline, the social planner distributes an untargeted transfer to all workers in the first period of the negative

aggregate productivity shock.[25] Agents do not expect it ("MIT" policy shock) and they correctly do not expect the transfer to be reiterated. I set the total value of the transfer to be equal to one-fifth of average wages (this would correspond to a transfer of roughly $1000).

The first policy is a standard unemployment benefit and targets all unemployed workers (dashed line). The second is a policy targeting the asset-poor (dotted line), and for comparability with the first policy, I set the threshold such that the same amount of workers get the transfer. Then, I also implement policies targeting only the unemployed or employed asset-poor (dash-dotted line and diamond line, respectively). There, I divide the total transfer to the 10% poorest. By targeting the transfer to workers with on average lower assets, the aggregate consumption drop is mitigated in the first period by more than 4 percentage points. This is especially true for the transfers targeted at the asset-poor unemployed workers, as these are the group with the largest share of hand-to-mouth. The targeted transfer also allows them to look for better jobs, which depresses aggregate consumption in the following periods through a relatively larger share of workers who remain unemployed (matching probabilities are lower for good jobs). This backlash effect on consumption (0.5 percentage points) is strongest when targeting the unemployed poor, and does not happen when targeting the poorest employed workers.

[25] Here I do not impose the government to balance its budget for simplicity. For this reason, in this section I always compare counterfactuals holding the total amount of transfer fixed.

Figure 1.12: Consumption effect of targeted transfers



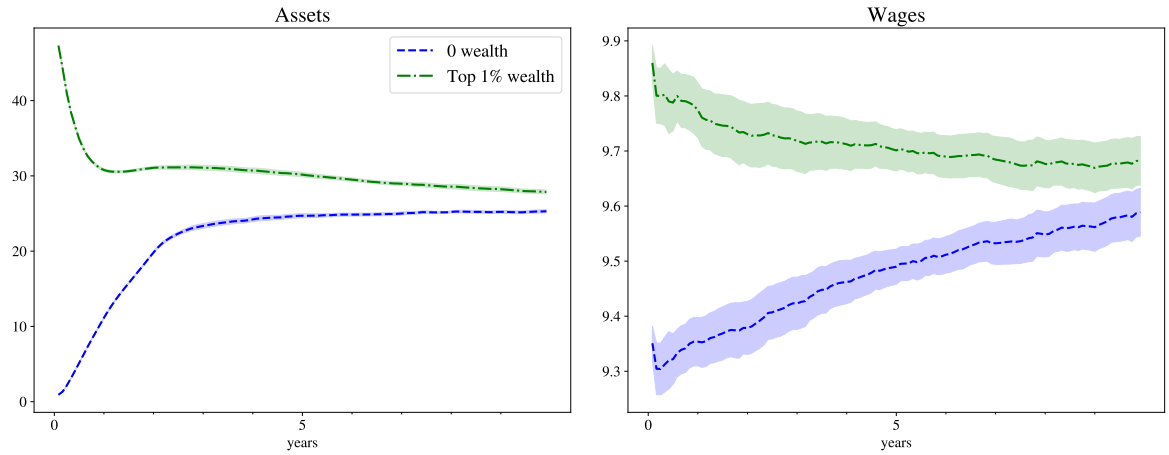
Note: All lines correspond to the same aggregate transfer, which amounts to one tenth of average equilibrium wages. The solid line represents the aggregate consumption response when the transfer is distributed to all agents (baseline). The other lines represent differences from this baseline. The dashed line distributes the transfer equally among unemployed; the dotted line to all workers at the bottom of the wealth distribution (the mass is chosen to be equal to the mass of unemployed); the dash-dotted line to the unemployed workers at the bottom 10% of the wealth distribution; and the diamond line to the employed worker at the bottom 10% of the wealth distribution.

5.3 Cyclical shocks have long term consequences

Whether the increase in inequality following an negative aggregate productivity shock is associated with long term consequences is an important policy question. In this model, cyclical fluctuations have long-lasting effects because of workers' assets accumulation and job search.

In Figure 1.13, I simulate two cohorts of 10'000 individuals, each starting either with the bottom or the top 1% wealth. I track them over time as aggregate productivity evolves according to different draws of the stochastic process. The left panel plots mean asset holdings, and the right panel plots mean wages; while the shaded areas represent 90% confidence interval (across aggregate productivity states). A striking result is that the initial asset position determine different asset and wages for at least the next 10 years. Comparing the poorest cohort with the richest, the right panel reveals that after 10 years, the cohort that started with the highest wealth continues to benefit from wages that are % higher. Wealth sorting leads asset-poor workers to accept lower wages, limiting their ability to accumulate savings during employment and thereby increasing their probability

Figure 1.13: Average outcomes for cohort starting with different levels of assets



Note: Each cohort is of 10'000 workers who share the same level of assets in $t = 0$. I then randomly simulate 20 different paths for aggregate productivity and follow each worker in the different cohorts. Lines represent the average worker, while shaded areas are the 90% confidence interval.

to apply to low-wage jobs if they become unemployed. In that sense, the presence of liquidity constraints in this setting generates a "poverty trap". Heterogeneous separation risk aggravates this phenomenon, because it disproportionately affects wealth-poor workers. Bad aggregate states intensify the poverty trap for wealth-poor unemployed workers, who are then driven to seek riskier, lower-wage jobs. It is worth mentioning that the model does not embed *permanent* inequalities; all heterogeneity in asset and wages are merely due to workers' initial condition in wealth and its interaction with labor market outcomes. Given the randomness of shock processes, average effects for the different cohorts converge to the same value in the long-run.

Next, I quantify the scarring effects of recessions along the wealth distribution by comparing two simulated aggregate states: a "recession" scenario, where the aggregate state is negative for the first two quarters (following the NBER definition) and then goes back to the unconditional mean, and a "tranquil" scenario, where the aggregate state is constant at the mean throughout. In Figure 1.14, I show the percentage difference in assets (left panel) and wages (right panel) for cohorts who began their unemployment spells in the "recession" scenario relative to a "tranquil" scenario. Moreover, I show how these differences vary between workers at the bottom and top of the wealth distribution (blue and green lines, respectively).

Figure 1.14: Long-term effects of recessions for cohort starting with different levels of assets



Note: Each cohort is of 10'000 workers who share the same level of assets in $t = 0$. I then randomly simulate 20 different paths for aggregate productivity and follow each worker in the different cohorts. Lines represent the difference between starting the unemployment spell in a recession (2 quarters negative growth) versus a tranquil period, separately for each wealth cohort. After the first 2 quarters, the aggregate state is the same across simulations.

Starting the unemployment spell in a recession has long-lasting effect for all workers. Wages are around 4.5% lower on impact, and are still 1% lower after 5 years.[26] Asset accumulation is positive in the very beginning, reflecting precautionary savings motives, but then becomes and stays negative for all workers. Those suffering from larger negative effects are the wealth-poor, whose wages are between 0.5 and 1 percentage points lower compared to the wealthiest. Moreover, those with initially zero assets accumulate much less in the "recession" scenario, by as much as 8% in the first year. The wealthiest also start decumulating assets, though to a smaller extent. As a consequence, wealth inequality between these two groups increases in the first years.

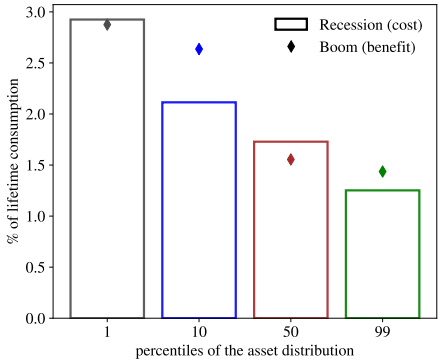
Finally, I calculate the welfare cost of beginning a job spell in a recession versus a boom across the wealth distribution. The solid bars in Figure 1.15 represent the lifetime cost of starting a job search during a recession, computed in a similar fashion as Lucas (1987) – see Appendix A7 for more details. The poorest workers would sacrifice 3% of lifetime consumption to avoid the recession scenario. This is more than two times larger than the

[26]The strong persistence is also due to the assumption of fixed wages throughout the employment duration. Wages therefore adjust to aggregate conditions only when the employed worker gets separated and finds a new job.

wealthiest workers, whose utility losses of starting in a recession are equivalent to 1.25% of lifetime consumption.

The diamonds show the benefits of starting in a boom respective to the tranquil scenario. The heterogeneity is slightly lower, mostly driven by the top 1%. In fact, these workers benefit more from a positive aggregate state as they suffer in a bad aggregate state – they would give up 1.5% of their lifetime consumption for the boom scenario. Instead, the benefits and symmetric to the cost of recession for the bottom 1%, while the 10th percentile gains relatively more in booms than what they lose from recessions.

Figure 1.15: Scarring effect of recessions and welfare gains from booms



Note: Each cohort is of 10'000 workers who share the same level of assets in $t = 0$ (respectively 5th and 95th percentiles). I compute the welfare cost of starting in a boom or recession, compared to tranquil times. I follow each worker in the different cohorts, and show outcomes for the median worker in the cohort.

6 Conclusion

This paper explores the relationship between wealth, job search behavior, and labor income risk over the business cycle. First, I present suggestive evidence that asset-poor workers have a relatively larger employment elasticity to aggregate output fluctuations. I then rationalize this finding with a theory based on risk aversion, liquidity constraints, and labor market search. I show that in the presence of incomplete markets, risk-aversion drives agents to sort positively on the labor market, even though bad jobs are more likely to be destroyed. This implies that wealthier individuals can afford to be more selective in their job search, thereby obtaining better job matches with higher wages and higher

security. During economic downturns, wealthier workers are able to cushion a potential job loss through savings, and their resulting job search implies more stable and higher income. Conversely, poor workers seek insurance and use the labor market to smooth their consumption. Wealth sorting is relatively stronger in bad aggregate states, and so are inequalities (in terms of wages and security). Positive wealth sorting generates a higher employment elasticity to aggregate shocks for low-wealth workers, in line with the empirical evidence. Moreover, it generates a "poverty trap", in which asset-poor workers struggle to accumulate assets due to short and low-wage employment contracts. Following a negative aggregate productivity shock, I show that a transfer targeted at the unemployed asset-poor is the most effective way to mitigate the drop in aggregate consumption but induces a small backlash in the next period due to more workers staying unemployed.

A Appendix

A1 Empirical analysis

Panel Study of Income Dynamics

The PSID is the world's longest ongoing longitudinal household panel dataset. This survey was conducted in the U.S. yearly from 1968 to 1997, and biennially afterwards. In total, more than $82,000$ individuals (coming from around $9,500$ families) were interviewed over 50 years. The panel consists of different subsamples. The first is the so-called SRC sample, which is representative of the U.S. population. The SEO samples add an over-sample of low-income families. Together, the SRC and SEO are referred to as the Core PSID sample, which is the sample I work with. My main variables of interest are individual demographics, employment, income, and wealth.

Sample selection I restrict the PSID to the heads in the Core sample, that are aged between 25 and 62. Data on wealth is available only from 1999 onward, which restricts my sample year to 1999 to 2017. I discard individuals with inconsistent data, e.g., those having positive hourly labor income lower than half of the federal minimum wage.

Demographics Household heads are individuals whose sequence number is equal to 1 – spouses instead are denoted with a sequence number equal to 2. Until 2017, heads are always male unless the household does not feature a spouse. The education level is not reported consistently throughout the years. I compute a consistent variable for each respondent and year and then attribute the education to that individual that is the highest computed over all observed years.

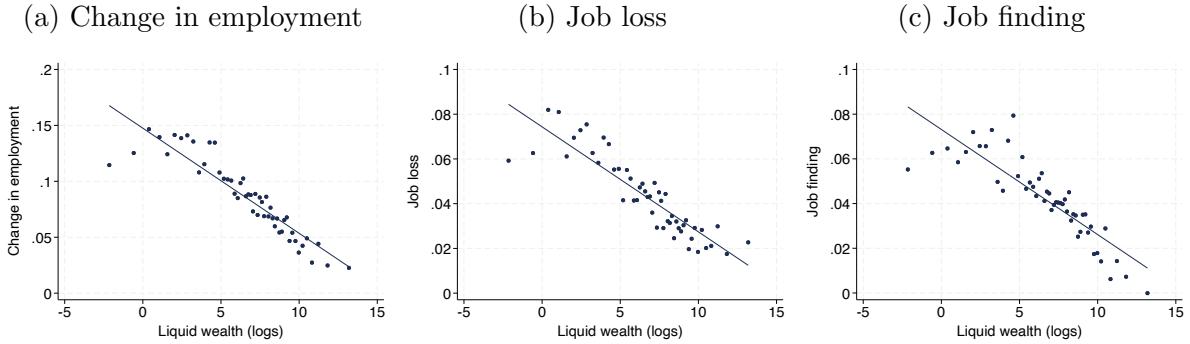
Employment and income The employment status is reported consistently after 1999, I can directly use the variable. I use the household head individual labor income, as reported in the data. It is defined as "Labor part of farm income and business income, wages, bonuses, overtime, commissions, professional practice, labor part of income from roomers and boarders or business income."

Wealth Wealth is reported at the household level since 1999. I use the total of savings and checks accounts as a measure of liquid wealth. Results are similar when using a constructed

measure of liquid wealth that sums savings and checks accounts to stock holdings.

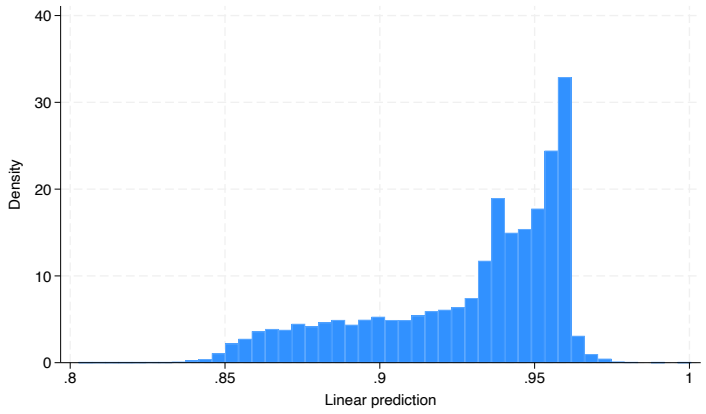
Sensitivity analysis

Figure A1: Employment and liquid wealth



Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Dots represent mean of x and y values within 50 equally populated bins. The $x-$ axis represents log liquid wealth holdings; the $y-$axis is the mean change in employment status. All panels control for a quadratic in age interacted with socio-demographs and past income. Liquid wealth is measured as the amount in the savings accounts and stocks holdings.

Figure A2: Histogram of predicted individual employment status



Note: The $x-$axis represents a linear prediction on the individual employment status from Eq. (1.1). The $y-$axis shows the density.

I also perform a sensitivity analysis using GDP measures at the aggregate level – Y_t represents the U.S real GDP.

Columns (1) to (4) of Table A1 present the estimates as the model is gradually saturated. The results are similar to the baseline estimates, though the magnitudes are approximately doubled.

Figure A3 reproduces the decile figures for the state-level analysis. Again, we can see that the pattern is essentially unchanged.

Table A1: Liquid assets and individual employment elasticity to aggregate fluctuations

	(1)	(2)	(3)	(4)
$\Delta \log Y_t$	0.61***			
	(0.084)			
a_{it-1}	-0.17***	-0.027**	-0.026**	-0.025**
	(0.014)	(0.011)	(0.011)	(0.011)
$a_{it-1} \times \Delta \log Y_t$	0.89***	0.77***	0.74***	0.68***
	(0.23)	(0.23)	(0.23)	(0.23)
FEs	No	Yes	Yes	Yes
Worker controls	No	No	Yes	Yes
Past income	No	No	No	Yes
R^2	0.056	0.47	0.47	0.47
N	32144	32144	32144	32144

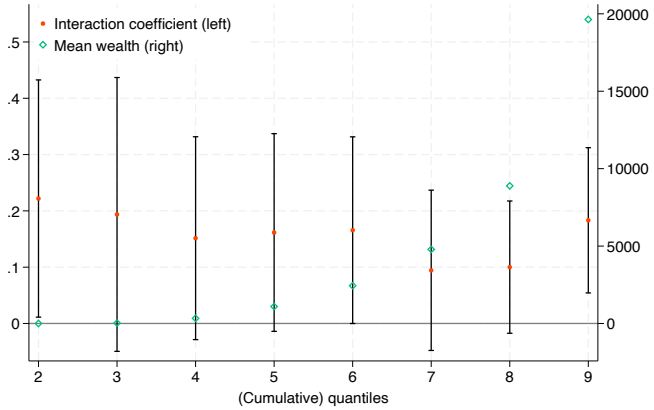
Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Standard errors in parentheses; $^{*}p < 0.1$,** $p < 0.05$,*** $p < 0.01$, clustered at the state by year level. The outcome variable is the employment status of the household head. Liquid wealth is measured as the checks and savings account and stocks holdings. $\bar{a}$ is equal to one if the household's liquid wealth lies in the first quartile of that year's liquid wealth distribution. Fixed effects include workers and year. Worker controls include a quadratic in age, and all the respective interactions with education, gender and race. Past income is the lagged labor income (if missing for the prior two years, it is the past income from the prior 4 years). GDP is at the state level, and the last column disentangles expansions (positive growth) to recessions (negative growth).

Table A2: Liquid assets and individual employment elasticity to aggregate fluctuations

	(1)	(2)	(3)	(4)
$a_{it-1} \times \Delta \log Y_{s,t}$	0.25**	0.25**	0.24*	0.24*
	(0.12)	(0.12)	(0.12)	(0.12)
Industry	No	Yes	No	Yes
Occupation	No	No	Yes	Yes
Industry × Occupation	No	No	No	Yes
R^2	0.37	0.37	0.37	0.37
N	30241	30241	30241	30241

Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Standard errors in parentheses; $^{*}p < 0.1$,** $p < 0.05$,*** $p < 0.01$, clustered at the state level. The outcome variable is the employment status of the household head. Liquid wealth is measured as the checks and savings account. a_{it-1} is equal to one if the household's liquid wealth lies in the first quartile of that year's liquid wealth distribution. All columns feature fixed effects at the worker and year by state level, and the following controls: a quadratic in age, and all the respective interactions with education, gender, race, and past income. Past income is the lagged labor income (if missing for the prior two years, it is the past income from the prior 4 years). The first column is the baseline regression.

Figure A3: Employment elasticity to state output fluctuations by liquid wealth deciles



Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Standard errors in parentheses; $^{*}p < 0.1$,** $p < 0.05$,*** $p < 0.01$, clustered at the state level. The $x-$axis represents different thresholds for the dummy variable indicating "asset-poor" status. The left $y-$axis displays the coefficient of interest which is the interaction term between log-changes in States' GDP and liquid wealth-poor dummy, estimated in the baseline model of Eq. (1.1). The red dots plot the point estimates, and the bars indicate 95% confidence intervals. The diamonds on the right $y-$axis plot the average levels of liquid wealth for each income decile.

Figure A4: Permanent asset position and individual employment elasticity to aggregate fluctuations

	(1)	(2)	(3)	(4)	(5)
$\Delta \log Y_t$	0.25***				
	(0.042)				
$\bar{a}_i$	-0.18***				
	(0.010)				
$\bar{a}_i \times \Delta \log Y_t$	0.12	0.19	0.20	0.21	0.095
	(0.13)	(0.18)	(0.18)	(0.18)	(0.39)
$\bar{a}_i \times \Delta \log Y_t \times \Delta \log Y_t^{>0}$					0.22
					(0.42)
FEs	No	Yes	Yes	Yes	Yes
Worker controls	No	No	Yes	Yes	Yes
Past income	No	No	No	Yes	Yes
R^2	0.064	0.46	0.46	0.46	0.46
N	32591	32150	32150	32150	32150

Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Standard errors in parentheses; $^{*}p < 0.1$,** $p < 0.05$,*** $p < 0.01$, clustered at the state level. The outcome variable is the employment status of the household head. Liquid wealth is measured as the checks and savings account and stocks holdings. $\bar{a}$ is equal to one if the household's liquid wealth lies in the first quartile of the average liquid wealth distribution. Fixed effects include workers and year. Worker controls include a quadratic in age, and all the respective interactions with education, gender and race. Past income is the lagged labor income (if missing for the prior two years, it is the past income from the prior 4 years). GDP is at the state level, and the last column disentangles expansions (positive growth) to recessions (negative growth).

Table A3: Iliquid assets and individual employment elasticity to aggregate fluctuations

	(1)	(2)	(3)	(4)	(5)
$\Delta \log Y_t$	0.26***				
	(0.039)				
a_{it-1}	-0.14***	-0.013*	-0.012*	-0.012*	-0.022
	(0.0096)	(0.0066)	(0.0066)	(0.0065)	(0.019)
$a_{it-1} \times \Delta \log Y_t$	0.25*	0.14	0.15	0.16	0.22
	(0.13)	(0.13)	(0.13)	(0.12)	(0.27)
$a_{it-1} \times \Delta \log Y_t \times \Delta \log Y_t^{>0}$					-0.34
					(0.36)
FEs	No	Yes	Yes	Yes	Yes
Worker controls	No	No	Yes	Yes	Yes
Past income	No	No	No	Yes	Yes
R^2	0.047	0.45	0.45	0.45	0.45
N	35961	35961	35961	35961	35961

Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Standard errors in parentheses; $^{*}p < 0.1$,$^{**}p < 0.05$,$^{***}p < 0.01$, clustered at the state level. The outcome variable is the employment status of the household head. Iliquid wealth is measured as the sum of real estate, pensions savings, other assets, vehicles and farm business. a is equal to one if the household's illiquid wealth lies in the first quartile of that year's illiquid wealth distribution. Fixed effects include workers and year. Worker controls include a quadratic in age, and all the respective interactions with education, gender and race. Past income is the lagged labor income (if missing for the prior two years, it is the past income from the prior 4 years). GDP is at the state level, and the last column disentangles expansions (positive growth) to recessions (negative growth).

Table A4: H2M and individual employment elasticity to aggregate fluctuations

	(1)	(2)	(3)	(4)
$\Delta \log Y_t$	0.29***			
	(0.055)			
$H2M_{t-1}$	-0.058***	-0.0015	-0.0013	0.00047
	(0.0065)	(0.0073)	(0.0075)	(0.0073)
$H2M_{t-1} \times \Delta \log Y_t$	0.14	0.16**	0.17**	0.16**
	(0.087)	(0.078)	(0.077)	(0.077)
FEs	No	Yes	Yes	Yes
Worker controls	No	No	Yes	Yes
Past income	No	No	No	Yes
R^2	0.011	0.47	0.47	0.47
N	32144	32144	32144	32144

Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Standard errors in parentheses; $^{*}p < 0.1$,$^{**}p < 0.05$,$^{***}p < 0.01$, clustered at the state level. The outcome variable is the employment status of the household head. $H2M$ is a dummy equal to 1 if the household's net worth is lower than a sixth of their labor income, following Aguiar et al. (2024). Fixed effects include workers, and year by state. Worker controls include a quadratic in age, and all th respective interactions with education, gender and race. Past income is the lagged labor income (if missing for the prior two years, it is the past income from the prior 4 years) and it is interacted with GDP.

Table A5: Liquid assets and individual change in employment status

	(1)	(2)	(3)
	Change	Job loss	Job finding
a_{it}	0.074***	0.036***	0.038***
	(0.0045)	(0.0034)	(0.0033)
R^2	0.067	0.024	0.057
N	36774	36774	36774

Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Robust standard errors in parentheses; $^{*}p < 0.1$,$^{**}p < 0.05$,$^{***}p < 0.01$. The outcome variable is the change in employment status of the household head. In column (1), the variable captures both job loss and job finding, while columns (2) and (3) only capture the former and the latter, respectively. Liquid wealth is measured as the checks and savings account. a_{it-1} is equal to one if the household's liquid wealth lies in the first quartile of that year's liquid wealth distribution. Regressions include year by state fixed effects and the following worker controls: a quadratic in age, and all the respective interactions with education, gender, race, and past income. Past income is the lagged labor income (if missing for the prior two years, it is the past income from the prior 4 years) and it is additionally interacted with GDP.

Table A6: Liquid assets and individual change in employment status

	(1) Change	(2) Job loss	(3) Job finding
Cross-section			
a_{it-1}	0.074***	0.036***	0.038***
	(0.0045)	(0.0034)	(0.0033)
R^2	0.067	0.024	0.057
N	36774	36774	36774
Cyclical exposure			
$a_{it-1} \times \Delta \log Y_t$	0.28**	-0.22**	0.061
	(0.13)	(0.099)	(0.078)
R^2	0.016	0.025	0.057
N	36634	36634	36634

Note: Observations come from the Core PSID dataset. The sample covers years from 1999 to 2017. Standard errors in parentheses; $^{*}p < 0.1$,$^{**}p < 0.05$,$^{***}p < 0.01$, clustered at the state level. The outcome variable is the change in employment status of the household head. Liquid wealth is measured as the checks and savings account. a_{it-1} is equal to one if the household's liquid wealth lies in the first quartile of that year's liquid wealth distribution. Fixed effects are year by state. Worker controls include a quadratic in age, and all the respective interactions with education, gender and race. Past income is the lagged labor income (if missing for the prior two years, it is the past income from the prior 4 years) and it is interacted with GDP.

A2 Proofs of two-period model

Matching function

As Menzio and Shi (2011); Eeckhout and Sepahsalari (2024), I assume a CES matching function.

$$
\begin{aligned}
m(\theta) &= \theta(1+\theta^{\gamma})^{\frac{-1}{\gamma}} \\
m'(\theta) &= (1+\theta^{\gamma})^{\frac{-1}{\gamma}} - \theta^{\gamma}(1+\theta^{\gamma})^{\frac{-1}{\gamma}-1} \\
m''(\theta) &= -(1+\theta^{\gamma})^{\frac{-1}{\gamma}-1}\left[1+\gamma\theta^{\gamma-1}\right] + \left(\frac{-1}{\gamma}-1\right)\theta^{2\gamma-1}(1+\theta^{\gamma})^{\frac{-1}{\gamma}-2}
\end{aligned}
$$

$$
\begin{aligned}
q(\theta) &= (1+\theta^{\gamma})^{\frac{-1}{\gamma}} \\
q'(\theta) &= -\theta^{\gamma-1}(1+\theta^{\gamma})^{\frac{-1}{\gamma}-1} \\
q''(\theta) &= -\theta^{\gamma-1}(1+\theta^{\gamma})^{\frac{-1}{\gamma}-1}\theta^{-1}\left[\gamma-1-(\gamma+1)\theta^{\gamma}(1+\theta^{\gamma})^{-1}\right]
\end{aligned}
$$

We can thus show that $(q'(\theta)+\theta q''(\theta))q(\theta)-(q'(\theta))^2\theta<0$.

$$\begin{aligned}
(q'(\theta)+\theta q''(\theta))q(\theta)-(q'(\theta))^2\theta &= \left(q'(\theta)+q'(\theta)\left[\gamma-1-(\gamma+1)\theta^\gamma(1+\theta^\gamma)^{-1}\right]\right)q(\theta)-(q'(\theta))^2\theta \\
&= q'(\theta)\left(1+\left[\gamma-1-(\gamma+1)\theta^\gamma(1+\theta^\gamma)^{-1}\right]\right)(1+\theta^\gamma)^{\frac{-1}{\gamma}}-(q'(\theta))^2\theta \\
&= q'(\theta)\left(\gamma(1+\theta^\gamma)^{\frac{-1}{\gamma}}-(\gamma+1)\theta^\gamma(1+\theta^\gamma)^{\frac{-1}{\gamma}-1}\right)-(q'(\theta))^2\theta \\
&= q'(\theta)\left(\gamma\left((1+\theta^\gamma)^{\frac{-1}{\gamma}}-\theta^\gamma(1+\theta^\gamma)^{\frac{-1}{\gamma}-1}\right)-\theta^\gamma(1+\theta^\gamma)^{\frac{-1}{\gamma}-1}\right)-(q'(\theta))^2\theta \\
&= q'(\theta)\left(\gamma m'(\theta)+\theta q'(\theta)\right)-(q'(\theta))^2\theta \\
&= \gamma q'(\theta)m'(\theta)<0
\end{aligned}$$

Proposition 1 : positive wealth sorting

Proof. Let $\phi(a_2^*,\theta^*)$ be the maximand of $U(a_1,x)$

$$\phi(a_2^*,\theta^*)=u(Ra_1-a_2^*)+\beta\left[m(\theta^*)\Lambda(x)u\left(Ra_2^*+\bar{y}-\frac{\varphi(x)}{\beta q(\theta^*)\Lambda(x)}\right)+(1-m(\theta^*)\Lambda(x))u(Ra_2^*)\right]$$

By the implicit function theorem, we have

$$\frac{\partial a_{t+1}}{\partial x_t}=-\frac{\begin{vmatrix}\phi_{a_{t+1}x_t} & \phi_{a_{t+1}\theta_t}\\ \phi_{\theta_t x_t} & \phi_{\theta_t\theta_t}\end{vmatrix}}{|H|}=-\frac{\phi_{a_{t+1}x_t}\phi_{\theta_t\theta_t}-\phi_{\theta_t x_t}\phi_{a_{t+1}\theta_t}}{|H|}$$

$$\frac{\partial \theta_t}{\partial x_t}=-\frac{\begin{vmatrix}\phi_{\theta_t x_t} & \phi_{\theta_t a_{t+1}}\\ \phi_{a_{t+1}x_t} & \phi_{a_{t+1}a_{t+1}}\end{vmatrix}}{|H|}=-\frac{\phi_{\theta_t x_t}\phi_{a_{t+1}a_{t+1}}-\phi_{\theta_t a_{t+1}}\phi_{a_{t+1}x_t}}{|H|}$$

Where $|H|>0$ is the determinant of the Hessian:

$$H=\begin{bmatrix}\phi_{a_{t+1}a_{t+1}} & \phi_{a_{t+1}\theta_t}\\ \phi_{\theta_t a_{t+1}} & \phi_{\theta_t\theta_t}\end{bmatrix} \tag{1.16}$$

We first derive the partial derivatives of the surplus function $U(a_2,x)$. Taking the envelope theorem into account, we have that

$$\begin{aligned}
U_{a_1} &= Ru'(Ra_1-a_2)\\
U_{a_1x} &= -Ru''(Ra_1-a_2)\frac{\partial a_2}{\partial x}
\end{aligned}$$

The condition for PAM is

$$\begin{aligned} U_{a_1 x} > 0 \quad &\Leftrightarrow \quad -Ru''(Ra_1 - a_2)\frac{\partial a_2}{\partial x} > 0 \\ \frac{\partial a_2}{\partial x} > 0 \quad &\Leftrightarrow \quad -\frac{\phi_{a_{t+1}x_t}\phi_{\theta_t\theta_t} - \phi_{\theta_t x_t}\phi_{a_{t+1}\theta_t}}{|H|} > 0 \end{aligned}$$

$$\phi_{a_2 x}\ \phi_{\theta\theta} < \phi_{\theta x}\ \phi_{a_2\theta} \tag{1.17}$$

Where we used the implicit function theorem in the second line. Eq. (1.17) is the condition for PAM, and we now compute the relevant partial derivatives

$$\begin{aligned} \phi_{a_2,x} &= \beta R m(\theta^*)\left[\Lambda'(x)(u'(c^*_{e,2}) - u'(c^*_{u,2})) + \Lambda(x)u''(c^*_{e,2})\left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2}\right)\right] \\ &= \beta R m(\theta^*)\left[\Lambda'(x)(u'(c^*_{e,2}) - u'(c^*_{u,2})) - \Lambda'(x)u''(c^*_{e,2})\frac{u(c^*_{e,2}) - u(c^*_{u,2})}{u'(c^*_{e,2})}\right] \\ &= \beta R m(\theta^*)\Lambda'(x)\left[(u'(c^*_{e,2}) - u'(c^*_{u,2})) - \frac{u''(c^*_{e,2})}{u'(c^*_{e,2})}(u(c^*_{e,2}) - u(c^*_{u,2}))\right] \end{aligned} \tag{1.18}$$

$$\begin{aligned} \phi_{\theta,a_2} &= \beta R\Lambda(x)\left(m'(\theta)\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] + u''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)}\right) \\ &= \beta R\Lambda(x)m'(\theta)\left(\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] - u''(c^*_{e,2})\frac{(u(c^*_{e,2}) - u(c^*_{u,2}))}{u'(c^*_{e,2})}\right) \end{aligned} \tag{1.19}$$

With DARA utility function, it holds that $\frac{u'(c^*_{e,2}) - u'(Ra_2)}{u(c^*_{e,2}) - u(Ra_2)} < \frac{u''(c^*_{e,2})}{u'(c^*_{e,2})}$ (Eeckhout and Sepahsalari, 2024). Therefore, Eq. (1.18) and Eq. (1.19) are negative, i.e., $\phi_{a_2,x} < 0$ and $\phi_{\theta,a_2} < 0$.

$$\begin{aligned} \phi_{\theta,\theta} &= \beta\Lambda(x)\Bigg[m''(\theta^*)\left[u\left(c^*_{e,2}\right) - u(c^*_{u,2})\right] + m'(\theta^*)u'(c^*_{e,2})\left(\frac{\varphi(x)q'(\theta)}{\beta\Lambda(x)(q(\theta))^2}\right) \\ &\quad + u''(c^*_{e,2})\left(\frac{\varphi(x)q'(\theta)}{\beta\Lambda(x)(q(\theta))^2}\right)\frac{\varphi'(x)\theta q'(\theta)}{\beta q(\theta)\Lambda(x)} + u'(c^*_{e,2})\frac{\varphi(x)}{\beta\Lambda(x)}\left(\frac{(q'(\theta) + \theta q''(\theta))q(\theta) - (q'(\theta))^2\theta}{(q(\theta))^2}\right)\Bigg] \\ &= \beta\Lambda(x)\Bigg[m''(\theta)\left[u\left(c^*_{e,2}\right) - u(c^*_{u,2})\right] \end{aligned} \tag{1.20}$$

$$+ \frac{\varphi(x)q'(\theta)}{\beta\Lambda(x)(q(\theta))^2}\left(m'(\theta)u'(c^*_{e,2}) + u''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)} + u'(c^*_{e,2})\frac{(q'(\theta) + \theta q''(\theta))q(\theta) - (q'(\theta))^2\theta}{q'(\theta)}\right)\Bigg] \tag{1.21}$$

Under CES matching function, Eq. (1.21) is negative as all terms are negative. We assume that it is the case.

$$\begin{aligned}
\phi_{\theta,x} = \beta\Bigg(& \Lambda'(x)\left[m'(\theta)(u(c^*_{e,2}) - u(c^*_{u,2})) + u'(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)}\right] \\
& + \Lambda(x)m'(\theta)u'(c^*_{e,2})\left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2}\right) \\
& + \Lambda(x)u''(c^*_{e,2})\left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2}\right)\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)} + \Lambda(x)u'(c_{e,2})\frac{\theta q'(\theta)}{\beta q(\theta)}\left(\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{(\Lambda(x))^2}\right)\Bigg) \\
= \beta & \left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2}\right)\left(\Lambda(x)m'(\theta)u'(c^*_{e,2}) + \Lambda(x)u''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)} - \Lambda(x)u'(c_{e,2})\theta q'(\theta)\right) \\
= \beta & \left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2}\right)\left(\Lambda(x)u'(c^*_{e,2})[m'(\theta) - \theta q'(\theta)] + u''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta q(\theta)}\right)
\end{aligned} \tag{1.22}$$

All terms in the second bracket are positive. A necessary condition for PAM is $\phi_{\theta,x} < 0$, and therefore

$$\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2} > 0 \qquad \Leftrightarrow \qquad \frac{\varphi'(x)}{\varphi(x)} > \frac{\Lambda'(x)}{\Lambda(x)} \tag{1.23}$$

To understand whether the condition is also sufficient, I now put terms together and write down the full condition for PAM

$$\begin{aligned}
& \beta R m(\theta^*)\Lambda'(x)\left[(u'(c^*_{e,2}) - u'(c^*_{u,2})) - \frac{u''(c^*_{e,2})}{u'(c^*_{e,2})}(u(c^*_{e,2}) - u(c^*_{u,2}))\right] \\
& \beta\Lambda(x)\Bigg[m''(\theta)\left[u\left(c^*_{e,2}\right) - u(c^*_{u,2})\right] \\
& + \frac{\varphi(x)q'(\theta)}{\beta\Lambda(x)(q(\theta))^2}\left(m'(\theta)u'(c^*_{e,2}) + u''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)} + u'(c^*_{e,2})\frac{(q'(\theta) + \theta q''(\theta))q(\theta) - (q'(\theta))^2\theta}{q'(\theta)}\right)\Bigg] \\
& < \beta\frac{\varphi(x)\theta q'(\theta)}{\beta q(\theta)}\left(u'(c^*_{e,2})\frac{\varphi'(x)}{\varphi(x)} - u''(c^*_{e,2})\frac{\Lambda'(x)}{\Lambda(x)}\frac{u(c^*_{e,2}) - u(c^*_{u,2})}{u'(c_{e,2^*})}\right) \\
& \beta R\Lambda(x)m'(\theta)\left(\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] - u''(c^*_{e,2})\frac{(u(c^*_{e,2}) - u(c^*_{u,2}))}{u'(c^*_{e,2})}\right)
\end{aligned}$$

With DARA utility functions, we know that the last parenthesis is negative. Simplifying on both

sides yields

$$\begin{aligned}
&\Lambda'(x)m''(\theta)\left[u\left(c^*_{e,2}\right)-u(c^*_{u,2})\right]\\
&+\frac{\Lambda'(x)}{\Lambda(x)}\frac{\varphi(x)q'(\theta)}{\beta(q(\theta))^2}\left(m'(\theta)u'(c^*_{e,2})+u''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)}+u'(c^*_{e,2})\frac{(q'(\theta)+\theta q''(\theta))q(\theta)-(q'(\theta))^2\theta}{q'(\theta)}\right)\\
&>\frac{\varphi(x)q'(\theta)}{\beta(q(\theta))^2}\left(u'(c^*_{e,2})\frac{\varphi'(x)}{\varphi(x)}-u''(c^*_{e,2})\frac{\Lambda'(x)}{\Lambda(x)}\frac{u(c^*_{e,2})-u(c^*_{u,2})}{u'(c_{e,2^*})}\right)m'(\theta)\\
&\quad=\frac{\Lambda'(x)}{\Lambda(x)}\frac{\varphi(x)q'(\theta)}{\beta(q(\theta))^2}\left(\frac{\Lambda(x)}{\Lambda'(x)}u'(c^*_{e,2})\frac{\varphi'(x)}{\varphi(x)}-u''(c^*_{e,2})\frac{u(c^*_{e,2})-u(c^*_{u,2})}{u'(c_{e,2^*})}\right)m'(\theta)
\end{aligned}$$

Where in the last line we simply extended the RHS so that we can then take the difference

$$\begin{aligned}
&\Lambda'(x)m''(\theta)\left[u\left(c^*_{e,2}\right)-u(c^*_{u,2})\right]+\frac{\Lambda'(x)}{\Lambda(x)}\frac{\varphi(x)q'(\theta)}{\beta(q(\theta))^2}\left(m'(\theta)u'(c^*_{e,2})\left(1-\frac{\Lambda(x)}{\Lambda'(x)}\frac{\varphi'(x)}{\varphi(x)}\right)\right.\\
&\left.+u'(c^*_{e,2})\frac{(q'(\theta)+\theta q''(\theta))q(\theta)-(q'(\theta))^2\theta}{q'(\theta)}+u''(c^*_{e,2})\left(\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)}+m'(\theta)\frac{u(c^*_{e,2})-u(c^*_{u,2})}{u'(c_{e,2^*})}\right)\right)>0
\end{aligned}$$

The last term in parentheses is equal to zero. Then, we can write (still using Eq. (1.26))

$$\Lambda'(x)\left[u\left(c^*_{e,2}\right)-u(c^*_{u,2})\right]\left[m''(\theta)-\frac{m'(\theta)}{m(\theta)}\left(m'(\theta)\left(1-\frac{\Lambda(x)}{\Lambda'(x)}\frac{\varphi'(x)}{\varphi(x)}\right)+\frac{(q'(\theta)+\theta q''(\theta))q(\theta)-(q'(\theta))^2\theta}{q'(\theta)}\right]>0$$

$$\Lambda'(x)\left[u\left(c^*_{e,2}\right)-u(c^*_{u,2})\right]\left[m''(\theta)-\frac{(m'(\theta))^2}{m(\theta)}\left(1-\frac{\Lambda(x)}{\Lambda'(x)}\frac{\varphi'(x)}{\varphi(x)}+\frac{(q'(\theta)+\theta q''(\theta))q(\theta)-(q'(\theta))^2\theta}{q'(\theta)m'(\theta)}\right)\right]>0$$

The sufficient condition is thus

$$\begin{aligned}
\frac{\Lambda(x)}{\Lambda'(x)}\frac{\varphi'(x)}{\varphi(x)}&>\frac{q'(\theta)m'(\theta)+(q'(\theta)+\theta q''(\theta))q(\theta)-(q'(\theta))^2\theta}{q'(\theta)m'(\theta)}\\
\frac{\varphi'(x)}{\varphi(x)}&>\frac{\Lambda'(x)}{\Lambda(x)}\left[\frac{q'(\theta)m'(\theta)+(q'(\theta)+\theta q''(\theta))q(\theta)-(q'(\theta))^2\theta}{q'(\theta)m'(\theta)}\right]
\end{aligned}$$

With CES matching function A2, this becomes

$$\frac{\varphi'(x)}{\varphi(x)}>\frac{\Lambda'(x)}{\Lambda(x)}\,(1+\gamma)$$

□

Uniqueness follows from the negative-semidefinite Hessian matrix (1.16).

Whether matching probability is cyclical can be verified by looking at the "strength" of sorting in different aggregate states. Assume that the matching function M features a state-dependent matching efficiency, $M(U,V) = A(z)\left[U^{\gamma} + V^{\gamma}\right]^{\frac{1}{\gamma}}$, such that in bad times (z^L) average matching efficiency is lower. Since A enters as a multiplicative term, it gets carried through in all derivatives of the job filling and job finding functions. I adapt the equation of sorting to include the average matching efficiency.

$$\Lambda'(x)A(z^L)m''(\theta)\left[u\left(c^*_{e,2}\right) - u(c^*_{u,2})\right] + \frac{\Lambda'(x)}{\Lambda(x)}\frac{\varphi(x)q'(\theta)m'(\theta)}{\beta(q(\theta))^2}u''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)A(z^L)m'(\theta)} \lesseqgtr$$
$$\Lambda'(x)A(z^H)m''(\theta)\left[u\left(c^*_{e,2}\right) - u(c^*_{u,2})\right] + \frac{\Lambda'(x)}{\Lambda(x)}\frac{\varphi(x)q'(\theta)m'(\theta)}{\beta(q(\theta))^2}u''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)A(z^H)m'(\theta)}$$
$$[A(z^L) - A(z^H)]\Lambda'(x)m''(\theta)\left[u\left(c^*_{e,2}\right) - u(c^*_{u,2})\right] + \frac{\Lambda'(x)}{(\Lambda(x))^2}\frac{(\varphi(x))^2\theta(q'(\theta))^2}{\beta^2(q(\theta))^3}u''(c^*_{e,2})\left[\frac{1}{A(z^L)} - \frac{1}{A(z^H)}\right] \lesseqgtr 0$$

Which is indefinite because the LHS is positive while the RHS is negative.

A3 Block recursive equilibrium

The proof follows Karahan and Rhee (2019) which is an extension of Menzio and Shi (2010, 2011), and proceeds in two steps. First, we show that there exists a value function for firms as well as market tightness functions that depend on the aggregate state of the economy only through exogenous shocks, and not through any endogenous distributions. This implies that we can reduce the state space for firms to only the exogenous shocks. In the baseline model without aggregate uncertainty, this means effectively that the value functions for firms and the market tightness do not depend on any aggregate state.

Second, we collapse the employed and unemployed problems and show that the overall household problem is a contraction. If the rental rate (which is exogenous) and the tightness functions are independent of the endogenous asset distribution, we show that the functional equation maps the set of functions that do not depend on the endogenous distribution into itself. Hence, the firm value function, market tightness functions and household problem constitute a block-recursive equilibrium.

A4 Existence

i) Let $\mathcal{J}(\mathcal{X}\times\mathcal{W}\times\mathcal{Z})$ be the set of continuous and bounded firm's value functions: $J(\mathcal{X}\times\mathcal{W}\times\mathcal{Z})\to\mathbb{R}$, and denote $\mathbb{T}_j$ as an operator associated with the firm's value function (Eq. (1.13)).The operator $\mathbb{T}_j$ maps $\mathcal{J}$ into itself; applying Blackwell's conditions it is straightforward to show that $\mathbb{T}_j:\mathcal{J}\to\mathcal{J}$ is a contraction.
Let $J^*\in\mathcal{J}$ be the fixed point of $\mathbb{T}_j$. J^* is a continuous, bounded function that does not depend on any endogenous aggregate state.

Then, we can rewrite the market tightness functions for open markets, from Eq. (1.14), as

$$\theta^*(x,w;z)=q^{-1}\left(\frac{\varphi(x)}{\mathbb{E}_t[J^*(x,w;z)]}\right)$$

ii) Denote the set of functions $\mathcal{R}:\{0,1\}\times\mathcal{A}\times\mathcal{W}\times\mathcal{Z}\to\mathbb{R}$. Let e be an indicator of the employment status ($e=1$ if the worker is employed), and let $R:\{0,1\}\times\mathcal{A}\times\mathcal{W}\times\mathcal{Z}$ denote the combined households' value functions:

$$\begin{aligned}R(e=0,a,w;\Gamma)&=U(a;\Gamma)\\R(e=1,a,w;\Gamma)&=E(a,w;\Gamma)\end{aligned}$$

If $R\in\mathcal{R}$, then the employed and unemployed value functions are also only a function of z and not Ψ. Let $\mathbb{T}_r$ be an operator such that

$$\begin{aligned}(\mathbb{T}_rR)(e,a,x,w;\Gamma)=(1-e)\Big\{&\max_{a',x,w}u(c_u)+\beta\mathbb{E}\big[m(\theta(x,w;z))R(e'=1,a',x,w;\Gamma')\\&+(1-m(\theta(x,w;z)))R(e'=0,a';\Gamma')\big]\Big\}\\+e\left\{\max_{a'}\quad u(c_e)+\beta\mathbb{E}\left[\lambda(x,z)R(e'=0,a';\Gamma')+(1-\lambda(x,z))R(e'=1,a',w';\Gamma')\right]\right\}\\\text{s.t.}\quad c_e+a'=Ra+w,\quad c_u+a'=Ra+b,&\qquad a'\geq\underline{a}\end{aligned}$$

Where we used the fact that market tightness does not depend on Γ (point i)). Assuming that $u(\cdot)$ is bounded and continuous, $\mathcal{R}$ is a set of bounded and continuous functions. We can show that $\mathbb{T}_r:\mathcal{R}\to\mathcal{R}$, so that Blackwell's sufficiency conditions imply that $\mathbb{T}_r$ is a contraction. Being the space complete and non-empty, there exists a unique fixed point $R^*\in\mathcal{R}$ such that $\mathbb{T}_r(R^*\in\mathcal{R})=R^*$. R^* is the solution to the household problem, and does not depend on any aggregate state.

Uniqueness

The uniqueness follows from the strict concavity of value functions. Given the assumptions on $u(\cdot)$, $R(e' = 1, a', x, w; \Gamma')$ is strictly concave in w, while $R(e' = 0, a'; \Gamma')$ is constant in w. With

Discussion

Under some different modeling assumptions, block recursivity breaks. Here are some examples.

1. If firms observe workers' wealth and post optimal contracts;
2. with on-the-job search;
3. if the interest rate is endogenous.

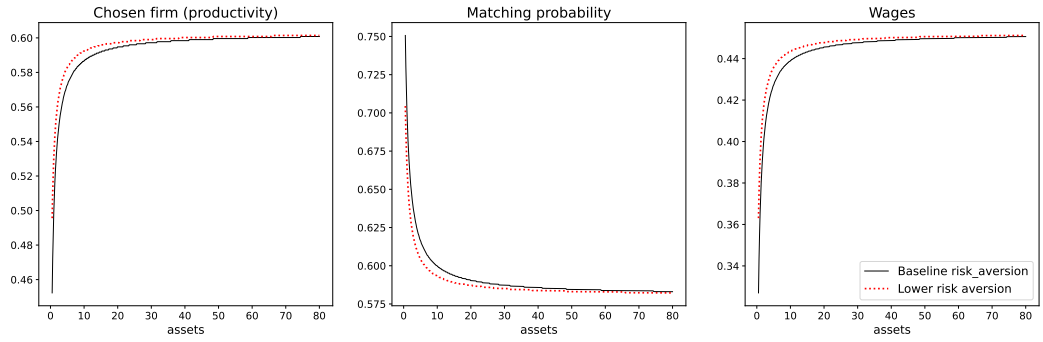
First, if firms would observe workers' wealth, intuitively they would post contracts to attract specific worker types; hence, the distribution of workers over asset and employment states would not be independent of their value function. However, it is in reality unlikely that the employer observes the assets of applicants. Second, on-the-job search would create differential incentives to search across the wealth distribution, and again firms would post contracts to attract targeted workers. In this case as well, firms' value functions would not only depend on the aggregate state through aggregate productivity. This assumption is a restriction on the equilibrium, as it is an established fact that workers search on the job and that job-to-job transitions account for a lot of labor market flows (see e.g., Faberman et al., 2022). Third, if the interest rate is endogenous it directly depends on the distribution of workers across assets. Interest rates influence the trade-off of labor market search – differently across the asset distribution – and therefore value functions of workers directly depend on the distribution of agents over states.

A5 Additional figures and tables

Table A7: Functional forms

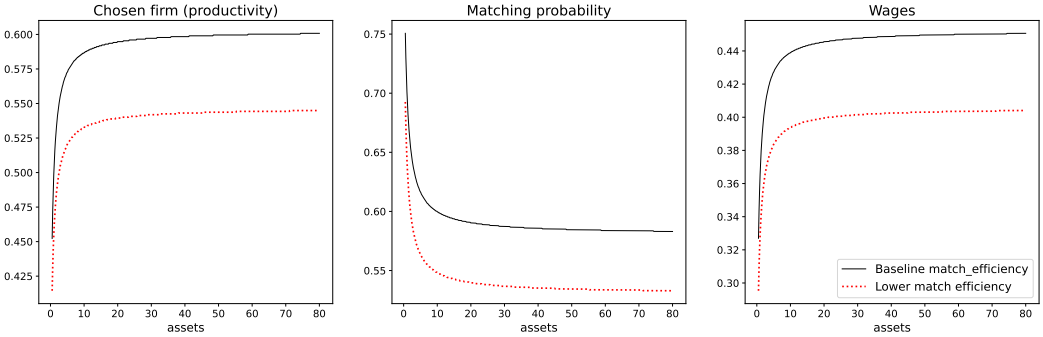
Matching function (CES)	$m(\theta) = \theta(1+\theta^{\gamma})^{\frac{-1}{\gamma}}$
Utility function	$\frac{c^{1-\sigma}}{1-\sigma}$
Separation function	$\bar{\lambda}\exp(\eta^{\lambda_z}(z-1))\exp(\eta^{\lambda_x}(x-\bar{x}))$
Vacancy cost function	$\bar{\varphi}\exp(\eta^{\varphi_z}(z-1))\exp(\eta^{\varphi_x}(x-\bar{x}))$
Production function	$x - w$

Figure A5: Equilibrium allocations with different risk aversion parameters



Notes: Baseline risk aversion: $\nu = 2$, counterfactual risk aversion: $\nu = 1.3$.

Figure A6: Equilibrium allocations with different matching friction parameters



Notes: Baseline matching efficiency: $\gamma = 0.41$, counterfactual matching efficiency: $\gamma = 0.36$.

Figure A7: Consumption policy functions

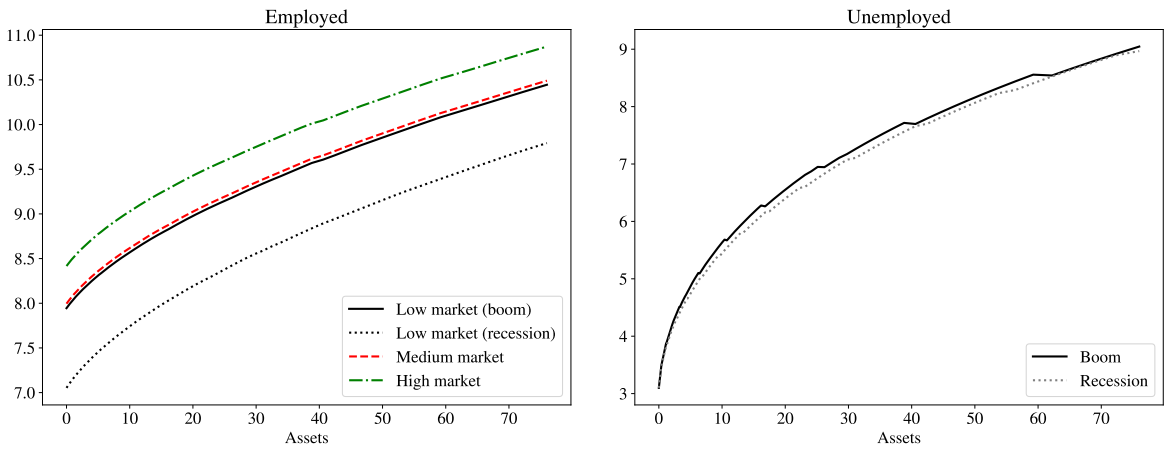
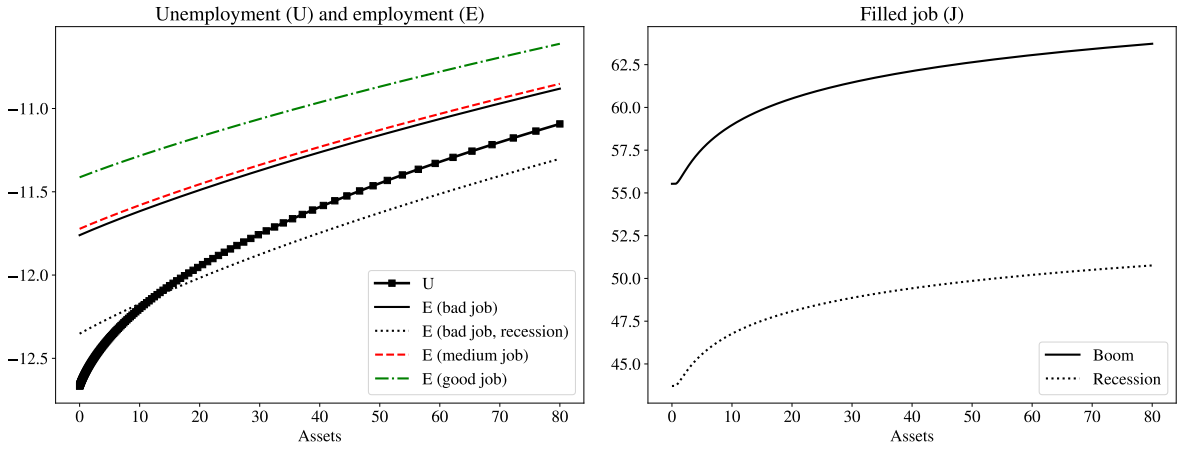


Figure A8: Workers' and firms' value functions



A6 Solution method

With Block Recursivity (BR), the solution method is greatly simplified, as one can solve the labor market problem orthogonal to the distribution of workers across employment states. In fact, the latter is not considered by agents in their optimal decision making.

In the baseline calibration, I use 90 grid points for assets, wages, and productivity, and 5 aggregate states of productivity.

The algorithm works as follows.

1. Given $V(x) = 0$, find the fix point of $J(x, w, z)$ using VFI on Eq. (1.13).

2. Compute the market tightness according to Eq. (1.14). Take a guess on $U^0(a, z)$, $E^0(a, x, w, z)$, $a_0^u(a, z)$, $a_0^e(a, x, w, z)$.

3. Take a guess for the tax rate τ. Solve for the workers' problem.

   (a) Apply policy function iteration (PFI) procedure on the employed workers' Euler equation.

      i. Fix a submarket (x, w). Write the employed workers' EE using the asset policy function initial guesses $a_0^u(a, z), a_0^e(a, z)$

$$u'\left(Ra + w - h^e(a,z)\right) = \beta R\, \mathbb{E}_{z'}\Big\{\lambda(x,z)u'\left(Ra_0^e(a,z) + b - a_0^u\left(a_0^e(a,z), z'\right)\right) + (1-\lambda(x,z))u'\left(Ra_0^e(a,z) + w - a_0^e\left((a_0^e(a,z), z'\right)\right)\Big\}$$

      Where we interpolate a_0^u and a_0^e on the value of assets given by $a_0^e(a, z)$.

The new update for the asset policy function is constructed as

$$a_1^e(a,z) = \begin{cases} h^e(a,z) & \text{if } h^e(a,z) \geq \underline{a} \\ 0 & \text{otherwise} \end{cases}$$

ii. Update on the policy function a^e in a next iteration k, until $a_k^e - a_{k-1}^e < \text{tol}$. Denote the fix-point policy function for a given guess on the unemployed policy function as $a^e(a,z)$.

iii. Loop over all submarkets and retrieve the consumption policy function as $c_e(a,x,w,z) = Ra + w - a^e(a,x,w,z)$.

(b) Apply PFI procedure on the unemployed workers' Euler equation.

i. Fix a submarket (x,w), construct the RHS of the EE using the asset policy function guesses $a_0^u(a,z), a^e(a,x,w,z)$

$$u'\left(Ra + b - h^u(a,z)\right) = \beta R\, \mathbb{E}_{z'}\Big\{ m(\theta(x,w,z))u'\left(Ra_0^u(a,z) + w - a^e\left(a_0^u(a,z),x,w,z'\right)\right) + (1 - m(\theta(x,w,z)))u'\left(Ra_0^u(a,z) + b - a_0^u\left(a_0^u(a,z),z'\right)\right)\Big\}$$

Where we interpolate a^e and a_0^u on the value of assets given by $a_0^u(a,z)$.

The new update for the asset policy function is constructed as

$$a_1^u(a,z) = \begin{cases} h^u(a,z) & \text{if } h^u(a,z) \geq \underline{a} \\ 0 & \text{otherwise} \end{cases}$$

ii. Update on the policy function a^u in a next iteration k, until $a_k^u - a_{k-1}^u < \text{tol}$. Denote the fix-point policy function for a given guess on the unemployed policy function as $a^u(a,z)$.

iii. Loop over all submarkets and retrieve the consumption policy function as $c_u(a,x,w,z) = Ra + b - a^u(a,x,w,z)$.

(c) Apply value function iteration (VFI) to find the fixed point of the workers' VF.

i. Solve for the employed VF given the policy functions a^u and a^e.

A. Compute the RHS using policy function from above and the guesses on the

workers' VFs.

$$E^1(a,x,w;z) = u(c_e(a,x,w,z)) + \beta \mathbb{E}_{z'}\Bigg[\lambda(x,z)U^0\Big(a^e(a,x,w,z);z'\Big) + (1-\lambda(x,z))E^0\Big(a^e(a,x,w,z),x,w;z'\Big)\Bigg]$$

We need to interpolate U_0 and E_0 on the next value of assets given by the policy function a^e.

B. Update the VF until $E^k - E^{k-1} < \text{tol}$.

ii. Apply VFI to find the fixed point of the unemployed worker' VF.

A. Compute the RHS using the policy function evaluated for all possible labor market choices, and the new guess for the employed VF.

$$U^1(a;z) = \max_{\tilde{x},\tilde{w}} u(c_u(a,\tilde{x},\tilde{w},z)) + \beta \mathbb{E}_{z'}\Bigg[m(\theta(\tilde{x},\tilde{w};z))E^1\Big(a^u(a,\tilde{x},\tilde{w},z),\tilde{x},\tilde{w};z'\Big) + (1-m(\theta(\tilde{x},\tilde{w};z)))U^0\Big(a^u(a,\tilde{x},\tilde{w},z);z'\Big)\Bigg]$$

The relationship between tightness and wages is pinned down by combining Eq. (1.13) and (1.12).

B. Update the VF until $U^k - U^{k-1} < \text{tol}$. For every (a,z), store the submarket policy function $\vartheta(x^*,w^*)$.

(d) Verify that $c_u^1(a,z) = c_u^1(a,x^*,w^*,z)$. If not, update the guess $c_u^0(a,z) = c_u^1(a,x^*,w^*,z)$, as well as value functions and other policy functions, and go back to point 3.

4. Verify that the government budget constraint holds. If not, say taxes are too low (high) to finance unemployment benefits, increase (decrease) the tax rate and go back to 3.

A7 Welfare costs

Similarly to Lucas (1987), I compute the welfare gain from an alternative model, as solving the following

$$\sum_{t=0}^{T} \beta^t \frac{(c_t(1-\delta))^{1-\sigma}}{1-\sigma} = \sum_{t=0}^{T} \beta^t \frac{\tilde{c}_t^{1-\sigma}}{1-\sigma} \tag{1.24}$$

, where $\tilde{c}_t$ is the consumption in the alternative model. In these computations, I solve the model under a given path of aggregate productivity. Then, the welfare cost is

$$\begin{aligned}
\sum_{t=0}^{T} \beta^t (c_t(1-\delta))^{1-\sigma} &= \sum_{t=0}^{T} \beta^t \tilde{c}_t^{1-\sigma} \\
(1-\delta)^{1-\sigma} \sum_{t=0}^{T} \beta^t (c_t)^{1-\sigma} &= \sum_{t=0}^{T} \beta^t \tilde{c}_t^{1-\sigma} \\
(1-\delta)^{1-\sigma} &= \frac{\sum_{t=0}^{T} \beta^t \tilde{c}_t^{1-\sigma}}{\sum_{t=0}^{T} \beta^t (c_t)^{1-\sigma}} \\
\delta &= 1 - \left(\frac{\sum_{t=0}^{T} \beta^t \tilde{c}_t^{1-\sigma}}{\sum_{t=0}^{T} \beta^t (c_t)^{1-\sigma}} \right)^{\frac{1}{1-\sigma}}
\end{aligned}$$

A8 Alternative two-period models

Model where aggregate productivity affects continuation value functions

Let $\phi(a_2^*, \theta^*)$ be the maximand of $U(a_1, x)$

$$\phi(a_2^*, \theta^*) = u(Ra_1 - a_2^*) + \beta \left[m(\theta^*) \mathbb{E}_z \left[(1 - \lambda(x,z)) u \left(Ra_2^* + z + \bar{y} - \frac{\varphi(x)}{\beta q(\theta^*) \Lambda(x)} \right) \right] + (1 - m(\theta^*)\Lambda(x)) u(Ra_2^*) \right.$$

Let me simplify notation and define $\tilde{u}(c) = \mathbb{E}_z \left[(1 - \lambda(x,z)) u(c,z) \right]$, and $\bar{u}(c) = \mathbb{E}_z \left[(1 - \lambda_x(x,z)) u(c,z) \right]$.

The FOCs w.r.t to a_2 and θ become:

$$-u'(c_1^*) + \beta R \left[m(\theta^*) \tilde{u}' \left(c_{e,2}^* \right) + (1 - m(\theta^*)\Lambda(x)) u'(c_{u,2}^*) \right] = 0 \tag{1.25}$$

$$\beta \left[m'(\theta^*) \left(\tilde{u} \left(c_{e,2}^* \right) - \tilde{u}(c_{u,2}^*) \right) + \tilde{u}' \left(c_{e,2}^* \right) \frac{\varphi(x) \theta^* q'(\theta^*)}{\beta q(\theta^*) \Lambda(x)} \right] = 0 \tag{1.26}$$

$$\beta m(\theta^*) \left[\left(\bar{u}(c_{e,2}^*) - \bar{u}(c_{u,2}^*) \right) + \tilde{u}'(c_{e,2^*}) \left(- \frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta^*)(\Lambda(x))^2} \right) \right] = 0$$

$$1 = \frac{-\tilde{u}'(c_{e,2}^*)}{\bar{u}(c_{e,2}^*) - \bar{u}(c_{u,2}^*)} \left(- \frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta^*)(\Lambda(x))^2} \right) \tag{1.27}$$

$\phi_{a_2 x}\ \phi_{\theta\theta} < \phi_{\theta x}\ \phi_{a_2 \theta}$

The partial derivatives become

$$\begin{aligned}
\phi_{\theta,x} &= \beta\Bigg(\left[m'(\theta)(\bar{u}(c^*_{e,2}) - \bar{u}(c^*_{u,2})) + \tilde{u}'(c^*_{e,2})\left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2}\right)\right] \\
&\quad + \tilde{u}''(c^*_{e,2})\left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2}\right)\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)} + \tilde{u}'(c_{e,2})\frac{\theta q'(\theta)}{\beta q(\theta)}\left(\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{(\Lambda(x))^2}\right)\Bigg) \\
&= \beta\left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2}\right)\left(\tilde{u}'(c^*_{e,2})[m'(\theta) + 1] + \tilde{u}''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)} - \tilde{u}'(c_{e,2})\theta q'(\theta)\right) \\
&= \beta\left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2}\right)\left(\tilde{u}'(c^*_{e,2})[m'(\theta) + 1 - \theta q'(\theta)] + \tilde{u}''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta q(\theta)}\right)
\end{aligned} \tag{1.28}$$

The second condition for positive wealth sorting is thus unchanged (first bracket). Moreover, as before under CES matching function, $\phi_{\theta,\theta} < 0$. We assume that it is the case. Therefore, positive sorting requires that $\phi_{a_2,x}$, $\phi_{\theta,a_2} < 0$. It holds

$$\begin{aligned}
\phi_{a_2,x} &= \beta R m(\theta^*)\left[(\bar{u}'(c^*_{e,2}) - \bar{u}'(c^*_{u,2})) + \tilde{u}''(c^*_{e,2})\left(-\frac{\varphi'(x)\Lambda(x) - \varphi(x)\Lambda'(x)}{\beta q(\theta)(\Lambda(x))^2}\right)\right] \\
&= \beta R m(\theta^*)\left[(\bar{u}'(c^*_{e,2}) - \bar{u}'(c^*_{u,2})) - \tilde{u}''(c^*_{e,2})\frac{\bar{u}(c^*_{e,2}) - \bar{u}(c^*_{u,2})}{\tilde{u}'(c^*_{e,2})}\right]
\end{aligned} \tag{1.29}$$

$$\begin{aligned}
\phi_{\theta,a_2} &= \beta R\left(m'(\theta)\left[\tilde{u}'(c^*_{e,2}) - \tilde{u}'(c^*_{u,2})\right] + \tilde{u}''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta\Lambda(x)q(\theta)}\right) \\
&= \beta R\Lambda(x)m'(\theta)\left(\left[\tilde{u}'(c^*_{e,2}) - \tilde{u}'(c^*_{u,2})\right] - \tilde{u}''(c^*_{e,2})\frac{\tilde{u}(c^*_{e,2}) - \tilde{u}(c^*_{u,2})}{\tilde{u}'(c^*_{e,2})}\right)
\end{aligned} \tag{1.30}$$

Now, even when Eq. (1.8) holds, condition (1.7) is not sufficient. In fact, it is necessary that it holds in expectations, both in terms of the derivative of the separation function and for the value function.

Model with heterogeneity in firm productivity

A different, and under some assumption similar, way to model sorting into cyclical jobs is to assume that there is a firm productivity distribution and that separations are a function of productivity (should it be endogenously or exogenously). Below, I derive the model under homogeneous separation and show under what conditions the model would endogenously destroy low productivity jobs in bad times. In the case of separations that exogenously depend on

productivity, the model is equivalent to the model exposed in the main text, as the only difference is the production function $f(x)$ and the latter does not matter for any proof.

Assume now that there is a continuum of risk neutral one-employee firms, with (observable) type $x \in \mathcal{X} = [\underline{x}, \bar{x}] \subset \mathbb{R}_+$. A firm of type x produces output $f(x)$ using labor as the only factor of production.

The values of employment and unemployment in $t = 2$ are unchanged, while the value of a filled job, given that wages and productivity are fixed, is now

$$J(x, w) = f(x) - w$$

We can then analyze the problem as a maximization with non-linear Pareto frontier $U(a, x)$, which denotes the value to the worker with assets a when matched with firm x

$$\begin{aligned} U(a_1, x) = \max_{a_2, \theta} \; & u(Ra_1 - a_2 + b) + \\ & \beta \left[m(\theta)(1-\lambda) u\left(Ra_2 + f(x) - \frac{\varphi(x)}{\beta q(\theta)(1-\lambda)} \right) + (1 - m(\theta)(1-\lambda)) u(Ra_2 + b) \right] \end{aligned}$$

The FOCs are

$$\begin{aligned} & u'(Ra_1 - a_2 + b) = \\ & \beta R \left[m(\theta)(1-\lambda) u'\left(Ra_2 + x - \frac{\varphi(x)}{\beta q(\theta)(1-\lambda)} \right) + (1 - m(\theta)(1-\lambda)) u'(Ra_2 + b) \right] \end{aligned} \tag{1.31}$$

$$\begin{aligned} 0 = {} & m'(\theta_t)(1-\lambda) \left[u\left(Ra_2 + x - \frac{\varphi(x)}{\beta q(\theta)(1-\lambda)} \right) - u(Ra_2 + b) \right] \\ & + u'\left(Ra_2 + x - \frac{\varphi(x)}{\beta q(\theta)(1-\lambda)} \right) \frac{\varphi(x) \theta q'(\theta)}{\beta q(\theta)(1-\lambda)} \end{aligned} \tag{1.32}$$

The first condition is an Euler equation where $t = 2$'s consumption depends on the probability of match and match outcome; the second condition pins down market tightness given productivity x.

The optimality condition for the choice of x is $U_x = 0$, i.e.,

$$\begin{aligned} &\beta R m(\theta)(1-\lambda)u'(c_{e,2^*})\left[f'(x) - \frac{\varphi'(x)}{\beta(1-\lambda)q(\theta)}\right] = 0 \\ \Leftrightarrow \quad &\varphi'(x) = f'(x)\beta(1-\lambda)q(\theta) \end{aligned} \tag{1.33}$$

PAM in this model only depends on the preference forms, there are thus less restrictions on the model to generate it.

Proposition 3. *A necessary and sufficient condition for positive assortative matching is*

$$\frac{u'(c^*_{e,2}) - u'(Ra_2)}{u(c^*_{e,2}) - u(Ra_2)} < \frac{u''(c^*_{e,2})}{u'(c^*_{e,2})}$$

Proof. The proof follows Eeckhout and Sepahsalari (2024).
The condition for PAM is unchanged

$$\phi_{a_{t+1}x_t}\phi_{\theta_t\theta_t} < \phi_{\theta_t x_t}\phi_{a_{t+1}\theta_t} \tag{1.34}$$

We now compute the partial derivatives. In optimum (using Eq. (1.33)), it holds that

$$\phi_{a_2,x} = 0 \tag{1.35}$$

$$\phi_{\theta,x} = u'(c_{e,2})\frac{\varphi'(x)\theta q'(\theta)}{\beta(1-\lambda)q(\theta)} < 0 \tag{1.36}$$

$$\begin{aligned} \phi_{\theta,\theta} = {} & m''(\theta)(1-\lambda)\left[u\left(c^*_{e,2}\right) - u(c^*_{u,2})\right] + m'(\theta)(1-\lambda)u'(c^*_{e,2})\left[\frac{\varphi(x)q'(\theta)}{\beta(1-\lambda)(q(\theta))^2}\right] \\ & + u''(c^*_{e,2})\left[\frac{\varphi(x)q'(\theta)}{\beta(1-\lambda)(q(\theta))^2}\right]\frac{\varphi'(x)\theta q'(\theta)}{\beta q(\theta)(1-\lambda)} + u'(c^*_{e,2})\frac{\varphi(x)}{\beta(1-\lambda)}\left(\frac{(q'(\theta)+\theta q''(\theta))q(\theta) - (q'(\theta))^2\theta}{(q(\theta))^2}\right) \end{aligned} \tag{1.37}$$

$$\phi_{\theta,a_2} = Rm'(\theta)(1-\lambda)\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] + Ru''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta(1-\lambda)q(\theta)} \tag{1.38}$$

The LHS of Eq. (1.34) is equal to 0, and $\phi_{\theta_t x_t} < 0$. The condition for PAM is thus $\phi_{a_2\theta} < 0$.
From the FOC, it holds

$$\phi_{a_2\theta} = Rm'(\theta)(1-\lambda)\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] + Ru''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta(1-\lambda)q(\theta)}$$

The sign so far is ambiguous, as the first term is negative and the second positive. However,

from the market tightness FOC we know that

$$\frac{\varphi(x)\theta q'(\theta)}{\beta(1-\lambda)q(\theta)} = -\frac{m'(\theta)(1-\lambda)\left(u(c^*_{e,2}) - u(c^*_{u,2})\right)}{u'(c^*_{e,2})}$$

Therefore, the condition for PAM boils down to

$$\begin{aligned} m'(\theta)(1-\lambda)\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] &< u''(c^*_{e,2})\frac{m'(\theta)(1-\lambda)\left(u(c^*_{e,2}) - u(Ra_2)\right)}{u'(c^*_{e,2})} \\ \frac{u'(c^*_{e,2}) - u'(Ra_2)}{u(c^*_{e,2}) - u(Ra_2)} &< \frac{u''(c^*_{e,2})}{u'(c^*_{e,2})} \end{aligned}$$

Which is satisfied for DARA utility functions (Eeckhout and Sepahsalari, 2024).

□

Whether matching probability is cyclical can be verified by looking at the "strength" of sorting in different aggregate states. Assume that the matching function M features a state-dependent matching efficiency, $M(U,V) = A(z)\left[U^\gamma + V^\gamma\right]^{\frac{1}{\gamma}}$, such that in bad times (z^L) average matching efficiency is lower. Since A enters as a multiplative term, it gets carried through in all derivatives of the job filling and job finding functions. I adapt the equation of sorting to include the average matching efficiency.

$$U_{a_1x}(z) = u'(c_{e,2})\frac{\varphi'(x)\theta A(z)q'(\theta)}{\beta(1-\lambda)A(z)q(\theta)}\left(R(1-\lambda)A(z)m'(\theta)\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] + Ru''(c^*_{e,2})\frac{\varphi(x)\theta A(z)q'(\theta)}{\beta(1-\lambda)A(z)q(\theta)}\right)$$

It is straightfoward to see that

$$\begin{aligned} & u'(c_{e,2})\frac{\varphi'(x)\theta q'(\theta)}{\beta(1-\lambda)q(\theta)}\left(R(1-\lambda)A(z^L)m'(\theta)\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] + Ru''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta(1-\lambda)q(\theta)}\right) \\ & \quad > u'(c_{e,2})\frac{\varphi'(x)\theta q'(\theta)}{\beta(1-\lambda)q(\theta)}\left(R(1-\lambda)A(z^H)m'(\theta)\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] + Ru''(c^*_{e,2})\frac{\varphi(x)\theta q'(\theta)}{\beta(1-\lambda)q(\theta)}\right) \\ \Leftrightarrow \quad & A(z^L)m'(\theta)\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] < A(z^H)m'(\theta)\left[u'(c^*_{e,2}) - u'(c^*_{u,2})\right] \\ \Leftrightarrow \quad & U_{a_1x}(z^L) > U_{a_1x}(z^H) \end{aligned}$$

Model with homogeneous vacancy cost

In this section, I expose why a heterogeneous vacancy cost is a necessary condition for PAM. Below, I derive the model with a homogeneous cost. The conclusion is that PAM cannot obtain under this specification.

With a homogeneous vacancy cost, the joint unemployed and firm problem becomes

$$U(a_1, x) = \max_{a_2, \theta} u(Ra_1 - a_2) + \beta \left[m(\theta)\Lambda(x) u \left(Ra_2 + \bar{y} - \frac{\varphi}{\beta q(\theta)\Lambda(x)} \right) + (1 - m(\theta)\Lambda(x)) u(Ra_2) \right]$$

where $\Lambda(x) = 1 - \lambda(x, z)$ and $\bar{y}$ is the common production output.

The FOCs with respect to a_2 and θ are, respectively:

$$-u'(c^*_{u,1}) + \beta R \left[m(\theta^*)\Lambda(x) u' \left(c^*_{e,2} \right) + (1 - m(\theta^*)\Lambda(x)) u'(c^*_{u,2}) \right] = 0 \tag{1.39}$$

$$\beta\Lambda(x) \left[m'(\theta^*) \left(u \left(c^*_{e,2} \right) - u(c^*_{u,2}) \right) + u' \left(c^*_{e,2} \right) \frac{\varphi \theta^* q'(\theta^*)}{\beta q(\theta^*)\Lambda(x)} \right] = 0 \tag{1.40}$$

where $c^*_{u,1} = Ra_1 - a^*_2$, $c^*_{e,2} = Ra^*_2 + \bar{y} - \frac{\varphi}{\beta q(\theta^*)\Lambda(x)}$ and $c^*_{u,2} = Ra^*_2$.

The first condition is an Euler equation where $t = 2$'s consumption depends on the probability of match and match outcome; the second condition pins down market tightness given productivity x.

Proposition 4. *There is no equilibrium featuring positive assortative matching.*

Proof. The first order condition for the choice of x is

$$\begin{aligned} \frac{\partial U}{\partial x} &= \beta m(\theta^*) \left[\Lambda'(x) \left(u(c^*_{e,2}) - u(c^*_{u,2}) \right) + \Lambda(x) u'(c_{e,2^*}) \left(\frac{\varphi \Lambda'(x)}{\beta q(\theta^*)(\Lambda(x))^2} \right) \right] \\ &= \beta m(\theta^*)\Lambda'(x) \left[\left(u(c^*_{e,2}) - u(c^*_{u,2}) \right) + u'(c_{e,2^*}) \left(\frac{\varphi}{\beta q(\theta^*)\Lambda(x)} \right) \right] \end{aligned} \tag{1.41}$$

The squared bracket of Eq. (1.41) is always positive, i.e., all workers always prefer the same type of jobs. There is no interior solution and hence no sorting. Depending on the sign of $\Lambda'(x)$, all workers will apply to the maximum (if positive) or minimum (if negative) type. □

Chapter 2

Effects of Monetary Policy on Labor Income: the Role of the Employer

with A. Bobasu*.

Abstract

This paper explores the role of firms in the transmission of monetary policy to individual labor income. Using German matched employer-employee administrative data, we study the effects of monetary policy shocks on individual employment and labor income conditioning on the firm type. First, we find that the employment of workers in young firms are especially sensitive to monetary policy shocks. Second, wages of workers in large firms react relatively more. The effects are strongly asymmetric, with differences between large and small firms more exacerbated in easings. The differential wage response is driven by above-median workers and cannot be fully explained by a worker component. We find evidence that larger firms adjust their wages more, even though they are not differently affected in terms of investment and turnover. Overall, monetary policy tightenings hurt low-skilled and low-wage earners relatively more. The effect of monetary policy on inequalities is however larger in easings – driven by a large increase in wages for top earners.

Keywords: labor market, workers type, employment, monetary policy.
JEL-Classification: E24, E52, E58.

* European Central Bank (ECB). The views expressed here do not necessarily reflect those of the ECB or the Eurosystem.

1 Introduction

The effects of monetary policy on economic inequality have gained attention in the public debate, fueled by the extensive asset purchase programs central banks have undertaken over the last decade, and more recently by the sharp tightening implemented in response to rising inflation. The impact and distributional effects of monetary policy on individual labor market outcomes remains an open question in the literature, and is relevant as labor is the major source of income for most households.

Although there is no direct theoretical link between monetary policy shocks and individual employment and labor income developments, workers are likely to be systematically affected by monetary policy through their work relationship. First, firms may be differently affected by monetary policy shocks through indirect general equilibrium effect. Recent literature in heterogeneous agent macroeconomics underlines the economic relevance of such indirect channels (Violante, 2021). Moreover, a long literature since the seminal paper of Gertler and Gilchrist (1994) highlights a credit channel of monetary policy, whereby tightenings affect small and young firms more strongly because the latter typically face larger credit frictions. Monetary policy may also affect firms' profits (Lieberknecht and Hartwig, 2020; González et al., 2022). Such differential firm exposure implies differential worker exposure to monetary policy shocks, which may be systematical in the presence of labor market sorting.[1] Second, even if all firms are affected to the same degree by monetary policy, they might still decide to pass through the shock differently to their workforce. In other words, different firms may offer different income insurance to their workers. Finally, institutional features such as collective wage bargaining agreements and minimum wage policies may also shape the way firms are able to adjust wages or employment following shocks. The different channels together determine the combined response of wages and employment, with a possible interaction between the two margins. In that sense, firms characteristics may affect the transmission of monetary policy as well as labor income inequality. In this paper, we characterize at the micro level the impact of monetary policy interventions on employment probabilities and labor income outcomes within and across heterogeneous firms and workers. We focus on Germany (1999 to 2017) and use a matched employer-employee dataset compiled by the Federal Employment Agency that allows us to track employment histories to the

[1] In Germany, Lochner and Schulz (2016) document a strong and increasing sorting between workers and firms in the labor market. Hagedorn et al. (2017) also find a strong degree of sorting with a rank correlation of 0.75 correlation between firm and worker type in Germany. Therefore, if a certain type of firm is more affected by monetary policy, it is likely that certain workers will also be systematically more affected.

day and offers good-quality wage data. We merge this granular data to the Euro Area monetary policy shocks exogenously identified by Jarociński and Karadi (2020). Our methodology builds on Abowd et al. (1999), extending their fixed effects panel regressions to include monetary policy shocks as well as firms' (and workers') characteristics.

We start by investigating whether firm size and age determine differential workers' employment response to monetary policy shocks. We then repeat the exercise focusing of the individual wage response. Finally, we explore the effect of monetary policy shocks on labor income inequality by focusing on the differential effect of the shocks by worker type.

The results can be summarized in three points. First, mirroring previous findings, we show that workers in young firms have an employment probability that is more responsive to monetary policy interventions compared to that of workers in more established firms. This is consistent with the credit channel of transmission of monetary policy shocks, whereby credit constrained firms (in our case, young ones) adjust their labor force by relatively more. Conversely, firm size is not a relevant determinant for differential employment response. Both firms and workers' characteristics contribute to the higher elasticity of employment to monetary surprises in young firms.

Second, we find that monetary policy shocks affect wages of workers employed in small firms by relatively less, compared to wages of workers in bigger firms. The differential is present within industries and across regions, and is robust to a series of sensitivity analyses. We find strong evidence of asymmetric effects, with wages reacting more in easing than in tightening episodes (consistent with the existence of downward wage rigidities), and the the difference between small and large firms is more pronounced during easing episodes. Using quantile regressions, we then show that the differential response by firm type is only significant for above-median earners. Instead, firm age does not seem to be a relevant determinant of differential wage response to monetary policy shocks. We show that the estimated coefficient is driven by workers changing employer, but not by the form of collective bargaining agreement nor minimum wages. We find that worker type alone cannot explain the differential response, and highlight a potential role played by the pass-through of firms' profit to wages. Moving to firm-level regressions, we find that while firm size does not determine differential reaction of firm investment or turnover to monetary policy shocks, it does so for the total wage bill. Consistent with this, we find that our baseline effect is particularly strong in firms offering a variable pay structure, with potential indexation of wages to equity or profits. Overall, our analysis is therefore consistent with the existence of a heterogeneous ability of firms to adjust wages, larger ones having more space to do

so.

Third, we find evidence that wages of workers ranked higher in the firm's wage distribution, those in the upper permanent wage distribution quintile, and the higher-skilled generally react more to monetary policy shocks. However, tightenings systematically disadvantage low-skilled and low wage workers, on both the employment and wage margin. Instead, easings benefit particularly the top of the wage distributions, who experience relatively larger wage increases. Monetary policy easings thus increase inequality because of the top, while tightenings increase inequality at the bottom (although to a smaller extent).

Our results highlight the importance of considering both wage and employment margins of firms' adjustment to monetary policy shocks. While high-type firms adapt strongly on the wage margin, young firms adapt more strongly on the employment margin, especially by adjusting labor of low-skilled workers.

Related literature This paper speaks to three different strands of literature. First, our paper adds to the recent literature empirically assessing the effect of monetary policy on individual labor market outcomes. Jasova et al. (2021) find that monetary expansions are associated with increase in wages and employment outcomes for workers working in firms that face liquidity constraints in Portugal, highlighting a central role of the credit channel of monetary policy. Our results on wages are in contrast with theirs. Moreover, we separate between the worker and the firm role in explaining the wage and employment responses to monetary policy. Using a quasi-experiment in Sweden, Coglianese et al. (2021) find that the surprise tightening induced a broad decrease in employment across firms, with a little role for credit frictions. They however find a critical role of nominal rigidities, with sectors with more rigid contracts witnessing a higher unemployment. Our paper differs in that we additionally consider wage responses to monetary policy shocks, which we find crucial to understand the overall transmission channels. Moreover, our results add to these papers as they highlight other channels of transmission at play beyond credit frictions and contract rigidities. In particular, we uncover a role of heterogeneous pass-through of firm-level shocks to wages. Our conclusion for the effect of monetary policy on labor income inequalities are thus also different from previous research. Broer et al. (2021) analyze the heterogeneous effect of monetary policy shocks on labor earnings using administrative matched employer-employee data in Germany. They focus on the employment, employment transitions and earning growth responses by income quantile, but do not consider the role of firms in the transmission mechanism of monetary policy on individual labor market outcomes, which is our main focus. Moreover, within

the same literature stream, our results also add to the (small) literature on asymmetric effects of monetary policy on labor market outcomes by providing evidence for the German economy. In the US, Singh et al. (2021) empirically assess the effect of monetary surprises on heterogeneous firms' employment and wages, finding evidence of asymmetric effects. Garibaldi (1997) focuses on asymmetric responses of job creation and destruction. Furceri et al. (2018) provide evidence of the effect of monetary policy shocks on income inequality among 32 advanced and developing countries. Using a non-linear empirical SVAR, Debortoli et al. (2020) find strong asymmetric effects of monetary policy, which they rationalize with a simple model of downward nominal wage rigidities.

Second, our paper is related to research on the transmission channels of monetary policy across heterogeneous firms. In this regard, the seminal work of Gertler and Gilchrist (1994) established an unequal effect of monetary policy on firms, particularly linked to their size and financial constraints. The credit channel has also found ground to explain employment dynamics across firms and over the business cycle (Fort et al., 2013; Chodorow-Reich, 2014; Abo-Zaid and Zervou, 2020; Lee et al., 2022; Popov and Rocholl, 2018). Related, Schoefer (2021) presents a model in which credit friction materializes in combination with nominal frictions, whereby firms subject to high nominal wage rigidities are forced to cut hiring due to financial constraints in recessions. Moving away from the credit channel, Baqaee et al. (2021) highlights that low-markup firms tend to pass a higher portion of marginal cost changes into prices, so that a monetary easing systematically reallocates resources from low-markup to high-markup firms. Lieberknecht and Hartwig (2020) instead finds a positive correlation between monetary policy and firms' profits. We contribute to this literature by conducting an analysis on both wages and employment responses. Moreover, we capture different channels of transmission of monetary policy shock together since our focus is on workers' outcomes.

Third, the paper contributes to the empirical literature on the implications of monetary policy interventions on income inequality (Coibion, 2012). Holm et al. (2021) show that contractionary monetary policy shocks reduce non-financial incomes, but most so at the bottom of the liquid asset distribution. Coibion et al. (2017) studies the effects of monetary policy on income and consumption inequality for the US economy, finding that contractionary monetary policy increases inequality in labor earnings and total income. In the Euro Area, Lenza and Slacalek (2018) study the effect of quantitative easing on inequality. They find that quantitative easing compresses income inequality since many low-income households become employed. Samarina and Nguyen

(2019) examine how monetary policy affected income inequality in the Euro Area between 1999 and 2014. They distinguish macroeconomic (wages and employment) and financial (asset prices and returns) channels through which monetary policy may have distributional effects. The two channels have opposite effects on inequality. Karaki (2020) analyses sectoral responses of job creation and destruction to monetary policy shocks. McKay and Wolf (2023) propose a unified framework to assess the overall effect of monetary policy on households, taking into account all traditional transmission mechanisms of monetary policy. A distinguishing feature of our analysis is its focus on the distributional effects of monetary policy-induced shocks on labor income via the firms to which workers are associated. Moreover, within this framework, we explore effects both on the wage and employment margins.

The remainder of the paper proceeds as follows. Section 2 introduces the data and discusses the institutional framework. Section 3 presents the empirical models that we use throughout our analysis. Our empirical results are shown in Section 4, and finally Section 5 concludes.

2 Institutional framework and data

Germany is one of the largest and most productive economy in Europe. Wage inequality in Germany increased since the mid-90s, mostly within skill and occupation groups (Felbermayr et al., 2014). Between companies differences explain up to 75% of the raised inequalities, highlighting the dominant role of plant characteristics in this phenomenon. In fact, a skill composition effect of the workforce only explains around 10-20% of the rise in income inequality between 1996-2010 – high-skilled workers having a larger wage dispersion and having become a more prominent share of the workforce. It is therefore an interesting laboratory to explore the role that firms play in the transmission mechanism of monetary policy shocks to individual wages and employment probabilities.

The German labor market historically features strong institutions protecting wages as well as sectoral collective agreements – around 54% of wages in Germany are set through unions or collective agreements in 2010. However, industry collective bargaining has been on a declining trend and firm-level agreements have become more common, implying a growing firm wage differentiation. These trends, together with labor market reforms in the nineties have had a positive impact on labor market flexibility, though leading to an increase in inequalities (Felbermayr et al., 2018). In the period we consider for our analysis (1999-2018), companies

already have a relatively high degree of decision power in the wage-setting process. Wage negotiations typically take place at the end of the year.[2] Joining a collective bargaining agreement is associated with increased wages (see Addison et al. 2014) and could introduce more downward wage rigidities.

Moreover, the so-called "wage cushions" moderate the rigidity of contracts for firms covered by collective bargaining agreements. In fact, Jung and Schnabel (2011) document that almost half of those firms pay a wage above the stipulated level. They find that the premium varies with the firms' profits, offering a way for firms to adapt their labor costs with their individual and aggregate conditions even when they are covered by a sectoral wage agreement.

In response to the low-wage sector increase, the government introduced a minimum wage of 8.5eur/hour of work in January 2015 (industry-level collective agreements paying less than the minimum wage were still valid until January 2017). The latter de facto implies complete downward wage rigidities, and also probabily bunching around that minimum wage. However, only few full time jobs were subject to minimum wages: 884'000 (around 2.4%) were paying less than 8.5eur/hour in 2014; and between 0.6% and 0.8% paid the minimum wage from 2015 to 2017, most of them in East Germany.[3]

The labor market in East and West Germany is structurally still quite different. For example, collective bargaining agreements are much more common in West Germany, while wage levels is lower in East Germany. Accordingly, wage cushions are more common in the West while the share of workers subject to the minimum wage is larger in the East. Because the level and structure of wages differ substantially between these regions, many have concentrated the analysis on West Germany (see e.g. Dustmann et al. 2009). We consider Germany as a whole in our main analysis, but show in the Appendix that our results are robust to separating between East and West.

2.1 Data and descriptive statistics

Micro-data

We use the Sample of Integrated Labor Market Biographies (SIAB), an administrative matched employer-employee dataset of German workers and establishments. This data is compiled by

[2] `https://www.worker-participation.eu/National-Industrial-Relations/Countries/Germany/Collective-Bargaining`

[3] Statistisches Bundesamt (Destatis), Erhebung über die Wirkung des gesetzlichen Mindestlohns, 2018; own computations based on report's Table 4 and Table 5.

the Federal Employment Agency (BA) at the Institute for Employment Research (IAB), and provides labor market histories since 1975. On the workers' side, we have information on income, unemployment spells, occupation, region, etc. On the establishment side, there is information on the size in terms of number of employees, the first and last appearance, sector of economic activities, total wage bill, worker flows and the region. There is no way to link establishments belonging to the same mother-firm, because of how the data is gathered. We thus conduct the whole analysis at the establishment level, which we use interchangeably with "firms" in the paper. The dataset provides a 2% random and representative sample of the German workforce. Data cleaning consists mostly of the sample selection, panel transformation, and censoring of wages. We give some details in the following paragraphs, but generally follow Dauth and Eppelsheimer (2020).

The data does not contain precise information on the number of hours worked; we only know whether the worker is part-time (defined as working less than 30 hours per week), full time or marginally employed (the last one since 1999). Following Card et al. (2013), we thus focus our analysis on full-time workers, to avoid extra noise given by changes in hours worked. We select all men and women between 20 and 60 years old. We treat men and women separately in a robustness check and verify that results hold across groups. We define three skills level corresponding to three education categories, following the literature (university degree, vocational training, or neither of those). Firm size reflects the number of employees; in our baseline we flag a firm as small in a certain year if the number of employees is less than fifty. Similarly, we flag a firm as young if the difference between the current year and the first appearance of the firm is less than five. We start the sample in 1999, when Germany started using the euro, for two reasons. First, the SIAB data has not been subject to major changes since that date (while the computation of daily unemployment benefits changed in 1998 for example); and second to maintain a stable monetary policy environment through our analysis.[4]

The data identifies employment spells, which we transform to annual frequency (from January to December) as follows, in line with the literature. We start by summing all employment spells by establishment and year for every worker. We then add up total earnings by establishment and year, and select as the main employer the one who contributed to the highest salary for

[4]The current version (SIAB 7519) includes complete data until 2016. For the years 2017 and 2018, the 18-month files were used, and the observations for 2019 originate from a 6-month file (complete data corresponds to inclusion of 36-month files). We therefore stop the analysis in 2018, and verify that all results hold when stopping in 2016.

that worker in a given year. We define as employed every individual who spent most of her time employed in a certain year. Unemployed are those who spent most time receiving unemployment benefits. We do not consider individuals who are neither employed nor receiving benefits, hence abstracting from the participation margin.
The income for each employment spell is reported as the average daily wage over the spell. Since 1984, the daily wage measure includes bonus payments and there is no systematic way to disentangle bonuses from base rates. Wages are right-censored, in particular those exceeding the upper earnings limit for statutory pension insurance are only reported up to this limit. To avoid biased estimation, we impute the upper tail of daily wages with a Tobit model, following methods developed and used in Gartner et al. (2005); Dustmann et al. (2009); Card et al. (2013). Figure A1 in Appendix shows the wage distribution with and without imputed values for two arbitrary years.

When exploring the transmission channels related to firm types, we make use of the linked employer-employee dataset of the IAB (LIAB). While the administrative data content is the same as in the SIAB, the LIAB sample is representative of establishments and, importantly for us, it is merged with a firm survey data – see Gartner et al. (2005) for a detailed description of the data product. The survey offers rich information on investment, turnover, types of wage contracts, coverage by collective bargaining agreements, firm legal form, etc. We clean the administrative matched employer-employee part of the data in the same way as SIAB, explained above.

The upper panel of Appendix Figure A3 shows the wage distribution for workers in small and big firms. On the bottom panel, we differentiate instead the wage distribution by workers' skills. The wage distribution shows that wages are on average lower in small firms, which is not suriprising given that size is expected to be correlated with productivity. The large wage gap between low and high skilled is easily observable, while medium skilled have a wage distribution quite similar to the whole population.

Monetary policy and aggregate data

For the monetary policy shocks, we use monthly monetary policy surprises for the Euro Area from the work of Jarociński and Karadi (2020). We aggregate them to a yearly frequency by adding up the monthly shocks. For interpretation purposes, in the analysis we standardize the shocks to have a mean of zero and standard deviation of 25btps. Figure A2 in the Appendix plots the non-standardized yearly series for our estimation sample. Most of the variation happens

in the first half of the sample; nevertheless the second half also still features some shocks. In a robustness test, we use the shadow interest rate as computed by Wu and Xia (2016). We take first differences – for comparability with the notion of "surprise" of our baseline analysis – and also standardised in a similar manner (WX_t). We also perform a robustness test using the EONIA deposit rate (D_t), transformed in the same way as WX_t.

As far as the other variables employed in the analysis are concerned, all nominal variables are deflated using German CPI. As control variables, we use as a proxy for the business cycle real GDP growth, and also the changes aggregate unemployment for the German economy in a robustness regression. The data on real GDP, inflation, unemployment and different proxies for the monetary policy interventions are all collected from Haver Analytics. All variables entering the regressions are described in table A1 in the Appendix. Table A2 in the Appendix present the summary statistics of our main variables. The data cleaning leaves us with a baseline estimation sample size of quasi eight million observations.

3 Empirical methodology

In this section, we lay down the empirical models that we use to estimate the effects of monetary policy shocks on labor market outcomes among a chosen heterogeneity dimension. We first focus on heterogeneous responses by firm type, also allowing for asymmetric responses. We next explore potential non-linear effects with a quantile regression. Finally, we present the model capturing effects on individual employment probabilities.

In all models, we make use of the matched employer-employee data features to estimate models that can identify workers' and firms' fixed effects. As we do not aim to identify sorting between workers and firms but merely are interested to quantify exposure to monetary policy shocks, we base our methodology on the seminal contribution of Abowd et al. (1999) (hereafter AKM) and perform fixed effects regressions. We augment it to include monetary policy shocks previously identified (as explained in the previous section) as well as firms and workers' characteristics.

Baseline model

Let $\mathbb{J}(i,t)$ identify the *unique* establishment employing worker i in time t. We assume that workers' log-wages $y_{i,t}$ are generated by a model composed by a worker component α_i, an establishment component $\Psi_{\mathbb{J}(i,t)}$, a set of time varying controls $x_{i,t}$ (including time fixed effects)

and an an error capturing all other factors $\varepsilon_{i,t}$.[5] α_i represents the contribution of personal attributes in the workers' wage, while $\Psi_{\mathbb{J}(i,t)}$ represents a wage premium that is paid by a certain establishment to all employees for that period of time.

$$y_{i,t} = \alpha_i + \Psi_{\mathbb{J}(i,t)} + x'_{i,t}\beta + \varepsilon_{i,t}$$

Identification of fixed effects is achieved by observing movers across firms. We assume that the conditional expectation of $\varepsilon_{i,t}$ is independent of the worker's job history ("exogenous mobility"), so that OLS yields unbiased coefficients. Previous empirical work supports the validity of the exogenous mobility assumption for Germany (Gerard et al., 2021). We cluster standard errors at the firm and worker level throughout the analysis.

We then introduce exogenous monetary policy shocks (MP) into the equation. Let $F_{\mathbb{J}(i,t)}$ represents a firm heterogeneity dimension of interest. To simplify notation, we write (j,t) instead of $\mathbb{J}(i,t)$. In order to estimate how differently monetary policy affects workers along the heterogeneity dimension, we interact MP_{t-1} with $F_{j,t}$. Although the shocks series is assumed to be exogenous, we attempt to treat any remaining endogeneity by further controlling by Germany's GDP growth, again interacted with MP.[6] Our baseline regression is thus

$$y_{i,t} = \alpha_i + \Psi_{j,t} + x'_{i,t}\beta + \gamma\ MP_{t-1} \times F_{j,t-1} + \zeta \Delta \ln GDP_{t-1} \times F_{j,t-1} + \varepsilon_{i,t} \tag{2.1}$$

γ is our coefficient of interest, and can be interpreted as the difference between wages responses along the heterogeneity dimension of interest that cannot be explained by workers and firms observed and unobserved characteristics.

On the firm side, we consider heterogeneity in terms of size, age and the firm's position in the average firm wage distribution. In particular, dummies for small and young firms, $S_{j,t-1}$ and $Y_{j,t-1}$ and a dummy equal to one if the firm pays on average a low wage $FR_{j,t-1}$.[7] On the worker side,

[5] We use education and an age polynomial as our baseline control variables. In the Appendix Table A5, we also show results further controlling for tenure and with aggregate employment instead of GDP, but this has practically no influence on our results.

[6] The monetary policy shocks are estimated residuals from a VAR (Jarociński and Karadi, 2020). Endogeneity would arise if monetary surprises nevertheless respond to aggregate conditions in Germany, which themselves are likely to affect wages. Controlling for such aggregate condition thus alleviates the potential concern.

[7] According to the EU commission definition, small firms are those with less than 50 employees and mini

we consider heterogeneity in terms of the worker's rank in the firm's wage distribution (a dummy equal to one if the worker's pay is larger than the firm's average wage), her position in the permanent income distribution, as well as skills, respectively denoted by $WR_{i,t-1}$, $\bar{y}^p_{i,t-1}$ and $\text{skill}_{i,t-1}$.

We differentiate between accomodative and restrictive monetary policy shocks by further interacting our coefficients of interest with a dummy variable equal to one if the monetary policy shock is negative (accomodative), and zero otherwise.

The identification strategy for the employment probability regressions follows the same idea as the wage regressions. We abstain from binary choice models, but verify that OLS predicts reasonable employment probabilities. Our specification is thus as Eq. (2.1), but with the dependint variable being an indicator of employment status (one if employed, zero if unemployed).

When estimating firm-level regressions, we use the following model

$$\ln H_{j,t} = \Psi_{j,t} + \beta_t + \gamma\ MP_{t-1} \times F_{j,t-1} + \zeta \Delta \ln GDP_{t-1} \times F_{j,t-1} + \varepsilon_{j,t} \tag{2.2}$$

, where we choose the dependent variable $H_{j,t}$ to be either firms' total real investment, turnover or wage bill.

Quantile regression

We then estimate an unconditional quantile treatment effect at key percentiles of the income distribution. This regression allows to test for heterogeneous effects of monetary policy shocks across the labor income distribution. We use the two-step estimation introduced by Borgen et al. (2021). The procedure first regresses our interaction of interest on the control variables using OLS and saves the residuals – assuming that they are independent of the outcome variable.

$$I_{i,t} = \alpha_i + \Psi_{j,t} + x'_{i,t}\beta + \zeta \Delta \ln GDP_{t-1} \times F_{j,t-1} + \nu_{i,t}$$

firms are those with less than 10 employees. We consider a firm "young" if it exists since less than 5 years. FR instead indicates firms that pay on average less than the mean of firms' wages in a specific year.

Where $I_{i,t} = MP_{t-1} \times F_{j,t-1}$. The second step uses the residuals as an independent variable in a quantile regression model.

$$\ln y_{i,t,\tau} = \beta_\tau \hat{\nu}_{i,t} + \epsilon_\tau \tag{2.3}$$

We bootstrap standard errors for both steps using 50 repetitions, re-sampling the data with replacement. In each re-sample, both steps are estimated.[8] This approach allows to perform quantile regressions with controls and multi-dimensional fixed effects (see their paper for more details).

4 Empirical results

In this section, we first characterize the effect of monetary policy shocks on individual employment, highlighting the role of firm type in the transmission mechanism. We then move to the response of individual wages. Finally, we explore what our results imply for the role of monetary policy interventions on labor income inequality.

4.1 Employment margin

We start by analysis the job loss and job finding channels in our empirical framework. These may be important especially when the labor market features substantial rigidities on wage setting. Moreover, employment is also the relevant margin of adjustment estimated in the literature on the transmission of shocks through credit constraints (see e.g. Chodorow-Reich, 2014).[9]

In what follows, we estimate individual employment probabilities by firm type, following a monetary policy shock. Note here that the estimated coefficients may be a combination of labor demand or labor supply responses.[10]

Table 1 presents the regressions' results. Columns (1) and (2) show coefficients for firm size, while columns (3) to (5) for firm age. Columns (1) and (3) show the regression with no fixed effects or

[8] Practically, we make use of the RQR command in Stata developed by (Borgen et al., 2022).

[9] Burya et al. (2022) explore the effect of labor market power in the transmission of monetary policy shocks, and also find that in the US workers are mainly affected through the employment margin rather than wage margin.

[10] Generally, we focus on workers who are attached to the labor market. In a recent paper, Graves et al. (2023) show that labor supply responses are much stronger than what was typically assumed in the literature. Nevertheless, their results are mostly driven by movements from and to the non-participation margin of employment, a dimension which we abstract from. Therefore, in our context, the results likely mostly reflect labor demand adjustments.

controls. The point estimates suggest that a 25bpt surprise tightening reduces the individual baseline employment probability by 0.17%. Moreover, the probability to become unemployed if working in small and young firms is higher relative to big and older firms. With the inclusion of fixed effects and controls, the probability of becoming unemployed if working in a young firm is significantly higher than if working in an older firm, of 0.05%. The coefficient on firm size instead becomes insignificant and essentially zero. Generally, the magnitudes are quite small, reflecting the little variation of the employment status measure at the yearly frequency.

Table 1: Employment probabilities on monetary policy shocks

	(1)	(2)	(3)	(4)	(5)
MP_{t-1}	-0.0017***		-0.0017***		
	(0.00010)		(0.000080)		
MP_{t-1}					
$\times$ $S_{j,t-1}$	-0.00073***	-0.0000030			
	(0.00016)	(0.00014)			
$\times$ $Y_{j,t-1}$			-0.0019***	-0.00052**	-0.00044**
			(0.00028)	(0.00024)	(0.00024)
$\times$ l skill$_{j,t-1}$					-0.00052**
					(0.00028)
$\times$ l skill$_{j,t-1} \times Y_{j,t-1}$					-0.00099
					(0.0010)
Controls & FEs	N	Y	N	Y	Y
N	7702906	7598813	7702906	7598813	7598813
R-sq	0.000	0.378	0.001	0.378	0.378

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year; $Y_{j,t-1}$ is a dummy equal to 1 if the firm exists since less than 5 years; and l skill$_{i,t-1}$ is a dummy equal to 1 if the workers' education level is: no diploma.

A natural question is whether the differential effect is the result of a worker component, a firm component or a combination of the two. The findings might be driven by workers' skills, with differences between firm types arising due to sorting of low-skilled worker into smaller firms. Alternatively, it could be a purely firm story, with different types of firm being differently affected by monetary policy and passing these effects through to their workforce in the same way, or firms being affected the same way but with different pass-through of shocks, or both. Finally, it could be that the phenomenon only happens for specific matches, in particular only for high-skilled who, through sorting, work in large firms.

In the following, we show that both firms' and workers' characteristics can explain unequal effects of monetary policy shocks on individual employment. For this, we introduce a triple interaction between monetary policy shocks, a firm and a worker characteristic of interest. Relevant coefficients are shown in column (5). The interactions between monetary policy and

both the firm and worker characteristic are both significantly negative. This indicates that both firm age and worker skills independently matter for the impact of monetary policy on employment probabilities. Interestingly, the skill component appears to be additive, as the magnitude of the interaction coefficient with firm age changes very little from column (4). Also, the coefficient on skills is of larger magnitude compared to the one corresponding to firm age (0.052% versus 0.044%). We explore the unequal effect of monetary policy shocks by worker types in Section 4.3. Nevertheless, while worker skills and firm age are significant independently, the interaction between young firms and low-skilled workers does not seem to induce significant differential impact of monetary policy on the employment probability, as shown in the last triple interaction coefficient of column (5). These results suggest that sorting alone cannot fully account for the greater sensitivity of workers' employment probabilities in young firms to monetary policy shocks. Importantly, they highlight that firm age alone matters in the elasticity of individual employment to monetary policy shocks.

Our results are in line with well established literature. Moser et al. (2022) find that within firms, initially lower-paid workers are more likely to leave employment following an adverse monetary policy induced credit supply shock. Similarly, Coglianese et al. (2021) find that the increase in unemployment following a monetary policy tightening is larger for workers at small, young firms.

4.2 Heterogeneous effect on wages and transmission mechanism

The second step consists of analyzing the effects of monetary policy on wages across firm types. We differentiate firms according to size, age and whether the firm's average paid wage is below or above relative to average wages paid the other firms in the sample. Our main result points to the fact that wages of workers in smaller firms are less affected by monetary policy shocks as compared to wages of workers in bigger firms following monetary policy interventions.

Table 2 shows our preferred specification for firm size in column (1). A 25bpt surprise monetary policy tightening decreases wages of workers in small firms by 0.63% less than for workers working in big firms. That is, half of the decrease in wages of workers in big firms. This result holds within industries and regions and is robust to a series of specification sensitivity and robustness analyses, as reported in the Appendix Tables A4 and A5. Results are comparable. Columns (1) to (4) of Appendix Table A3 presents the results of regressing Equation (2.1), gradually saturating the regression with fixed effects and controls. The first column shows a result of monetary policy non-neutrality, whereby a monetary policy surprise tightening shock decreases wages by 1.7% in our sample. As we include fixed effects, the R^2 increases from 0.15 to 0.90 and

the coefficient in the interaction becomes smaller, suggesting that some of the effect of monetary policy shocks go through firms, workers, industry and region fixed effects.

Next, we present evidence that firm size matters on its own for the differential effect of monetary policy shocks on wages. The regression presented in column (2) introduces a triple interaction between monetary policy, workers skills and firm size (similarly to column (5) in Table 1). Interestingly, the triple interaction coefficient is insignificant and our main coefficient remains almost unchanged. In other words, firm size matters on its own for the elasticity of wages to monetary policy shocks. Workers skills also imply a differential wage response to monetary policy shocks, though the magnitude is half of the firm size coefficient.

Table 2: Individual wages on monetary policy shocks by firm type

	(1)	(2)	(3)	(4)	(5)
MP_{t-1}					
$\times$ $S_{j,t-1}$	0.0063***	0.0066***	0.044***		
	(0.00065)	(0.00067)	(0.0015)		
$\times$ l skill$_{j,t-1}$		0.0033**			
		(0.00137)			
$\times$ l skill$_{j,t-1}$ $\times$ $S_{j,t-1}$		-0.0034			
		(0.0021)			
$\times$ $S_{j,t-1} \times MP_{t-1}^{<0}$			-0.22***		
			(0.0064)		
$\times$ $Y_{j,t-1}$				0.00036	
				(0.00098)	
$\times$ $FR_{j,t-1}$					0.0095***
					(0.00065)
N	7889680	7889680	7889680	7889680	7889680
R-sq	0.902	0.902	0.902	0.902	0.902

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. All regressions include year, worker, firm, industry (of the firm) and industry by year fixed effects; as well as aggregate GDP growth as a control variable. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year; $Y_{j,t-1}$ is a dummy equal to 1 if the firm exists since less than 5 years; $FR_{j,t-1}$ is a dummy equal to 1 if the firm's average wage is below average; and l skill$_{i,t-1}$ is a dummy equal to 1 if the workers' education level is: no diploma.

Depending on the underlying channels at play, easings and tightening could affect wages in an asymmetric manner. In fact, we find that wages in big firms – our baseline category – react in absolute terms about two and a half times more in easing than in tightening episodes. This is not that surprising in the presence of downward wage rigidities, but highlights a strong positive effect of monetary policy easings effects on wages. Column (3) of Table 2 shows that the difference between small and large firms is more exacerbated when monetary policy eases (22% versus only

4% in tightening), both in terms of magnitude and percent of wage change.[11]

In columns (4) and (5), we show our coefficient of interest for firm age and firm rank (a dummy equal to one if the firm is paying on average a low wage relative to the other wages paid by firms included in the sample). First, we see that firm age is not a relevant dimension of heterogeneous wage responses to monetary policy shocks in Germany. Second, results sustain that low-paying firms adjust wages by almost 1% less, a coefficient slightly higher than firm size. Although size and pay are correlated, they capture something different, in particular they may differ in their implications for sorting – in terms of workers characteristics. Column (2) of Table A4 in the Appendix shows the results of regressing Eq. (2.1) using a population-estimated AKM firm effect interacted with the monetary policy shock series. We find that wages of workers working in firms that are in the upper quartile of the firm AKM distribution are the ones reacting more to monetary policy shocks. As we argued previously, the AKM effect can be interpreted as a premium paid by the firm to their workers, which may come from a productivity component, different rent-sharing across firms, or also strategic firm behavior (Bellmann et al., 2020). Hence, while the coefficient cannot help to pin down one specific channel, it confirms the general idea that differences of monetary policy shock responses come mostly from high-paying, highly productive firms.

We next present quantile regression results, to uncover potential non-linearities. Figure 1 shows our baseline estimated elasticities for firm size, estimated on various percentiles of the wage distribution. Interestingly, the effect is only significant for median and above earners – there is no difference between the responses of wages in small and large firms for the lowest paid quartile of the wage distribution. This suggests that large firms adjust their wages more and especially for high-earning workers following a monetary policy shock.[12]

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[11] The regression is the following,

$$\ln y_{i,t} = \alpha_i + \Psi_{j,t} + x'_{i,t}\beta + \gamma_1\ MP_{t-1} + \gamma_2\ F_{j,t-1} + \gamma_3\ MP_{t-1} \times F_{j,t-1} + \gamma_4\ n_t + \gamma_5\ n_t \times MP_{t-1} + \gamma_6\ n_t \times F_{j,t-1} + \gamma_7 n_t \times F_{j,t-1} \times MP_{t-1} + \zeta \Delta \ln GDP_{t-1} \times F_{j,t-1} + \varepsilon_{i,t} \quad (2.4)$$

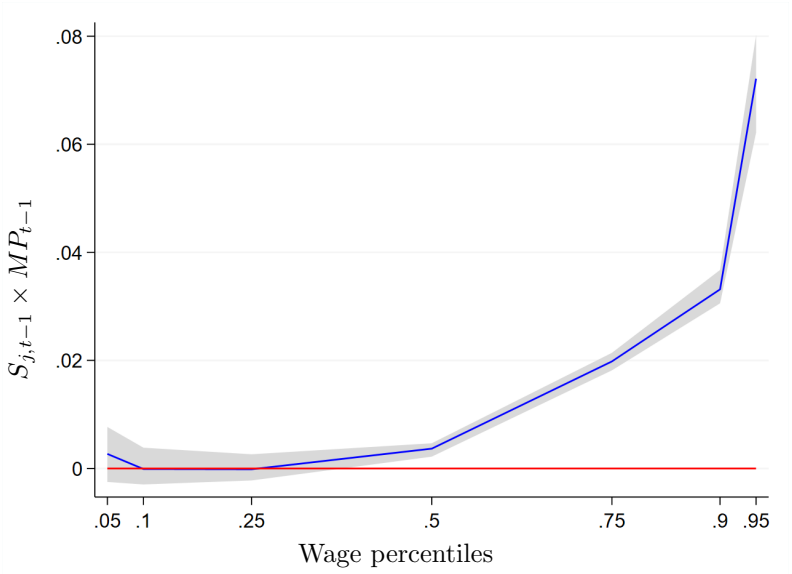
, where n_t is the dummy for the sign of the shock.

We only show the relevant interaction coefficients of Eq. (2.4), which can be interpreted as follows.

$$\begin{aligned} MP_{t-1} \times S_{j,t-1} &= \frac{\partial \ln y}{\partial \iota}\Big|_{n=0;S=1} - \frac{\partial \ln y}{\partial \iota}\Big|_{n=0;S=0} \\ MP_{t-1} \times S_{j,t-1} \times MP^{<0}_{t-1} &= \frac{\partial \ln y}{\partial \iota}\Big|_{n=1;S=1} - \frac{\partial \ln y}{\partial \iota}\Big|_{n=1;S=0} \end{aligned}$$

[12] Note that we do not plot the top 5% of the wage distribution, because most of the wages in that section are imputed. The graph would look even more non-linear if we would plot it. At the 90th percentile, less

Figure 1: Individual wages on monetary policy shocks by firm size



Note: Confidence bands at the 95% level. Errors are clustered at the individual and firm level. Standard errors are obtained by bootstrap with 50 repetitions. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year.

Composition effect Recent literature explains the observed wage pro-cyclicality with workers changing jobs, occupation and skill mismatch over the business cycle (see e.g. Gertler et al., 2020; Bauer and Lochner, 2020; Black and Figueiredo, 2022). We follow that literature and explore whether such a channel can be at play. In fact, our results could reflect a difference in the possibility to move on the job ladder between large and small firms, the former potentially having more (internal) opportunities. Column (7) and (8) in Appendix Table A4 show that our baseline results are driven by the population of job switchers, namely workers who were working in small and large firms, and then changed employer within two years. On the contrary, there is no significant difference in wages between stayers, i.e. those who remained working for the same employer for more than two years. These findings suggests that different poaching behavior across small and big firms might play a role in explaining the baseline results.

Heterogeneous pass-through of shocks to wages Results until now suggest that large firms change their wages more following monetary policy shocks, especially for their high-pay workers. We now seek the reason behind this, in particular we explore whether it is because they are affected more by monetary policy, or because their pass-through of shocks to wages is

than 5% of observations are imputed and at the 90th around 50% are censored.

relatively higher. We discuss the role of collective bargaining in the next paragraph. For this analysis, we use firm-level data information from LIAB.

Table 3 present the results of estimating Eq. (2.2). There is no significant difference between small and large firms concerning the impact of monetary policy shocks on investment and turnover, as we can read from columns (1) and (2). Therefore, it does not seem that our baseline results come from heterogeneous exposure of small and large firms to monetary policy shocks. Rather, column (3) shows that small and large firms adjust their wage bills in a different way, small firm decreasing it by relatively less.

Table 3: Firm-level variables on monetary policy shocks by firm size (LIAB)

	(1) investment	(2) turnover	(3) wages
$MP_{t-1} \times S_{j,t-1}$	0.46	0.21	0.043**
	(0.64)	(0.17)	(0.020)
N	5552400	4401851	6318541
R-sq	0.817	0.975	0.993

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year. In Column (1), the dependent variable is real total investment; in Column (2) it is real turnover; and in Column (3) total real wages.

Underlying transmission mechanisms Our analysis is consistent with a heterogeneous "wage cushion" response – or in general variable pay structure or bonuses, larger firms being more likely to use them. We stress here again that labor income in the German administrative data also accounts for bonuses, and those are typically concentrated in bigger firms. In fact, if monetary policy tightenings are associated with lower firm profits, bigger firms seem to have a greater ability to transfer this to their workers through the variable component.[13] We show direct suggestive evidence of this channel using information on whether the firm implements profit sharing. Columns (7) and (8) of Appendix Table A12 shows that the estimated difference of wage adjustments in big and small firms is bigger for those with profit sharing than those who do not use profit sharing.

We next discuss the role of institutional labor market characteristics of the German economy. Branten et al. (2018) present evidence from a survey in the Euro Area about nominal wage rigidities. While they find that wage adjustment frequency is positively correlated with firm size, it is not possible to disentangle optimal wage adjustments from true rigidity components

[13]In a different setting, Di Maggio et al. (2022) find that idiosyncratic firm uncertainty shocks are passed through wages of the top-earners through variable pay adjustments.

in their analysis. This is crucial for us, as our baseline result can arise if smaller firms face higher rigidities. In what follows, we argue that institutional aspects alone cannot account for the significant difference in wages responses between small and large firms. First, (**?**) find that greater union density shows a robust relationship with downward real wage rigidity. Secondly, evidence that the minimum wage affects mostly smaller firms (Dütsch and Himmelreicher, 2020), could introduce more downward rigidities for these firms and explain the lower sensitivity of small firm's wages to monetary policy interventions. However, column (4) in Appendix Table A4 shows that the difference between small and large firms was present before the introduction of the minimum wage policy. Second, one may think that collective bargaining agreements introduce different wage flexibility and because larger firms are more likely to be in such agreements, the results mirror the effect of being in a collective bargaining agreement.[14] If anything, our analysis suggests rather that collective bargaining agreements have an effect on how firms decide to structure their wage contracts. Within the LIAB dataset, we show that our baseline result holds for all types of collective agreement coverage, although stronger so for those subject to a sectoral agreement (see columns (4)-(6) of Appendix Table A12). Another piece of suggestive evidence is that the difference between small and large firms is also present in East Germany, where collective bargaining agreements are much less common (Columns (6) and (7) of Appendix Table A4).

Heterogeneous matching frictions across worker types in the sense of capital-skill complementarities (e.g. Dolado et al. (2021) support the hypothesis that high-paid workers are subject to lower matching frictions as these workers are more complementary to capital than substitutable unskilled ones are), cannot explain why firm size alone implies a differential wage response to monetary policy shocks.

Our results are supported by similar findings of Moser et al. (2022) indicating that higher-paid workers see relative bigger wage declines following a tightening in credit supply. However, they are different from Jasova et al. (2021) who find that in Portugal monetary policy interest rate cuts are associated with a higher wage for workers working in small firms, through a firm relaxed liquidity constraint channel. They argue that in case of back-loaded wages, young and small firms should react more to monetary policy shock, in contrast with our findings.[15] In Germany, the

[14]The effect would still be ambiguous, as firms subject to an agreement are more likely to revise wages upward (Addison et al., 2014), but may also have more downward wage rigidities.

[15]Firm size and age have been thought in the literature as proxies for a firm's credit access and financial constraints since Gertler and Gilchrist (1994). Against this, using the firm level survey data, we test

credit channel does not materialize in the same way; in fact, we find the opposite wage response. If anything, we find that the credit channel materializes on the employment margin.

4.3 Effect on inequalities

So far, we characterized the effect of monetary policy shocks on individual wages and employment outcomes. We are next interested in assessing the overall effect on labor income inequalities. We first run our baseline model using worker's characteristics as the differentiating dimension. Our results mirror those of previous section, because of sorting in the labor market – e.g. low paid workers are more likely to work in smaller firms. We confirm whether the asymmetric effect of monetary policy on wages systematically affect workers ranked lower. Finally, we look at the effect on individual employment probability.

Columns (1) to (4) of Table 4 present results for the heterogeneous response of workers' wages to monetary surprises along three heterogeneity dimensions, namely the worker rank in the firm WR_t, their position in the permanent income distribution $\bar{y}^p$, and their skill level. We find that wages of workers ranked higher in the firm's income distribution (column (1)), those in the upper permanent income distribution quintile (column (2)), and the higher-skilled (column (3)) react more to monetary policy shocks. Interpreting the three measures as proxies for worker productivity and in light of our baseline results, these results could mirror a strong positive labor sorting between workers and firms in Germany.[16] We also find some evidence of U-shaped effects, those in the middle of the permanent income and skill distribution being less affected by monetary policy shocks than those on the extremes. This reminds of findings by Guvenen et al. (2014). We show that our results are robust to a series of specification and sample choices in the Appendix Tables A6 and A7.

Having concluded that low-skilled, low-payed and poorer workers have less variation in their wages due to monetary policy, we next explore whether this is true both in tightenings and easings.

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whether another proxy of financial constraints can explain the results, but find no evidence there either (see column (3) in Appendix Table A12).

[16]The AKM model is unable to identify sorting between workers and firms, because the firm fixed effect is not independent of the worker' fixed effect (Eeckhout and Kircher, 2011; **?**). Hagedorn et al. (2017) prove that one can identify the sign and magnitude of sorting using a matched employer-employee data, but estimating labor market sorting within the SIAB is outside of the scope of this paper.

Table 4: Individual wages on monetary policy shocks by worker type

	Wages				Employment	
	(1)	(2)	(3)	(4)	(5)	(6)
MP_{t-1} ×						
$WR_{i,t-1}$	-0.0097***			-0.0088***	0.00052***	
	(0.00065)			(0.0014)	(0.00014)	
$WR_{i,t-1} \times MP_{t-1}^{<0}$				-0.021***		
				(0.0055)		
$\bar{y}_{i,t-1}^{p}$=3		0.012***				
		(0.0011)				
$\bar{y}_{i,t-1}^{p}$=5		-0.015***				
		(0.0014)				
$\text{skill}_{i,t-1}$=2			-0.00034			0.00047
			(0.0010)			(0.00029)
$\text{skill}_{i,t-1}$=3			-0.011***			0.0011***
			(0.0016)			(0.00032)
N	7889680	6271208	7791504	7889680	7598813	7512590
R-sq	0.904	0.914	0.902	0.904	0.378	0.379

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $WR_{i,t-1}$ is a dummy equal to 1 if the worker's wage is below the firm mean wage; $\bar{y}_{t-1}^{p}$ is the quantile of the past 3 years' average income distribution; and $\text{skill}_{i,t-1}$ represents the workers' education level (1: no diploma, 2: vocational training, 3: university degree).

Our baseline category of highly-ranked workers (within firms) see their wages increase more in easing periods than they decrease in tightening periods (in absolute terms, more than 3 times more). As we see from column (4), the difference between low- and high-ranked workers are of an order of magnitude smaller than between small and large firms, confirming the relatively more important role of the firm type compared to worker type in the wage response to monetary policy shocks. Moreover, our results highlight that low-ranked workers are systematically disadvantaged: their wage decrease by relatively more in tightenings and increase by relatively less in easings (respectively by -0.9% and -2.1%). Overall, monetary policy increases wage inequalities in tightenings by less than in easings. These results seem to confirm the evidence from (**?**). The authors argue that, while collective pay agreements reduce downward wage adjustments, the increase in the probability of downward base wage responses following a decrease in demand is significantly smaller than the increase in the probability of upward wage responses associated with an increase in demand. At the same time, our findings seem to stand in contrast with the analysis of Furceri et al. (2018) who conclude that inequality increases by more following a tightening than it declines when monetary policy eases.

On top of the effect going through sorting of high-skilled into larger firms, these results could reflect that an unexpected monetary easing favors high-skilled workers, in light of a capital-skill complementarity channel (see e.g. Dolado et al., 2021).

Moving on to the employment probability response to monetary policy shocks. The employment of high-ranked and high skilled workers are less exposed, as we read from the positive coefficients in columns (5) and (6). On the one hand, hiring and firing costs are generally bigger in case of high-skilled than of low-skilled workers. Thus, shocks tend to affects more the unemployment of low-skilled workers for which adjustment costs of firms are smaller. Zens et al. (2020) also find looking into the US labor market that workers at the bottom of the skill distribution are disproportionately affected by monetary policy interventions. Beyond the firm related channels that we discussed above, the phenomenon is consistent with models of frictional labor markets – such as the standard search-and-match – in which the replacement rate is an important driver of wage and employment dynamics. For example, in the model of Abbritti and Consolo (2022), low skilled prefer to get unemployed than to accept wage cuts because they have a relatively higher replacement value.

5 Conclusion

The transmission mechanisms of monetary policy to individual wages are complex and not yet fully understood, although they are relevant for policy decisions and the debate about implications on welfare and consumption behavior. This paper sheds light on the role of firms in determining workers' wages and employment responses following monetary policy shocks.

We use high-quality administrative data that provides employment histories of a representative sample of German workers together with their relative employers. We find that workers in young firms have an employment probability that moves more with monetary policy interventions than workers in older firms. Moreover, firms respond differently on the wage margin following monetary policy shocks: workers in larger firms experiencing a relatively larger wage adjustment relative to workers in small firms. The effect is asymmetric, with wages reacting more in easing than in tightening episodes, and differences between large and small firms being more exacerbated in easings. We next show that wages of workers ranked higher in the firm's income distribution, those in the upper permanent income distribution quintile, and the higher-skilled react more to monetary policy shocks. However, their employment probability is less sensitive to monetary policy shocks compared to low-skilled workers. Overall, our results highlight the importance of considering both wage and employment margins of firms' adjustment to monetary policy shocks. While inequality remains outside central banks' objective, its distributional effects need to

be considered due to their role in shaping the effectiveness of monetary policy transmission. Therefore, a deeper understanding of the interplay between monetary policy and labor market outcomes remains an important issue for debate going forward.

*We acknowledge the data base and its documentation, conforming with the Research Data Centre (FDZ) of the German Federal Employment Agency (BA) rules.
Berge, Philipp vom; Frodermann, Corinna; Ganzer, Andreas; Schmucker, Alexandra (2021): "Factually anonymous Version of the Sample of Integrated Labour Market Biographies (SIAB-Regionalfile) – Version 7519 v1". Research Data Centre of the Federal Employment Agency (BA) at the Institute for Employment Research (IAB). DOI: 10.5164/IAB.SIAB-R7519.de.en.v1 Data access was provided via a Scientific Use File supplied by the Research Data Centre (FDZ) of the German Federal Employment Agency (BA) at the Institute for Employment Research (IAB).
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A Appendix

A1 Data description and sources

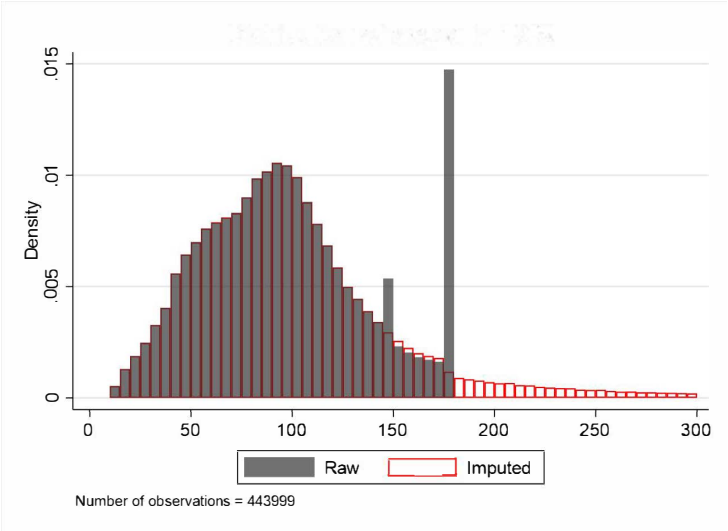
The variables, including the individual wages, enter the regressions in real terms. All nominal variables are deflated using German CPI. As control variables, the analysis employees as a proxy for the business cycle real GDP growth, and also the changes aggregate unemployment for the German economy in a robustness regression. The control data such as real GDP, inflation, unemployment and different proxies for the monetary policy interventions are all collected from Haver Analytics.

Table A1: Variables Used in the baseline regressions

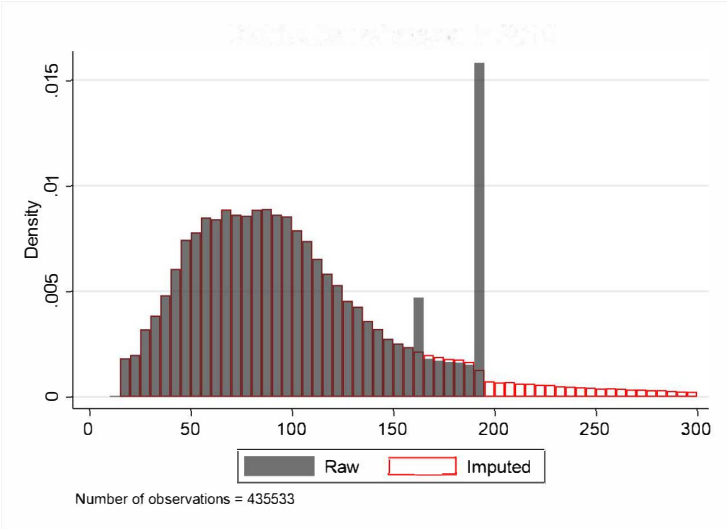
Variable	**Description**	**Source**
Individual wages	Deflated with HICP	SIAB (LIAB)
Individual employment status	1 if employed, 0 if unemployed	SIAB (LIAB)
Monetary policy shocks	Standardized onetary policy surprises	Jarocinski and Karadi (2020)
Economic growth	Real gross domestic product (SA)	Haver (Eurostat)
Consumer price inflation	Harm. Index of Consumer Prices (SA)	Haver (Eurostat)
Unemployment	Unemployment rate (SA)	Haver(Eurostat)

A2 Wage imputations and summary statistics

Figure A1: distribution of ln-wages in different years



(a) 1999



(b) 2014

Table A2: Summary statistics of main variables of interest

	Mean	**SD**	**Min**	**Max**
Age	41	10	20	59
Education	2.1	.48	1	3
Female	.45	.5	0	1
East	.19	.39	0	1
ln-wage	4.48	.62	2.3	8.1
H^s	.45	.5	0	1
H^y	.14	.35	0	1
Employed	0.998	.05	0	1
MP	0	.25	-.33	.5
$MP^{<0}$	.44	.5	0	1
$\Delta \ln Y$	.011	.019	-.043	.035
Observations	7980952			

Figure A2: Monetary policy shocks

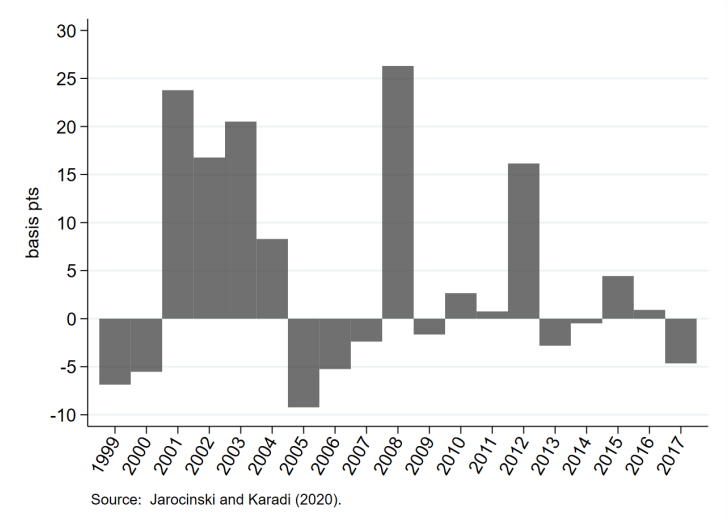
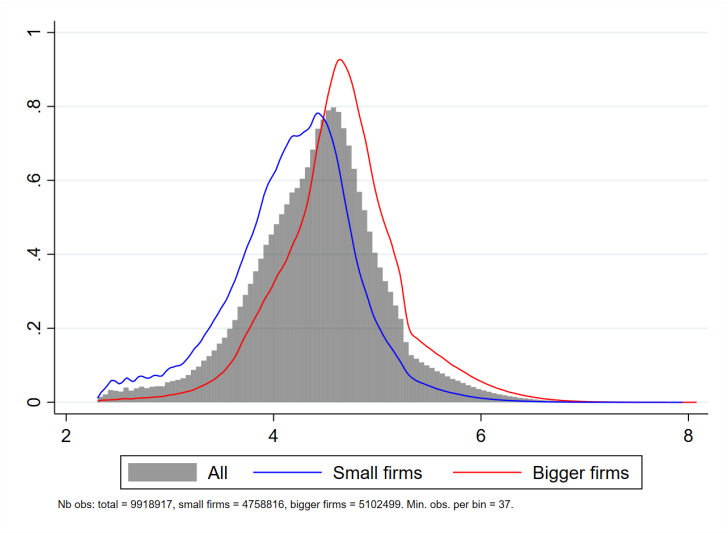
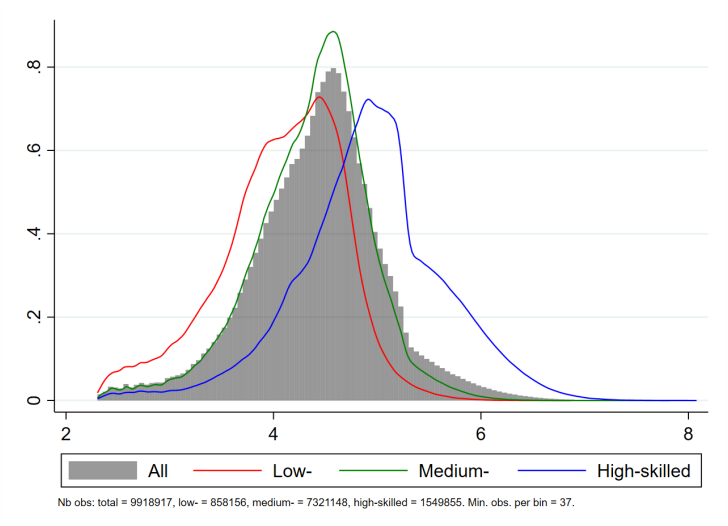


Figure A3: Kernel density of ln-wages by type



(a) Firm size



(b) Worker skills

A3 Additional results

Table A3: Individual wages on monetary policy shocks by firm type, sequential adding of fixed effects

	(1)	(2)	(3)	(4)
$S_{j,t-1}$	-0.41***			
	(0.0046)			
MP_{t-1}	-0.017***	-0.63***	-0.63***	-0.46***
	(0.00100)	(0.011)	(0.011)	(0.053)
$\times \quad S_{j,t-1}$	0.024***	0.010***	0.010***	0.0063***
	(0.0016)	(0.00068)	(0.00068)	(0.00065)
Agg. Controls	N	Y	Y	Y
Fixed Effects				
AKM	N	Y	Y	Y
Industry	N	N	Y	Y
Industry × Yr	N	N	N	Y
N	7980952	7906742	7889680	7889680
R-sq	0.151	0.902	0.902	0.902

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year; $Y_{j,t-1}$ is a dummy equal to 1 if the firm exists since less than 5 years; $FR_{j,t-1}$ is a dummy equal to 1 if the firm's average wage is below average.

Table A4: Individual wages on monetary policy shocks by firm size, different subsamples

	(1) mini	(2) AKM	(3) male	(4) < 2015	(5) west	(6) east	(7) stayers	(8) switchers
$MP_{t-1}\times$								
$S^m_{j,t-1}$	0.0072***							
	(0.00071)							
AKM^F_{t-1}=2		-0.00058						
		(0.0015)						
AKM^F_{t-1}=3		-0.0026*						
		(0.0014)						
AKM^F_{t-1}=4		-0.0087***						
		(0.0014)						
$S_{j,t-1}$			0.0069***	0.0058***	0.0065***	0.0051***	0.0026	0.0068***
			(0.00086)	(0.00064)	(0.00074)	(0.0013)	(0.0090)	(0.00066)
N	7889680	7583056	4326061	6431716	638014 1	1497344	244129	7240532
R-sq	0.902	0.897	0.896	0.911	0.89 9	0.914	0.928	0.907

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S^m_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 10 employees in a certain year; AKM^F_{t-1} are AKM effects quantiles estimated on the whole population; $S^s_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year; $WR_{i,t-1}$ is a dummy equal to 1 if the worker's wage is below the firm mean wage.

Table A5: Individual wages on monetary policy shocks by firm size, sensitivity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$S_{j,t-1} \times MP_t$	0.020***						
	(0.00077)						
$S_{j,t-1} \times MP_{t-1}$		0.0062***	0.012***	0.0028***	0.0016***		
		(0.00065)	(0.00068)	(0.00055)	(0.00015)		
$\text{tenure}_{i,t-1}$		0.000016***					
		(0.00000024)					
$S_{j,t-1} \times \Delta WX_{t-1}$						0.046***	
						(0.0034)	
$S_{j,t-1} \times \Delta D_{t-1}$							0.063***
							(0.0025)
N	7889680	7889680	7076227	7883007	788968 0	4451899	6180086
R-sq	0.902	0.903	0.909	0.914	0.902	0.919	0.909

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year; Column (1) shows the $t-t$ model, Column (2) controls for tenure, Column (3) controls for aggregate unemployment instead of GDP, Column (4) uses the non-imputed wage measure, and Column (5) divides the measure of wages by the average wage. WX_{t-1} is the shadow interest rate as computed by Wu and Xia (2016); and D_{t-1} the EONIA deposit rate.

Table A6: Individual wages on monetary policy shocks by worker rank, different subsamples

	(1)	(2)	(3)	(4)
	male	< 2015	west	east
$WR_{i,t-1} \times MP_{t-1}$	-0.012***	-0.0099***	-0.011***	-0.0056***
	(0.00095)	(0.00064)	(0.00075)	(0.0013)
N	4326061	6431716	6380141	1497344
R-sq	0.897	0.912	0.901	0.916

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $WR_{i,t-1}$ is a dummy equal to 1 if the worker's wage is below the firm mean wage.

Table A7: Individual wages on monetary policy shocks by worker type, sensitivity

	(1)	(2)	(3)	(4)	(5)
$MP_t \times WR_{i,t-1}$	-0.0059***				
	(0.00071)				
$MP_{t-1} \times WR_{i,t-1}$		-0.0097***	-0.0069***	-0.0045***	-0.0024***
		(0.00065)	(0.00067)	(0.00055)	(0.00015)
$\text{tenure}_{i,t-1}$		0.000014***			
		(0.00000023)			
N	7889680	7889680	7076227	7883007	7889680
R-sq	0.904	0.904	0.910	0.916	0.904

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $WR^{s}_{i,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year; Column (1) shows the $t-t$ model, Column (2) controls for tenure, Column (3) controls for aggregate unemployment instead of GDP, Column (4) uses the non-imputed wage measure, and Column (5) divides the measure of wages by the average wage.

Table A8: Employment probabilities, role of firms' and workers' effects

	Firm type		Education type		
	small	*large*	*low*	*medium*	*high*
	(1)	(2)	(3)	(4)	(5)
MP_{t-1} ×					
$\text{skill}_{i,t-1}$=2	0.00037	0.00046			
	(0.00046)	(0.00034)			
$\text{skill}_{i,t-1}$=3	0.00046	0.0011***			
	(0.00053)	(0.00038)			
$S_{j,t-1}$			-0.00056	0.00012	-0.00072**
			(0.00055)	(0.00016)	(0.00034)
N	3274085	4152403	525311	5718022	122257 1
R-sq	0.477	0.346	0.480	0.406	0.382

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year; and $\text{skill}_{i,t-1}$ represents the workers' education level (1: no diploma, 2: vocational training, 3: university degree).

Table A9: Employment probabilities, role of firms' and workers' effects

	Firm type		Worker rank	
	small	*large*	*low*	*high*
	(1)	(2)	(3)	(4)
MP_{t-1}×				
$WR_{i,t-1}$	0.00046**	0.00049***		
	(0.00021)	(0.00017)		
$S_{j,t-1}$			-0.00011	0.00015
			(0.00016)	(0.00022)
N	3326894	4184192	3516444	3886889
R-sq	0.477	0.346	0.468	0.456

Table A10: Role of the firms' and workers' effects

	Firm type		Worker rank	
	small	*large*	*bottom*	*top*
	(1)	(2)	(3)	(4)
$WR_{i,t-1} \times MP_{t-1}$	-0.0057***	-0.013***		
	(0.00086)	(0.00094)		
$S_{j,t-1} \times MP_{t-1}$			0.0076***	0.0031***
			(0.00075)	(0.00086)
N	3471081	4321231	3606133	4070038
R-sq	0.928	0.869	0.922	0.912

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year; and $\text{skill}_{i,t-1}$ represents the workers' education level (1: no diploma, 2: vocational training, 3: university degree).

Table A11: Role of the firms' and workers' effects

	Firm type		Worker tenure	
	small	*large*	*low*	*high*
	(1)	(2)	(3)	(4)
l1ltenure=1 × MP_{t-1}	0.0082***	0.0088***		
	(0.0017)	(0.0019)		
$S_{j,t-1}$=1 × MP_{t-1}			0.0041	0.0067***
			(0.0084)	(0.00064)
N	3471081	4321231	185676	7398804
R-sq	0.927	0.867	0.913	0.908

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year; and $\text{skill}_{i,t-1}$ represents the workers' education level (1: no diploma, 2: vocational training, 3: university degree).

Table A12: Individual wages on monetary policy shocks by firm size (LIAB)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MP_{t-1}	-0.012***							
	(0.0047)							
× $S_{j,t-1}$	0.021***	0.011***	0.011***	0.0079*	0.022**	0.018***	0.048***	0.12***
	(0.0051)	(0.0026)	(0.0026)	(0.0048)	(0.011)	(0.0068)	(0.0075)	(0.022)
Controls & FEs	N	Y	Y	Y	Y	Y	Y	Y
N	14128181	14128181	14102718	979636	1559824	4144978	1468888	1120151
R-sq	0.187	0.880	0.880	0.924	0.845	0.875	0.907	0.845

Note: standard errors in parenthesis; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Errors are clustered at the individual and firm level. Monetary policy shocks are standardized series from Jarociński and Karadi (2020). $S_{j,t-1}$ is a dummy equal to 1 if the firm employs less than 50 employees in a certain year. Column (1) and (2) replicate our basline results in the LIAB data. Column (3) uses the subsamples of non-credit constrained firms; Column (4)-(6) use subsamples with different collective representation (none, inhouse, and sectoral respectively); Column (7) uses the subsample of firms not sharing profits in the pay while Column (8) uses the subsample of firms implementing profit sharing.

Chapter 3

Energy Price Shocks, Monetary Policy and Inequality

with A. Bobasu* and M. Dobrew*.

Abstract

We study how monetary policy shapes the aggregate and distributional effects of an energy price shock. Based on the observed heterogeneity in consumption exposures to energy and household wealth, we build a quantitative small open-economy HANK model that matches salient features of the Euro Area data. Our model incorporates energy as both a consumption good for households with non-homothetic preferences as well as a factor input into production with input complementarities. Independently of policy energy price shocks always reduce aggregate consumption. Households with little wealth are more adversely affected through both a decline in labor income as well as negative direct price effects. Active policy responses raising rates in response to inflation amplifies aggregate outcomes through a reduction in aggregate demand, but speeds up the recovery by enabling households to rebuild wealth through higher returns on savings. However, low-wealth households are further adversely affected as they have little savings to rebuild wealth from and instead loose due to further declining labor income.

Keywords: energy prices, open economy, heterogeneous agents, monetary policy.

JEL-Classification: E52, F41, Q43.

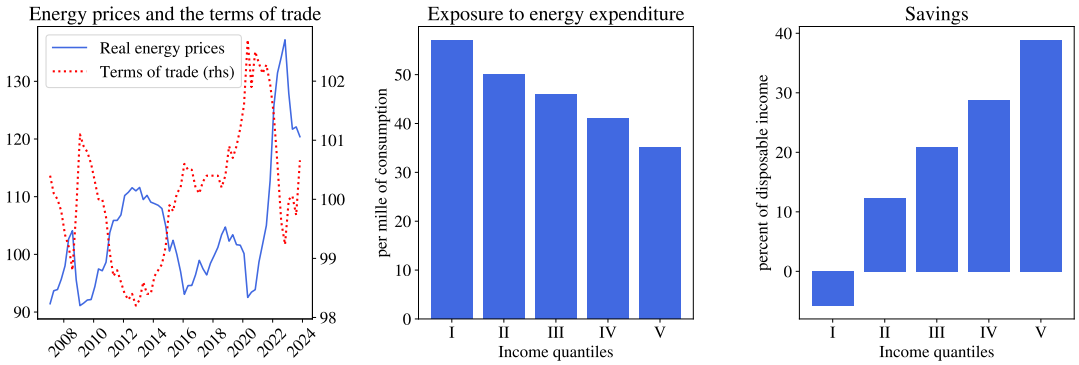
* European Central Bank (ECB). The views expressed here do not necessarily reflect those of the ECB or the Eurosystem.

1 Introduction

Energy prices have reached historical heights, starting their rise in mid-2021 after most economies reopened from COVID-19 lockdowns and being catalysed early 2022 by the Russian invasion of Ukraine. Figure 1 (left panel) shows that real energy prices in the Euro Area have risen by 60 percent from their lows in 2020 and by 30 percent compared to their average over the past 20 years. At the same time, the terms of trade deteriorated with negative implications for domestic purchasing power. Despite the Euro Area being an energy importer facing an exogenous shock, monetary policy reacted to the energy price surge by raising rates at unprecedented speed. The rise in energy prices and subsequent policy response naturally have heterogeneous effects on households, with less wealthy households likely being affected the most. First, these households are more exposed to energy prices through their consumption basket as they spend a larger fraction of their income on energy-related goods (middle panel). Second, their limited savings makes it difficult for them to smooth their consumption in response to temporary price increases (right panel).[1] Third, low-wealth households almost solely rely on labor income and do not benefit from higher returns on savings.

[1]For more details on smaller adjustment margins for low-income households given their consumption basket and savings positions, see also Hobijn and Lagakos (2005), Bobasu et al. (2023) and Bils and Aguiar (2010).

Figure 1: Energy prices, terms of trade, households' consumption exposures and savings across the income distribution



Note: The "real energy price" indicates the ratio between the energy component of the HICP and the overall HICP index. The terms of trade are proxied by the ratio between the GDP deflator and the private consumption deflator. Charts in the middle and right are based on distributional statistics from the "Household budget survey" and the experimental "Income, consumption, and wealth" datasets provided by Eurostat.

Based on the observed heterogeneity in household consumption and wealth, we build a small open economy heterogeneous agent New Keynesian (HANK) model to analyse the aggregate and distributional effects of energy price increases and how these effects are shaped by monetary policy. We show first, that an energy price shock is always recessionary in an open economy that imports all energy because it constitutes a wealth transfer from the domestic to the foreign economy. Second, the initial adverse aggregate effects are smaller when monetary policy remains "passive", i.e. keeps the real rate constant. "Active" monetary policy reacting to inflation by raising the real rate exacerbates the initial negative effects, yet implies a faster recovery. By decomposing the aggregate consumption response we show that under a passive policy the negative effects of energy price shocks mainly arise through negative real income effects. In contrast, under an active policy consumption declines predominantly due to a rising real rate instead of the shock itself. Third, low-wealth households are affected the most by an energy price shock. Active policy exacerbates negative effects for low-wealth households through a further decline in labor income, but benefits high-wealth households through higher returns on savings.

In our small open economy model energy features as both a consumption good and a factor input to production. All energy used in the domestic economy has to be imported. Households have non-homothetic preferences over energy and non-energy goods modelled

as a Stone-Geary utility function. They face idiosyncratic income risk that they can only imperfectly insure against due to an occasionally binding borrowing constraint. Firms produce domestic goods utilizing labor and energy as inputs, with limited substitutability between them. While prices are flexible we introduce sticky wages through labor unions. We model monetary policy as a Taylor rule, which can react either to contemporaneous inflation measures or their forecasts. These measures include headline inflation, defined as the change in aggregate prices, core inflation, defined as the change in domestic goods prices, and energy price inflation. We contrast these rules with a baseline policy that remains passive by keeping the real rate constant.

We calibrate our model to data from the Euro Area in order to quantify the aggregate and distributional effects of an energy price shock. We take particular care in matching the heterogeneity observed in household consumption baskets. In particular we use Eurostat's "Household budget survey (HBS)" and "Income, wealth and consumption statistics" (ICWS) to match an average household expenditure on energy of around 9 percent and match the degree of non-homotheticity to target higher energy expenditures of the lowest income quintile of around 13 percent. Additionally, we target an average aggregate marginal propensity to consume of around 0.3 delivering substantial income and wealth heterogeneity in our model. On the firm side, we calibrate the degree of complementarity between factor inputs to recent estimates in Bachmann et al. (2022) and additionally take into account information based on input-output tables indicating that the energy use in production is nearly double that of consumption.

We start by illustrating the importance of non-homothetic preferences and input complementarities for the aggregate and individual consumption and income response to an energy price shock under our baseline passive policy. Non-homotheticity imposes a constraint on low-wealth households, while elasticities of substitution in consumption and production govern the ability of households and firms to respond to the shock in relative prices. We show that less wealthy households suffer a larger consumption expenditure shock compared to wealthy households, thereby further raising their already elevated marginal propensity to consume (MPC). When the elasticity of substitution across consumption goods is large, the energy price shock is less severe for all households as they are able to substitute away from more expensive energy goods towards cheaper domestic goods. Similarly, a high

elasticity of substitution in the production function allows firms to decrease their demand for energy and therefore mitigates the decline in labor demand, predominantly benefiting low-wealth households.

Turning to the aggregate effects of an energy price shock we show the strong dependence on the monetary policy response. We contrast a baseline in which monetary policy keeps the real rate constant, i.e. is fully passive, to policy rules which react either to contemporaneous or forecast measures of inflation. In our open economy model, where all energy is imported, an energy price shock is always recessionary regardless of the policy response, as the benefits from higher energy prices solely accrue to the foreign economy. In contrast to the passive baseline, a policy responding to either contemporaneous headline or core inflation raises real interest rates. Higher real rates in turn induce a strong decline in consumption and output that is four times bigger than under the baseline. Rules responding to either forecast measures of headline or core inflation instead effectively "look through" the initial energy price increase. Real rates rise very little under these "passive" responses, thereby alleviating most of the negative effects on aggregate demand. In turn, the decline in both consumption and labor income is less pronounced compared to the baseline rule with otherwise very similar implications. Responding to energy inflation has remarkably different implications. Under such a policy, the increase in the real rate is the highest with an initial complete suppression of energy and therefore headline inflation. However, this comes at the cost of a strong recession that is initially significantly larger than under a headline rule. Additionally, completely containing inflation in the short term comes at the cost of higher inflation in the medium-term, when a speedy recovery of domestic goods demand together with rising foreign demand ultimately raises core and headline inflation.

By analyzing the drivers of the aggregate consumption response we show that the negative effects of an energy price shock stem from indirect negative real income effects but are strongly exacerbated under an active policy response through direct real rate effects. We decompose the consumption response into a direct effect arising from changes in the real interest rate, an indirect effect arising from changes in labor income and a relative price effect. The latter captures a decline in consumption arising from the energy price shock, causing higher expenditures on subsistence consumption thereby leaving a smaller share of income for consumption beyond the subsistence level. Under a fixed real rate, four-fifths

and therefore the majority of the consumption decline is due to indirect income effects whereas one fourth is driven by the relative price effect. Since monetary policy is passive, there are no direct real rate effects. This implies that the adverse effects of an energy price shock work predominantly through a reduction in real income with an additional margin for rising costs of the consumption basket. In stark contrast, under an active policy response, three-fourths of the decline in consumption is accounted for by the direct effect and therefore directly related to the rise in the real rate. Forecast rules that are sufficiently passive trigger only a small increase in real rates which positively contributes to aggregate consumption by providing higher returns on savings without adverse effects on aggregate demand and therefore labor income.

Finally, we show that low-wealth households are generally affected the most by an energy price shock. Absent any policy response the decline in their consumption is three times larger relative to high-wealth households. An active policy response amplifies the consumption decline for all households. Although this decline is larger for wealthier households, the driver of the underlying consumption starkly differ between low- and high-wealth households. Low-wealth households *have to* reduce consumption because of the strong decline in labor income. In contrast, wealthy households optimally *choose* to reduce their consumption because higher real rates incentivize them to save more. For these households price effects are immaterial and labor income effects are a lot smaller than for low-wealth households. A passive policy response instead does not induce a (strong) response of real rates and thereby does not cause a strong consumption decline for wealthy households as the energy shock itself does not substantially affect them. However, low-wealth households substantially benefit from a passive policy response because of the strongly mitigated adverse effects on labor income associated with such a policy.

Related literature We relate to three main strands of the literature investigating the aggregate and distributional effects of energy shocks in open economy models, including the implications and propagation mechanisms under different monetary policy conducts. The core analysis builds on an established body of literature which focuses on the transmission of oil price shocks in open-economy representative-agent models (Mendoza, 1995; Kose, 2002 and more recently Baqaee and Farhi, 2019) including the appropriate monetary policy

response (Bodenstein et al., 2011; Natal, 2012). Blanchard and Gali (2007) study the propagation of oil prices in an open economy representative agent model, by including oil in the production function in order to account for the role of intermediate production factors. Bernanke et al. (1997) conduct counterfactual monetary policy simulations and conclude that monetary policy significantly influences the transmission of oil price shocks in the economy. Bodenstein et al. (2011) use a New Keynesian model with oil in consumption and production to examine the effects of different monetary policies in response to energy shocks, by distinguishing between core and headline inflation. The authors find an optimal response to an adverse energy supply shock involves a persistent rise in core and headline inflation. Bodenstein et al. (2013) using the same model find that the effects of oil shocks on aggregate demand are rather cushioned when monetary policy is constrained by the zero lower bound compared to normal times when monetary policy is unconstrained. Natal (2012) in an optimal policy design argues that policies which perfectly stabilize prices entail significant welfare costs. We add to this literature by studying energy price shocks in a similar open economy setting but with a focus on household heterogeneity which allows us to also study distributional effects of energy price shocks and how they relate to different monetary policy responses. More recently, Gagliardone and Gertler (2023) have estimated a New Keynesian model incorporating oil and showing that studying oil price shocks and monetary policy combined provides a good description of the recent aggregate data. While all these papers focus on aggregate outcomes, Del Canto et al. (2023) notably develop an empirical framework to analyze the impact of inflationary shocks throughout the distribution, separately studying energy and monetary policy shocks. Our paper can be understood as a structural counterpart to their empirical approach, with a focus on how the effects of energy shocks are shaped by monetary policy. Despite the differences in approaches, we similarly conclude that energy price shocks are generally regressive and that the monetary policy response can have a substantial impact in shaping these effects. We also relate to a growing literature analyzing the domestic effects of shocks emerging in foreign economies in the context of open-economy heterogeneous agent (HA) models. de Ferra et al. (2020) quantify the aggregate and distributional effects of capital flow reversals in Hungary, where agents hold different amounts of foreign currency debt. Guo et al. (2020) study the distributional effects of international shocks when agents differ

by their sector of work and their financial integration, finding that these sources of heterogeneity can play a major role and create trade-offs in the conduct of monetary policy. Other recent papers studying the redistributive effects of external shocks include Zhou (2020), Oskolkov (2022) and Otten (2021). Cugat (2019) introduces household heterogeneity in an open-economy New Keynesian model and study its role in the transmission of foreign shocks. Auclert et al. (2019) study monetary transmission in an open-economy HANK, providing general conditions under which households' heterogeneity matters emphasizing the presence of a strong real-income channel that can lead to contractionary devaluations. Guntin et al. (2020) show how introducing household heterogeneity can inform macroeconomic theories of aggregate consumption adjustment to sudden stops. We contribute to this literature by explicitly studying energy price shocks and their aggregate and distributional consequences adding monetary policy as a source impacting foreign shocks.

Third, we contribute to an emerging literature studying energy shocks in macroeconomic models with at least some degree of household heterogeneity. Chan et al. (2022) focus on the production side highlighting the demand spillovers arising from input complementarity in a two-agent New Keynesian model. They show that a higher complementarity leads to a stronger decline in labor demand hurting constrained households more and additionally study optimal policy in this setting with limited heterogeneity. While also modelling input complementary, we instead emphasize the demand side heterogeneity in both consumption and income in a fully-fledged HANK model and compare how different monetary policy rules benefit or hurt different households along the income distribution. Gornemann et al. (2023) using a similar two agent model study how supply shortages can lead to self-fulfilling fluctuations and analyze how monetary policy can remove determinacy risks. In a recent paper, Olivi et al. (2023) study how monetary policy should react to aggregate and sectoral disruptions in a multi-sector New Keynesian model. They focus on an analytical derivation of two wedges related to heterogeneous consumption expenditures when households have non-homothetic preferences and show that applied to UK data these wedges are quantitatively important. We differ from their paper by explicitly modelling energy and considering shocks to energy prices instead of aggregate productivity. As we show, energy price shocks have considerably different aggregate and distributional

implications compared to other supply shocks. Additionally, their focus on tractable heterogeneity precludes them to fully study distributional effects as we do in our model. Audzei and Sutóris (2023) similarly use a tractable heterogeneous agent model, albeit studying the incentives to invest in energy abatement capital in response to an energy price shock. Perhaps the closest papers to ours are Auclert et al. (2023) and Pieroni (2023). Pieroni (2023) builds a closed economy HANK model to study how a shock to energy supply affects macroeconomic outcomes. We instead employ an open economy model and innovate by explicitly studying different monetary policy rules and how they affect both aggregate and distributional outcomes, also studying the drivers of individual consumption responses and how they differ across the wealth distribution. Auclert et al. (2023) similarly build an open economy HANK model with differences in the model setup, e.g. abstracting from input complementarities in production. They study how the interaction of fiscal policy and monetary policy specified as an exogenous rate path can mitigate energy price shocks albeit solely focusing on aggregate effects. We instead explicitly study distributional outcomes and specify monetary policy through a more commonly used Taylor rule that endogenously reacts to either contemporaneous or forecast measures of inflation.

The remainder of the paper is organised as follows. In Section 2 we present our theoretical model and in Section 3 we describe the calibration and steady state of the model. Section 4 focuses on the implications of an energy price shock in the context of different monetary policy frameworks, highlighting the role of the elasticities of substitution in consumption and production. The section also examines the aggregate and distributional effects under both a baseline keeping the real rate fixed and various active policy rules. Finally, section 5 concludes.

2 Model

In this section we introduce a small open economy New Keynesian model with heterogeneous households. Energy features as both a consumption good as well as a factor input to production. Households have non-homothetic preferences over non-energy and energy goods with less wealthy households spending a larger share of their income on energy. Production of non-energy goods requires labor and energy as inputs which cannot be easily

substituted. A labor union flexibly supplies labor to firms charging a wage rate that they can only infrequently change, whereas goods prices are perfectly flexible. All energy has to be imported from abroad and we model an energy crisis as an exogenous shock to the foreign price of energy.

2.1 Households

Environment The economy is populated by a continuum of households of measure one. Households are infinitely-lived and time is discrete. The domestic economy is part of a continuum of foreign countries distributed over the unit interval, each populated by a representative foreign agent (à la Gali and Monacelli, 2005). Each domestic household faces idiosyncratic income risk in the form of shocks to labor productivity, which follow a first order Markov process with states $s_t \in \mathcal{S}$ and transition probabilities $\xi(s_{t+1}|s_t)$. Households can only imperfectly insure against labor income risk by saving in a mutual fund, which yields ex-post return r_t.

A household with assets a and productivity s at time t optimally chooses consumption of domestically produced goods c_h, imported energy goods c_e and savings a' solving the dynamic program

$$V_t(a,s) = \max_{c_h,c_e,a'} u(c_h,c_e) - v(N_t) + \beta \mathbb{E}_t \left[\sum_{s' \in \mathcal{S}} \gamma(s'|s) V_{t+1}(a',s') \right]$$

$$\begin{aligned} \text{subj. to} \quad & c + a' = (1+r_t)a + s w_t N_t \\ & \Omega' = \mathcal{T}(\Omega), \quad c \geq 0, \quad a' \geq \underline{a} \end{aligned} \tag{3.1}$$

where w_t is the real wage, N_t is labor supply determined by labor unions as described below and $\underline{a}$ is an ad-hoc borrowing limit. We use a time subscript for the value function to indicate the dependence on a vector of aggregate states $\mathbf{X}_t$ to be specified below and $\Omega_t = \Omega_t(a,s)$, the distribution of agents over asset holdings $a \in \mathcal{A}$ and income productivity $s \in \mathcal{S}$.

Preferences Period utility is separable in consumption and labor hours and takes CRRA form

$$u(c_h, c_e) = \frac{c^{1-\sigma}}{1-\sigma}, \qquad v(N) = \psi \frac{N^{1+\varphi}}{1+\varphi}$$

with the consumption basket given by a Stone-Geary aggregator

$$c = \left[(1-\alpha_h)^{\frac{1}{\eta}} c_h^{\frac{\eta-1}{\eta}} + \alpha_h^{\frac{1}{\eta}} (c_e - \underline{c})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{3.2}$$

where $\underline{c}$ denotes the subsistence level of energy consumption. Subsistence consumption introduces non-homotheticity in the utility function implying that the expenditure share of energy declines with income. As in the data households therefore do not only differ in the level but also in the composition of spending with less wealthy households spending a larger share on energy. The parameter σ denotes the inverse elasticity of intertemporal substitution, φ the inverse Frisch elasticity of labor supply, η the elasticity of substitution between energy and non-energy consumption and α_h measures the share of energy consumption in the overall consumption basket. The consumer price index for these preferences is given by

$$P_t \equiv \left[(1-\alpha_h) P_{h,t}^{1-\eta} + \alpha_h P_{e,t}^{1-\eta} \right]^{\frac{1}{1-\eta}} \tag{3.3}$$

where $P_{h,t}$ is the price of domestically produced non-energy goods and $P_{e,t}$ is the domestic price of imported energy goods. Consumption expenditure minimization implies that a household in state (a, s) with total consumption $c_t(a, s)$ splits purchases between both goods according to

$$c_{h,t}(a,s) = (1-\alpha_h) \left(\frac{P_{h,t}}{P_t} \right)^{-\eta} c_t(a,s) \tag{3.4}$$

$$c_{e,t}(a,s) = \alpha_h \left(\frac{P_{e,t}}{P_t} \right)^{-\eta} c_t(a,s) + \underline{c} \tag{3.5}$$

The first order conditions of the dynamic program yields a standard Euler equation, which holds with equality whenever the borrowing constraint does not bind

$$1 \geq \mathbb{E}_t \left[\beta \sum_{s_{t+1}} \xi(s_{t+1}|s_t)(1+r_{t+1}) \left(\frac{c_{t+1}}{c_t} \right)^{-\sigma} \right] \tag{3.6}$$

2.2 Labor union

We introduce sticky wages following Erceg et al. (2000). A competitive labor packer combines labor provided by a continuum of labor unions $k \in [0,1]$ into an aggregate employment service N_t using a constant elasticity of substitution technology $N_t = \left(\int_0^1 N_{kt}^{\frac{\varepsilon_w - 1}{\varepsilon_w}} di \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}}$, where ε_w is the elasticity of substitution between varieties of union labor. The packer sells this labor aggregate at real wage w_t to the intermediary production sector. The demand for union labor is $n_{it} = \left(\frac{W_{it}}{W_t} \right)^{-\varepsilon_w} N_t$.

Each labor union employs all households for an equal number of hours. Unions engage in monopolistic competition and are in charge of setting nominal wages by maximizing welfare of the average household. Wage adjustments are subject to a quadratic cost in terms of household utility. The objective function of union k is then given by

$$\max_{W_{kt}} \quad \sum_{\tau \geq 0} \beta^{t+\tau} \left[\left(\frac{C_{t+\tau}^{1-\sigma}}{1-\sigma} - \int_0^1 \psi \frac{n_{it+\tau}^{1+\varphi}}{1+\varphi} \right) d\Omega_{it+\tau} - \frac{\chi}{2} \left(\frac{W_{t+\tau}}{W_{t+\tau-1}} - 1 \right)^2 \right]$$

In a symmetric equilibrium all unions charge the same wage and employ households for the same number of hours. The dynamics of aggregate nominal wage inflation $1 + \pi_{wt} = W_t / W_{t+1}$ are given by a non-linear New Keynesian wage Philips Curve[2]

$$\pi_t^w (1 + \pi_t^w) = \frac{\epsilon_w}{\chi} \left[\psi N_t^{1+\varphi} - \frac{\epsilon_w - 1}{\epsilon_w} C_t^{-\sigma} \frac{W_t N_t}{P_t} \right] + \beta \mathbf{E}_t [\pi_{t+1}^w (1 + \pi_{t+1}^w)] \tag{3.7}$$

In the following, we opt for a framework that features sticky nominal wages but fully flexible prices. Our reasons are threefold. First, rigid wages are crucial to capture salient features of micro data on household earnings. As argued by Auclert et al. (2021a), households on average have very small marginal propensities to earn (MPE), which is the labor market equivalent of marginal propensities to consume (MPC). The fact that households do not adjust their labor supply in response to income changes can only be captured if there is some form of wage stickiness. Second, New Keynesian models with sticky prices typically feature countercyclical profits. While this can matter in the case of representative agent models as shown by Broer et al. (2020), it becomes crucial for heterogeneous agent models,

[2]Appendix A1 contains further details on the derivation of the New Keynesian wage Philips Curve.

where the distribution of dividends plays an important role for aggregate dynamics. Third, assuming sticky prices would be at odds with the observed evolution of markups during the recent inflation surge both in the US and the Euro Area. With sticky prices, an increase in marginal cost would lead to a decrease in markups as firms can reset their prices only with a certain probability. Under flexible prices, markups instead remain constant in line with markups empirically having mostly remained constant or even increased. Real wages instead have seen a marked decline consistent with sticky nominal wages but flexible prices.

2.3 Domestic production

Final goods producer A representative final-goods producer aggregates domestic intermediary goods $Y_{j,t}$ with $j \in [0,1]$ through a CES production function $Y_t = \left(\int_0^1 Y_{j,t}^{\frac{\varepsilon_f - 1}{\varepsilon_f}} dj \right)^{\frac{\varepsilon_f}{\varepsilon_f - 1}}$, where ε_f denotes the elasticity of substitution between intermediate goods. Cost minimization yields the producer demand for intermediate good j given by $Y_{j,t} = \left(\frac{p_{j,t}}{P_{h,t}} \right)^{-\varepsilon_f} Y_t$ and a domestic final goods price $P_{h,t} = \left(\int_0^1 p_{j,t}^{1-\varepsilon_f} dj \right)^{\frac{1}{1-\varepsilon_f}}$.

Intermediate-good producers A continuum of monopolistically competitive firms produces intermediate goods with a CES production technology

$$Y_{j,t} = \left[\alpha_f^{\frac{1}{\theta}} E_{j,t}^{\frac{\theta-1}{\theta}} + (1-\alpha_f)^{\frac{1}{\theta}} \gamma_t N_{j,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{3.8}$$

using energy E_t and labor N_t as an input, where γ_t captures labor-augmenting aggregate productivity, θ governs the elasticity of substitution across factor inputs and α_f is the share of imported energy used in production.[3] In a symmetric equilibrium factor demand for imported energy and labor satisfies

$$\frac{P_{e,t}}{P_t} = \frac{\alpha_f}{\mathcal{M}_t} \frac{P_{h,t}}{P_t} \left(\frac{Y_t}{E_t} \right)^{\frac{1}{\theta}} \tag{3.9}$$

$$\frac{W_t}{P_t} = \frac{1-\alpha_f}{\mathcal{M}_t} \frac{P_{h,t}}{P_t} \gamma_t \left(\frac{Y_t}{N_t} \right)^{\frac{1}{\theta}} \tag{3.10}$$

[3]For simplicity we abstract from capital in the production function. Our setup is equivalent to assuming a capital stock that is in fixed supply.

where $\mathcal{M}_t$ is the real mark-up. This markup arises from imperfect substitution between intermediate goods due to market power despite prices being fully flexible.
Intermediate goods producers pay real dividends in the amount of

$$D_t = \frac{P_{h,t}Y_t - P_{e,t}F_t - W_tN_t}{P_t} = \frac{P_{h,t}}{P_t}Y_t\left(1 - \frac{1}{\mathcal{M}_t}\right) \tag{3.11}$$

2.4 Mutual fund

A domestic, unconstrained and risk-neutral mutual fund holds an asset portfolio composed of shares in intermediate goods firms as well as nominal domestic and foreign bonds yielding nominal returns i_t and i_t^* respectively. Firm shares pay a return $\frac{D_{t+1}+j_{t+1}}{j_t}$, where j_t is the share price in period t. The fund issues claims to households with aggregate real value A_t and maximizes the ex-post return on these liabilities, r_{t+1}.
Equilibrium non-arbitrage conditions imply a Fisher relation between nominal and real returns, covered interest parity between domestic and foreign bonds and return equalization across all investment opportunities

$$1 + i_t = (1 + r_{t+1})\frac{P_{t+1}}{P_t} \tag{3.12}$$

$$1 + r_t = (1 + i_t^*)\frac{Q_{t+1}}{Q_t} \tag{3.13}$$

$$1 + r_{t+1} = \frac{D_{t+1} + j_{t+1}}{j_t} \tag{3.14}$$

where Q_t is the real exchange rate, defined below.

2.5 International markets and prices

We define e_t as the nominal exchange rate expressed in terms of the domestic price for a unit of foreign currency. An increase of e_t therefore indicates an exchange rate depreciation. The world price of energy $P_{e,t}^*$ is exogenous in terms of a world currency, where we use an asterisk to denote foreign variables. Assuming that the law of one price holds the domestic price of energy is given by

$$P_{e,t} = e_t P_{e,t}^*$$

The real exchange rate is defined as

$$Q_t = \frac{e_t P_t^*}{P_t} = \frac{P_{e,t}}{P_{e,t}^*}\frac{P_t^*}{P_t} = \frac{P_{e,t}}{P_t} \Big/ \underbrace{\frac{P_{e,t}^*}{P_t^*}}_{\equiv \mathcal{P}_t^*} \tag{3.15}$$

Without loss of generality, we normalise the foreign price level P_t^* to one. Although there is full pass-through of the world price of energy to domestic energy prices, purchasing power parity (PPP) does not necessarily hold as exogenous variations in $\mathcal{P}_t^*$ generate real exchange rate fluctuations.

Domestic prices can be rewritten as a function of the real exchange rate,

$$\frac{P_{h,t}}{P_t} = \left[\frac{1 - \alpha_h Q_t^{1-\eta} \mathcal{P}_t^{*1-\eta}}{1 - \alpha_h}\right]^{\frac{1}{1-\eta}} \tag{3.16}$$

We define the terms of trade as the price of domestic goods over the price of energy

$$\mu_t = \frac{P_{h,t}}{P_{e,t}} = \frac{P_{h,t}}{e_t P_{e,t}^*}$$

Foreign demand for the domestic good depends on the terms of trade and is given by

$$C_{h,t}^* = \left(\frac{P_{h,t}^*}{P_{e,t}^*}\right)^{-\lambda} C^* \tag{3.17}$$

where C^* is a foreign aggregate demand and λ captures the inverse elasticity of foreign demand to the foreign price of domestic goods.

Nominal net exports are the difference between foreign sales of domestic production and energy imports for domestic consumption and production

$$NX_t = P_{h,t} c_{h,t}^* - P_{e,t} c_{e,t} - P_{e,t} E_t \tag{3.18}$$

The net foreign asset position is defined as $NFA_t = A_t - j_t$ and evolves according to

$$NFA_t = NX_t + (1 + r_{t-1}) NFA_{t-1} + (r_t - r_{t-1})(A_{t-1} - j_{t-1}) \tag{3.19}$$

where the last two terms capture revaluation effects, which are equal to zero in our zero net foreign asset position steady state.

2.6 Monetary Policy

Our main focus is to analyse the effects of monetary policy on the transmission of energy price shocks. The monetary authority sets the nominal interest rate according to a Taylor rule

$$i_t = r_{ss} + \phi_{\pi_k} \pi_{k,t} \qquad k \in \{b, cpi, h, e\} \tag{3.20}$$

This specification nests several special cases. In our baseline, monetary policy keeps the real rate constant, $\phi_{\pi_b} = 1$. In alternative scenarios policy can also react to headline, core or energy price inflation, defined as $\pi_{cpi,t} = P_t/P_{t-1}$, $\pi_{h,t} = P_{h,t}/P_{h,t-1}$ and $\pi_{e,t} = P_{e,t}/P_{e,t-1}$ respectively. We also study forecast rules and allow for policy to react to the inflation forecast, $\mathbb{E}_t \pi_{k,t+1}$, instead of contemporaneous measures of inflation. In the following we will label a policy rule "active" if it induces a strong real rate response and as "passive" if the real rate response is muted.

2.7 Equilibrium

Given a sequence of foreign energy prices $\{P^*_{e,t}\}$, an initial wealth distribution $\Omega_0(a, z)$ and an initial portfolio allocation for the mutual fund, an equilibrium is a path of value and policy functions $\{V_t(a, z), a'_t(a, z), c_{h,t}(a, z), c_{e,t}(a, z)\}$, distributions $\{\Omega_t(a, z)\}$, prices $\{r_{h,t}, r_t, i_{h,t}, i_{f,t}, Q_t\, w_t, \pi_{w,t}, P_{e,t}, P_{h,t}, P_t\}$ and aggregate quantities $\{Y_t, E_t, N_t, A_t, D_t, j_t, C^*_{h,t}, NX_t, NFA_t\}$ such that all agents optimize and market clearing holds for asset markets, $A_t = \int a'(a, z) d\Omega_t$, and the domestic goods market, $Y_t = C_{h,t} + C^*_{h,t}$, where $C_{h,t} = \int c_h(a, z) d\Omega_t$. The aggregate state is given by the distribution function $\Omega_t(a, z)$ and $\mathbf{X}_t = \{r_{t-1}, w_{t-1}\}$.

3 Calibration and steady state

We calibrate the model at a quarterly frequency for the Euro Area and list key model parameters in Table 1. We choose some parameters relying on standard values in the

literature and match others to target empirical moments from Euro Area data. Household and firm exposure to imported energy, the heterogeneous consumption exposure of households across the income distribution, and aggregate marginal propensities to consume, are based on data from Eurostat and available empirical estimates. We calibrate the discount factor β to 0.968 to target an annualized nominal interest rate of two percent in steady state in line with recent estimates by Best et al. (2020). We assume an intertemporal elasticity of substitution σ equal to 1, consistent with King-Plosser-Rebelo preferences and a balanced growth path along the steady state. We calibrate the inverse Frisch elasticity of labor supply $\varphi = 2$ within the standard range of values reported in Chetty et al. (2011). For the idiosyncratic productivity process we follow typical estimates like Auclert et al. (2021c) and assume an AR(1) process with persistence of 0.92 and cross-sectional standard deviation of 0.6. We set the borrowing constraint $\underline{a} = 0$.[4] We assume an elasticity of substitution between varieties of labor of 19 implying a wage markup of roughly 5% and set adjustment costs to 190 to yield a Philips curve slope of 0.1. Following Chan et al. (2022) and Auclert et al. (2021c) we calibrate the foreign demand elasticity λ to 1/3. We set the consumption elasticity of substitution between energy and non-energy goods η to 0.4. For the elasticity of substitution in production we chose a value of 0.5. Both parameters are well within the range reported by Bachmann et al. (2022). We show sensitivity to the choice of these parameters in Section 4.1.

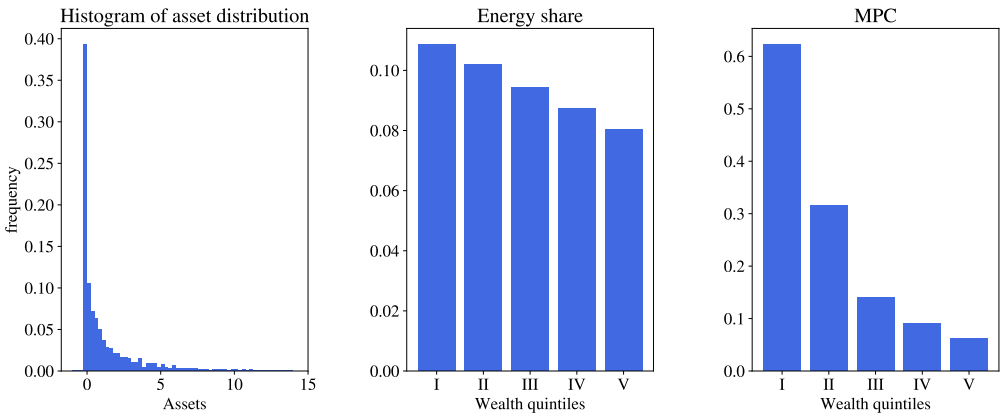
[4]We choose a zero borrowing constraint to be in line with the vast majority of the HANK literature. However, having a negative borrowing constraint matching the level of savings in the lowest wealth quintile does not materially affect any of our results.

Table 1: Calibration

Parameter	Definition	Value	Source/Target
Households			
β	Household discount factor	0.968	Annual nominal rate 2%
σ	Household risk aversion	1	Literature
α_h	Energy share in consumption	0.051	Eurostat $c_e/c = 0.09$
$\underline{c}$	Subsistence level energy consumption	0.037	Eurostat $c_e^{Q1}/c^{Q1} = 0.13$
η	Elasticity of substitution consumption	0.4	Bachmann et al. (2022)
φ	Inverse Frisch elasticity	2	Literature
ψ	Utility weight of labor	0.543	$\pi = 0$
Labor Unions			
ε_w	Elasticity of substitution labor	19	Wage markup of 5%
χ	Wage adjustment cost	190	NKPC slope of 0.1
Firms			
α_f	Energy share in production	0.201	Eurostat $E = 0.16$
θ	Elasticity of substitution production	0.5	Acurio (2015)
$\mathcal{M}$	Price markup	1.01	Carroll et al. (2017) MPC =0.32
World Trade			
C^*	Foreign demand level	0.181	$NX = 0$
λ	Foreign demand elasticity	1/3	Auclert et al. (2021)

To calibrate the rest of the household and firm parameters we jointly target four moments from the data. From Eurostat's "Income wealth and consumption statistics" (IWCS) we use the fact that household expenditure on energy is around 9%. The IWCS also shows that the bottom quintile of the income distribution has higher expenditures on energy of around 13% pointing to strong non-homotheticity in the consumption basket. Input-output tables from Eurostat furthermore show that the use of imported energy in production is almost twice the size of the use for consumption. Finally, we also target an average MPC of 0.32 as reported in Carroll et al. (2017). These targets jointly determine the energy share of consumption α_h and production α_f, the subsistence level of energy consumption $\underline{c}$ and the size of firm markups $\mathcal{M}$. Lastly, we chose the utility weight of labor ψ and the foreign demand level C^* such that inflation in steady state is zero and the economy initially has zero net foreign assets. We solve the model by solving the household problem relying on the endogenous gridpoint method developed by Carroll (2006), approximating the continuous distribution on a discrete grid as suggested by Young (2010). We compute dynamics using the sequence space approach as developed by Auclert et al. (2021b).

Figure 2: Steady state wealth distribution, consumption composition and MPCs



Note: The left graph shows the histogram over assets choices a'. The middle graph shows the expenditure on energy by wealth quintile. The right graph shows marginal propensities to consume out of an additional dollar of income.

Our steady state captures salient facts on household heterogeneity as displayed in Figure 2. There is substantial wealth inequality in our economy. Around 20 percent of households are financially constrained with zero savings and unable to smooth shocks to their income or changing prices of their consumption basket. Almost half of all households have only very little savings and therefore are substantially exposed to energy prices. The energy share in the consumption of households with little wealth is substantially higher than that of high-wealth households. For example, the low-wealth households spend roughly 3 percentage points more on energy than the high-wealth households. The substantial wealth heterogeneity and hence unequal ability to self-insure against shocks is also reflected in a wide dispersion of MPCs. Low-wealth households, defined as those in the bottom quintile of the wealth distribution, spend on average 60 percent of an additional euro on consumption. Wealthy households, defined as the top quintile of the wealth distribution, instead behave close to the permanent income hypothesis and only spend around 7 percent of an additional euro in response to a transitory income change.

4 Energy price shocks and monetary policy

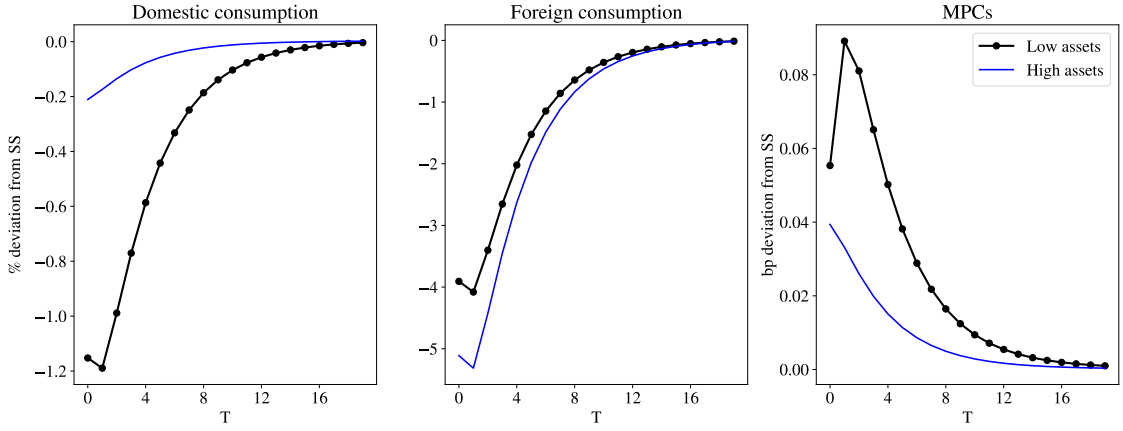
In this section we study the aggregate and distributional effects of an energy price shock and how monetary policy shapes these effects. Our main exercise of interest simulates

an energy price shock comparable to the one that hit the Euro Area in the beginning of 2022. In particular, we consider a 30 percent increase in the foreign price of energy with a persistence of 0.8 matching the magnitude of the rise in energy prices when compared to their average over the past 20 years as shown in Figure 1. We start by illustrating the role of substitution elasticities in consumption and production before turning to the discussion of aggregate and distributional effects of an energy price shock. Throughout, we contrast active rules raising real interest rates with a baseline under which the real rate is constant.

4.1 Elasticities of substitution in consumption and production

We start by illustrating how non-homotheticity in consumption and input complementarity in production affect the consumption response across households. Following the increase in the price of foreign energy, there are two main channels at play in the transmission of the energy shock through aggregate demand: *i*) consumption expenditure and *ii*) general equilibrium income effects. Although both are important drivers of aggregate effects, in this section we focus on the former.

Figure 3: Transmission channel of non-homothetic preferences



Note: The plots show equilibrium "price" effects, capturing only relative price changes as described in Appendix A2. The shock is a 30% increase in foreign energy prices. Monetary policy implements a fixed interest rate rule. The circled line corresponds to the average consumption response of the lowest wealth quintile, while the solid line corresponds to the average consumption response of the second highest wealth quintile.

Figure 3 plots the effect of a rising energy price on the optimal expenditure shares between energy and non-energy goods in the consumption basket as well as MPCs by wealth.

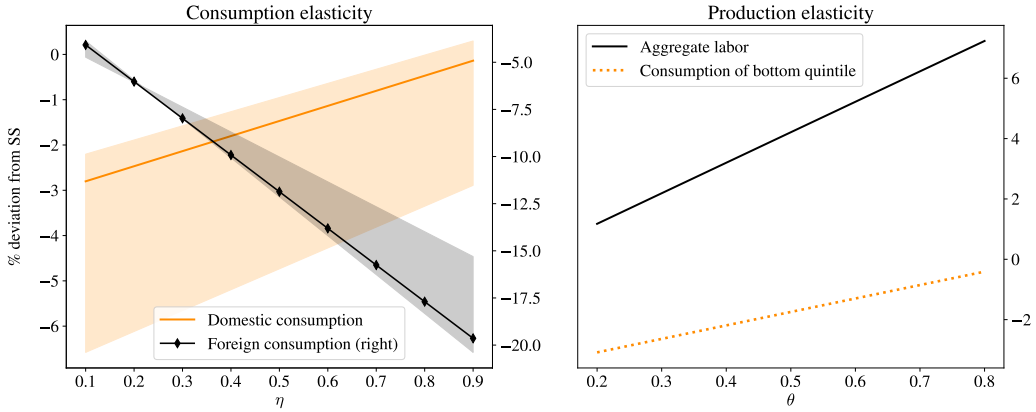
As energy becomes more expensive, households want to substitute away from it but are constrained by the subsistence level of energy consumption. In fact, low-wealth households are not able to decrease their energy consumption as much as wealthy households, as illustrated in the middle panel. In turn, this implies that households with little wealth suffer a larger consumption expenditure increase following the shock. Moreover, since they cannot insure against this income shock, their domestic consumption drops by relatively more (left panel). MPCs for low-wealth households thus increase by relatively more. These partial equilibrium forces are important drivers of general equilibrium responses, as is also visible from comparing the heterogeneous agent economy to a representative agent economy (see Appendix A3 for more details).

The magnitude of the consumption expenditure effect is governed by the elasticity of substitution across energy and non-energy goods. On the left panel, Figure 4 plots the initial consumption response to the energy price shock for different values of the elasticity of substitution parameter. In particular, we vary the consumption elasticity of substitution η from a very low degree of substitutability ($\eta = 0.1$) to both goods having a very high degree of substitutability ($\eta = 0.9$) an therefore being almost perfect substitutes. Foreign consumption declines by less when η is low, as households cannot substitute consumption of foreign goods by purchasing more domestic goods. This also imposes a larger negative income shock to households, as they cannot mitigate the energy price increase, thereby decreasing their domestic good consumption by relatively more. The response of consumption across the wealth distribution is illustrated with shaded areas and highlights large differences across income quintiles. When substitutability is high, the differences in foreign consumption are exacerbated because less wealthy households are constrained by the subsistence level of energy consumption.

In the right panel of Figure 4, the solid line shows the initial response of aggregate labor under different calibration of the production function elasticity of substitution across labor and energy goods. As firms are increasingly able to substitute energy (going from low to high θ), they demand relatively more labor to mitigate the rise in energy input costs. Higher labor demand also raises real wages and overall sustains labor income. A high degree of substitutability between factor inputs therefore somewhat allows to mitigate the effects of an energy price shock. As shown by the dotted line, it also benefits low-wealth

households which predominantly rely on labor income.[5]

Figure 4: Role of elasticity of substitution in consumption and production



Note: The shock is a 30% increase in foreign energy prices, points correspond to time 0 responses. Monetary policy implements a fixed interest rate rule. The shaded areas correspond to the difference from the lowest to second highest wealth quintiles of the distribution. Foreign consumption responses correspond to the right axis in the left panel.

4.2 Aggregate effects

To gauge the aggregate effects of an energy price shock and how they depend on monetary policy, we contrast a policy rule that keeps the real interest rate fixed (baseline) with policy rules reacting either to contemporaneous or forecast measures of inflation. We characterize a policy response as active if the real rate rises substantially and as passive if the real rate response is muted or nil. In the following we show that, a shock to imported energy has adverse consequences regardless of policy as it constitutes a wealth transfer from the domestic to the foreign economy. Active policies like contemporaneous policy rules exacerbate the negative aggregate effects in contrast to passive policies like most forecasting rules.

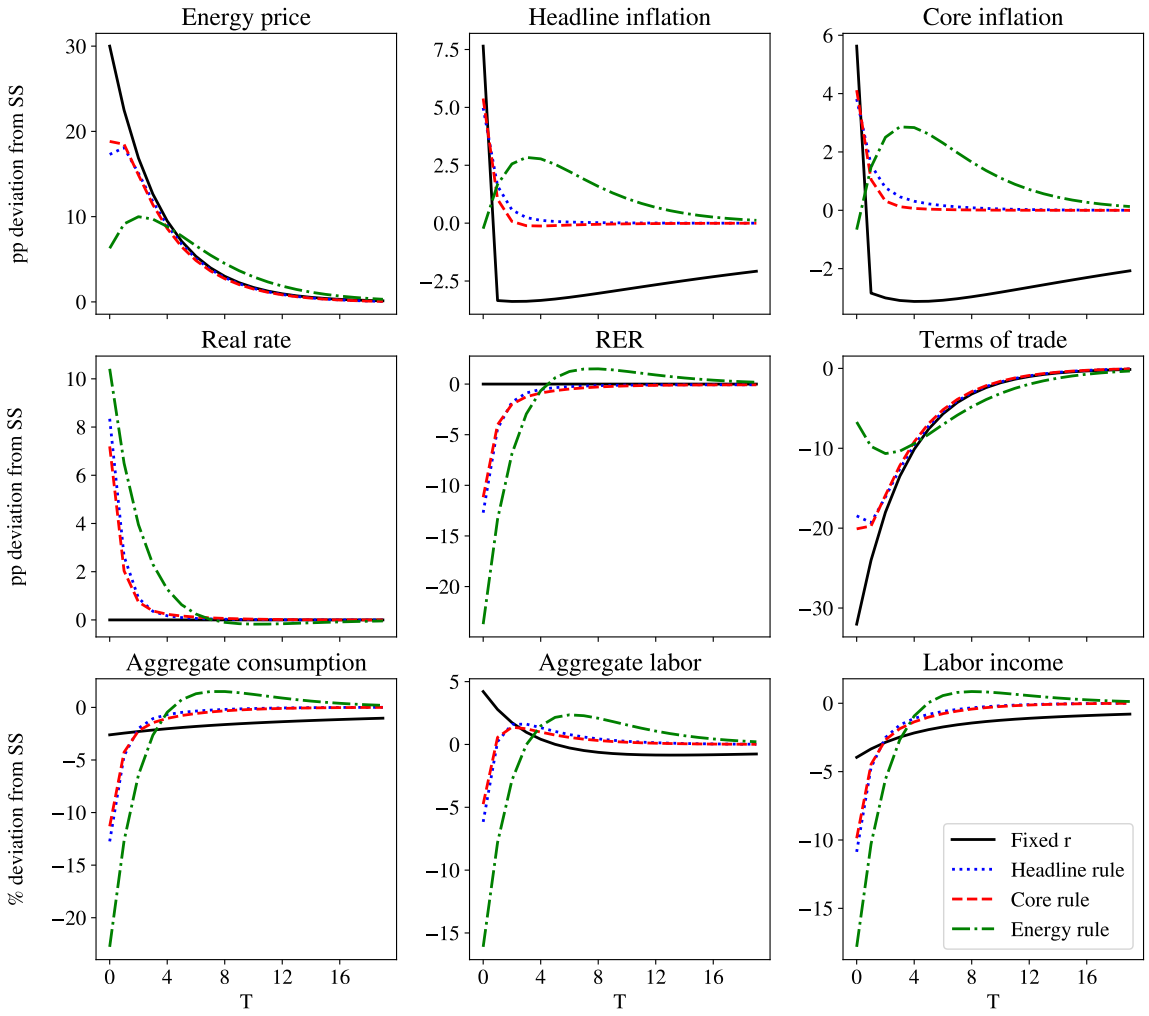
Figure 5 shows impulse responses for selected aggregate variables contrasting the baseline with rules reacting to contemporaneous inflation. Under the baseline rule, an energy price shock leads to a sharp initial rise in inflation that quickly reverts and turns negative after a few quarters. To keep the real rate constant, the Fisher equation implies that the nominal

[5]We analyze the distributional effects of the energy price shock in more details in Section 4.4.

rate has to be set as the sum of the real rate and *future* inflation. The nominal rate therefore mirrors the path for inflation with an initial large increase and a subsequent quick decline. Despite the surge in inflation and an initial strong increase in the nominal rate the baseline rule results in the smallest decrease in aggregate consumption and output. This is due to two channels. First, household consumption-savings decisions are based on the *real* interest rate. In the baseline the real rate does not change, remaining substantially below real rates associates with active policy rules, and hence does not incentivize households to save more and consume less. Second, domestic aggregate demand is also supported through the open economy channel. Because the domestic real rate does not change, it does not differ from the foreign real rate implying a constant real exchange rate via the uncovered interest parity condition. The resulting high pass-through of foreign energy prices to domestic energy inflation causes two effects. First, it prompts a stronger substitution of domestic demand towards domestic goods and therefore leads to a pronounced fall in the terms of trade which boosts foreign demand for domestic goods. Second, high inflation rates combined with flexible prices cause a strong real wage decline. This decrease in wages is more than compensated for by an increase in labor demand overall leading to a relatively muted impact on labor income.[6]

[6]In Appendix A4 we show that the initial recession is indeed stronger and associated with a decline in aggregate labor, if the open economy demand channel is absent. Nevertheless, aggregate outcomes would still be far less contractionary under a fixed real rate compared to active policy rules.

Figure 5: Effects of an energy price shock under contemporaneous monetary policy rules



Note: Impulse response of aggregate variables to a 30 percent increase in foreign energy prices contrasting a rule that keeps real rates fixed with rules reacting to a contemporaneous measure of inflation as described in Section 2.

All policy rules reacting to contemporaneous measures of inflation would actively respond to an energy price shock by raising the real rate. A headline rule raises the real rate around 1.5 percentage points higher than a rule reacting to core inflation (around 8 percentage points). The differences between a headline and a core inflation rule in terms of real rates and inflation outcomes are hardly noticeable though a rule targeting core inflation implies slightly higher inflation rates. Given substantially higher real rates, the decline in consumption and output is about fourfold compared to the baseline. As households consume less domestic goods the decrease in demand for domestic goods amplifies negative effects on labor hours. Additionally, a higher real rate causes a real

exchange rate appreciation that mitigates the pass-through of foreign energy price. This prevents the terms of trade from falling as strongly and therefore weakens the foreign demand channel.

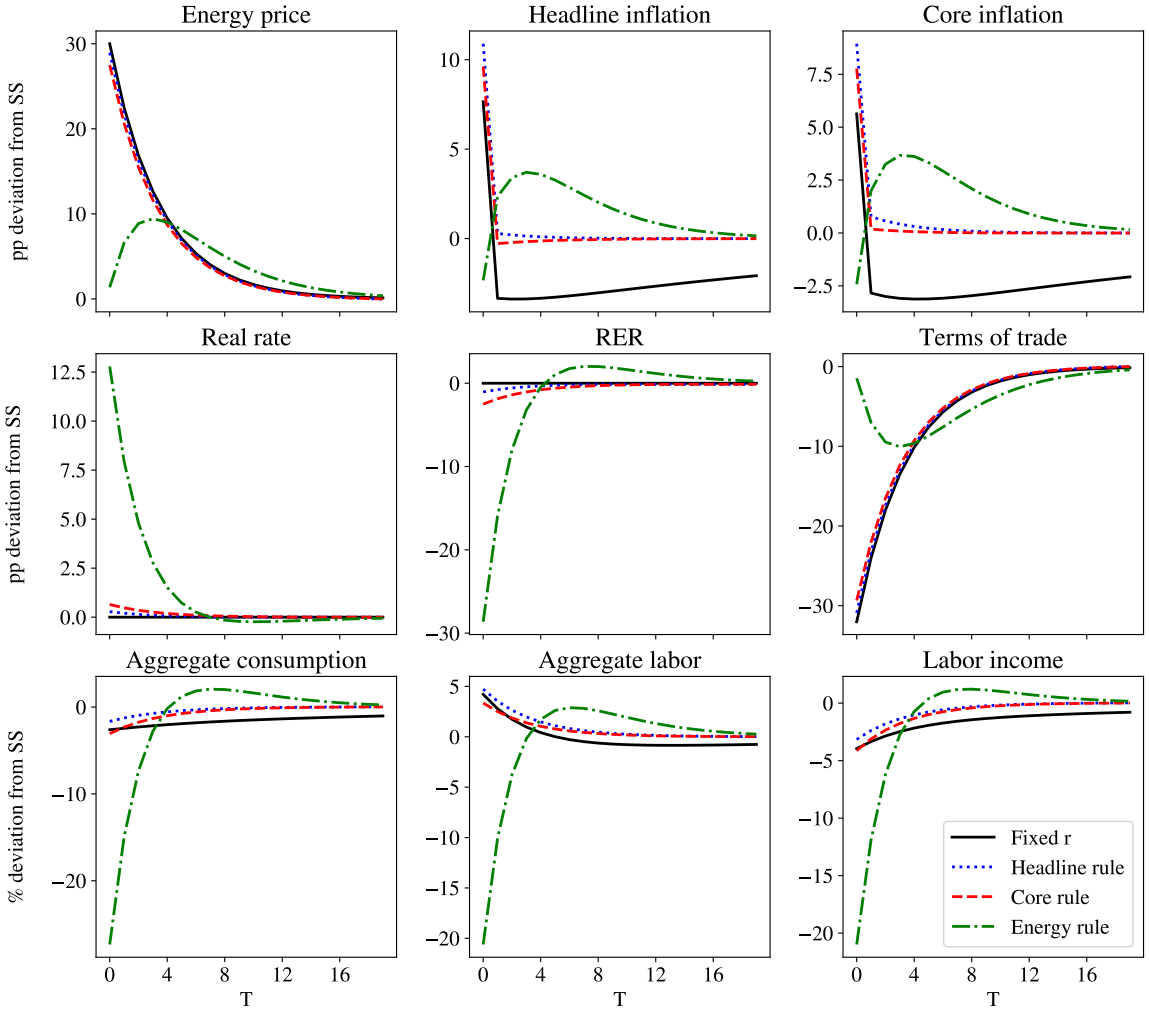
A policy rule directly responding to energy inflation induces a severe contraction thereby successfully containing inflation in the short run though at the expense of higher medium-term inflation. Real interest rates are highest under an energy price rule rising to around 12 percent and therefore exert a substantial negative effect on domestic goods demand initially turning core inflation even negative. However, in subsequent periods core inflation rises strongly and remains elevated for 3-4 times as long as other policy rules. This medium-term effect arises from two channels. First, containing domestic energy inflation requires a severe contraction in domestic demand which subsequently needs to revert triggering a strong recovery in labor demand and associated labor income. Second, the strong increase in real rates leads to a strong real exchange rate appreciation as foreign interest rates do not move. This implies a complete lack of pass-through of foreign to domestic energy prices effectively containing the energy price shock in the short-term. Since inflation is initially zero the real exchange rate appreciation directly translates into a nominal exchange rate appreciation that subsequently unwinds through depreciations which continuously raise foreign demand for domestic goods adding to the domestic recovery.

It is noteworthy that reacting to different *measures* of inflation is not equivalent to varying the *strength* of the reaction, e.g. through a higher inflation coefficient in the Taylor rule. Figure 5 shows that the differences between targeting headline or core inflation are rather small and that the headline rule can be interpreted as a stricter version of the core rule. Unsurprisingly, the large share of domestic goods in the overall consumption basket implies that the headline inflation rate associated with the entire consumption basket is heavily influenced by its core component mimicking the core inflation profile although being somewhat higher due to high inflation of the energy component. In stark contrast, targeting energy inflation implies an entirely different inflation profile, mitigating inflation in the short-term at the cost of higher inflation in the medium-term for the reasons described above.

Policy rules reacting to forecast measures of inflation can strongly mitigate the negative amplification of contemporaneous rules, but only if they are sufficiently passive, i.e. come

with a significantly muted real rate response. In Figure 6 we plot impulse responses of aggregate variables for forecast rules. Anticipating that an energy price spike will subsequently revert, one could think that a forecast rule would effectively "look through", i.e. remain passive to an energy price price shock. This is indeed true for forecast rules reacting to either headline or core inflation, which show a strongly muted real rate response thereby mitigating the negative effects on aggregate demand. For both rules the decline in consumption as well as labor income is even slightly smaller than under a fixed rate rule with otherwise very similar implications.

Figure 6: Effects of an energy price shock under forecast rules



Note: Impulse response of aggregate variables to a 30 percent increase in foreign energy prices contrasting a rule that keeps real rates fixed with rules reacting to a forecast measure of inflation as described in Section 2.

However, a forecast rule responding to energy inflation is instead very active raising real

rates even higher than its contemporaneous counterpart thereby further amplifying adverse aggregate effects. Despite rising *foreign* energy prices, *domestic* energy inflation initially falls before strongly increasing after a couple of quarters. The causes are the same as for the contemporaneous energy rule. The large increase in the real rate induces a severe recession while the real exchange rate substantially appreciates which implies an even larger appreciation of nominal exchange rates due to the falling price level. The initially elevated exchange rate prevents a pass-through of rising energy prices to the domestic economy and even leads to initially lower energy prices. However, this price effect comes at the cost of substantial negative adjustments in quantities on the real side. Moreover, as energy prices in subsequent periods are passing through to the domestic economy and with aggregate demand strongly recovering, inflation rates in the medium term are even higher than under a policy rule responding to contemporaneous energy inflation.

While we treat energy price developments in the past two years as a one-time unanticipated shock that quickly recedes, they can also be viewed as an initial unexpected price spike followed by further anticipated price increases before eventually subsiding. In Appendix A5 we analyze such a hump-shaped energy shock modelled as an AR(2) process. With a fixed real rate the aggregate responses are initially smaller with output, consumption and labor exhibiting a similar hump-shaped profile peaking a couple of quarters after the shock occurs. In the receding phase of the shock, aggregate outcomes are qualitatively and quantitatively comparable to the effects of an AR(1) shock. Forecast rules perform overall better than rules reacting to contemporaneous inflation but the differences are not as pronounced as under a purely unexpected shock, given that they are a lot more active responding to the shock with significant real rate increases, albeit smaller than contemporaneous rules.

In Appendix A6 we additionally argue that energy price shocks have different aggregate implications than other supply shocks and are therefore crucial to be studied on their own. A recessionary TFP shock for example decreases labor productivity and therefore implies an increase in labor demand similar to an energy shock. However, there is additional substitution of factor demand towards the energy input to compensate for the decline in labor productivity, implying a *higher* demand for energy as an input whereas an energy price shock leads to substitution away from energy. A price markup shock implies a

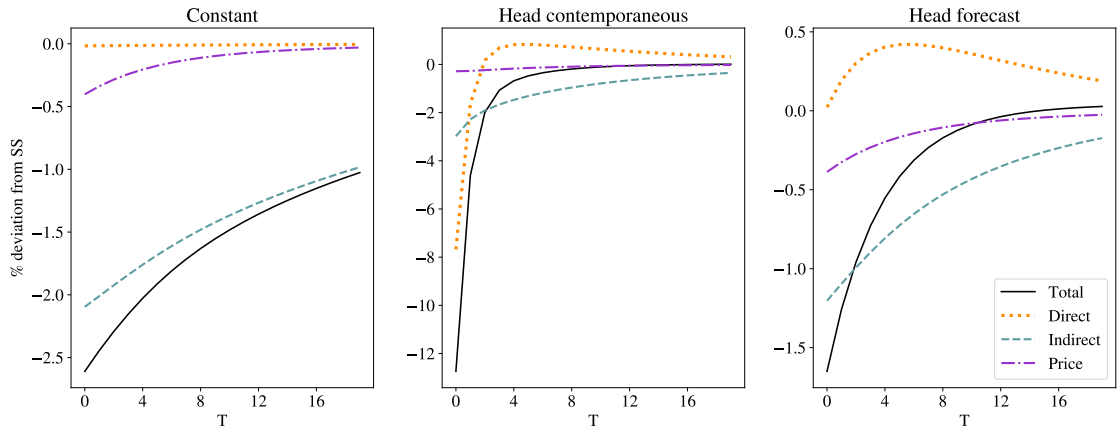
reduction of both factor inputs as firm owners react to higher desired markups by both raising prices and reducing production. However, a markup shock leads to a redistribution from high MPC to low MPC households in the *domestic* economy, but does not constitute a wealth loss to the foreign economy implying substantially muted effects on real outcomes like output.

4.3 Decomposition of aggregate consumption response

The key drivers of the aggregate consumption response differ starkly across monetary policy rules as we show in the following through a decomposition of aggregate consumption. Figure 7 shows the key drivers of the total consumption response for the baseline (left panel) contrasting it to a policy rule reacting to headline inflation either contemporaneously (middle) or its forecast (right).[7] We decompose the aggregate consumption response into three effects, a direct effect arising from changes in the real interest rate, an indirect effect arising from changes in labor income and a price effect. The latter captures a decline in consumption arising from an increase in energy prices, that causes higher expenditures on subsistence consumption thereby leaving a smaller share of income for consumption expenditures beyond the subsistence level. Any increase in the price of the *overall* consumption basket absent changes in the relative price of goods instead reduces real income and therefore constitutes an indirect effect in our decomposition.

[7]Results for targeting core or energy inflation as wells as further technical details on the consumption decomposition can be found in Appendix A2.

Figure 7: Aggregate consumption decomposition for contemporaneous and forecast rules



Note: Decomposition of the aggregate consumption response to an energy price shock. The "direct" effect captures the contribution from a change in the real interest rate, the "indirect" effect captures income effects and the "price" effect captures relative price changes as described in Appendix A2.

The negative consumption response to an energy price shock is mostly driven by indirect real income effects with the relative price effect playing an additional role (left panel). In the baseline, the energy price shock makes energy goods relatively more expensive and thereby raises the cost of subsistence consumption. This price effect accounts for one fifth of the total consumption decline. However, the majority of the consumption decline (four fifth) arises from indirect general equilibrium effects through falling labor income. In contrast, and in line with the absence of any real rate response, direct (partial equilibrium) effects are zero.

Despite initial inflation rates being substantially higher under a passive policy, the consumption decline is substantially smaller compared to active policy rules. In itself, higher inflation erodes real incomes more strongly, but the fixed real rate is sufficiently stimulative to overturn this real income effect through higher labor demand and therefore higher labor income. Overall, the negative indirect effect on consumption through labor income is even 25 percent smaller compared to active rules. The major difference comes from avoiding any negative consumption effects through rising real rates. Overall, the decline in consumption is almost an order of magnitude smaller compared to an active policy rule.

Policy rules reacting to contemporaneous inflation strongly amplify the negative consumption response through rising real rates. Whereas direct effects are completely absent in the baseline, they account for over three-fourths of the consumption decline under an active

rule. Despite the increase in real rates, there is no noticeable reduction in the price effect. However, the restrictive policy is further amplifying negative indirect effects. Despite containing inflation more strongly than a passive policy, the decline in labor demand caused by a reduction in aggregate demand leads to a substantial decrease in labor income which adds to the overall consumption decline. Nevertheless, since an active policy ultimately fosters a faster recovery the contribution of the direct effect turns positive after a couple of quarters as higher real rates help households that hold a sufficient amount of assets rebuild their wealth faster over time.

Forecast rules reacting to headline or core inflation, which show a very muted real rate response, can even mitigate the consumption decline through positive real rate effects as well as less severe indirect effects. Compared to an active policy response, the fall in total consumption is an order of magnitude smaller. The small rise in real rates can even exert a positive impact on consumption as it is insufficient to substantially lower aggregate demand but instead helps most households rebuild wealth through higher returns on savings. Additionally, given the lack of negative demand effects the decline in aggregate labor income is strongly mitigated, as displayed by an indirect effect that is almost half the size compared to a fixed real rate rule

Further decompositions for the core and energy rule as shown in Appendix A2 are quantitatively different but feature the same underlying forces driving the decline in consumption for the headline rule as discussed in this section. The exception is a forecast rule targeting energy inflation, which triggers a strong decline in consumption through a substantial rise in real rates akin to contemporaneous policy rules albeit with larger magnitude.

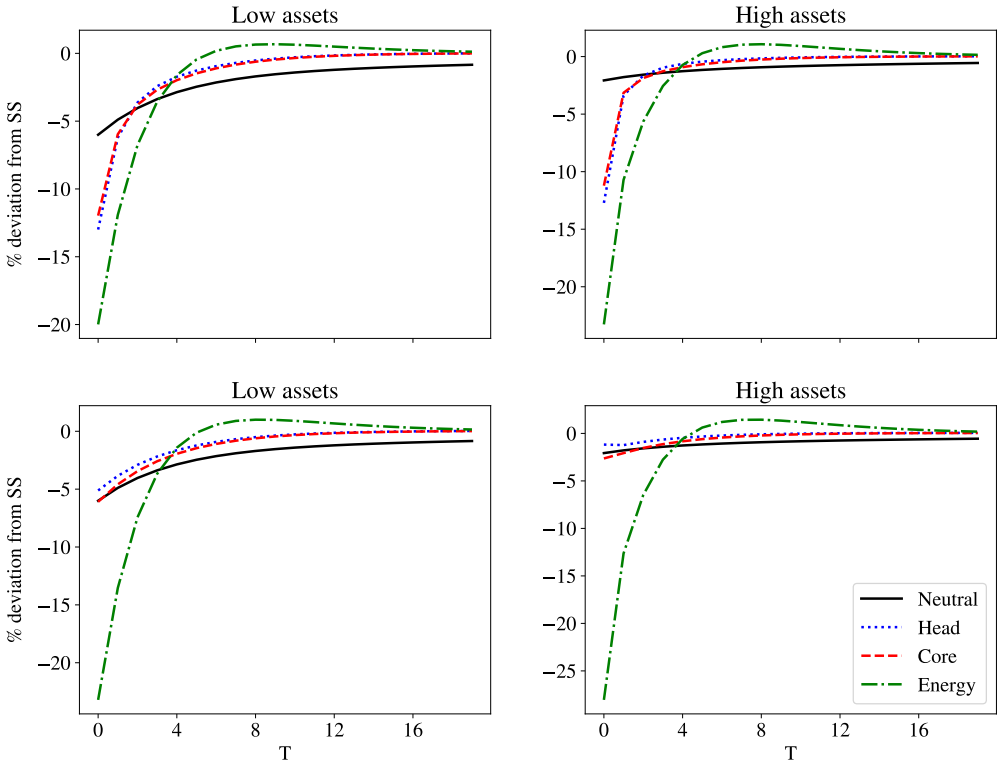
4.4 Distributional effects

An energy price shock does not only have adverse aggregate consequences but as we show in this section also affects households with little wealth disproportionately more. Especially active policy rules are strongly amplifying the consumption response through high real rates that reduce aggregate demand and therefore labor income but also benefits wealthy households through higher returns on savings.

To compare the distributional effects across different monetary policy rules, we separately

plot the consumption response of low-wealth and high-wealth households for various policy rules in Figure 8. We define low-wealth households as those in the lowest wealth quintile and wealthy households as those in the second highest wealth quintile. In our calibration, low-wealth households are also borrowing constrained without any savings to rely on.

Figure 8: Consumption response of low- and high-wealth households under contemporaneous and forecast monetary policy rules



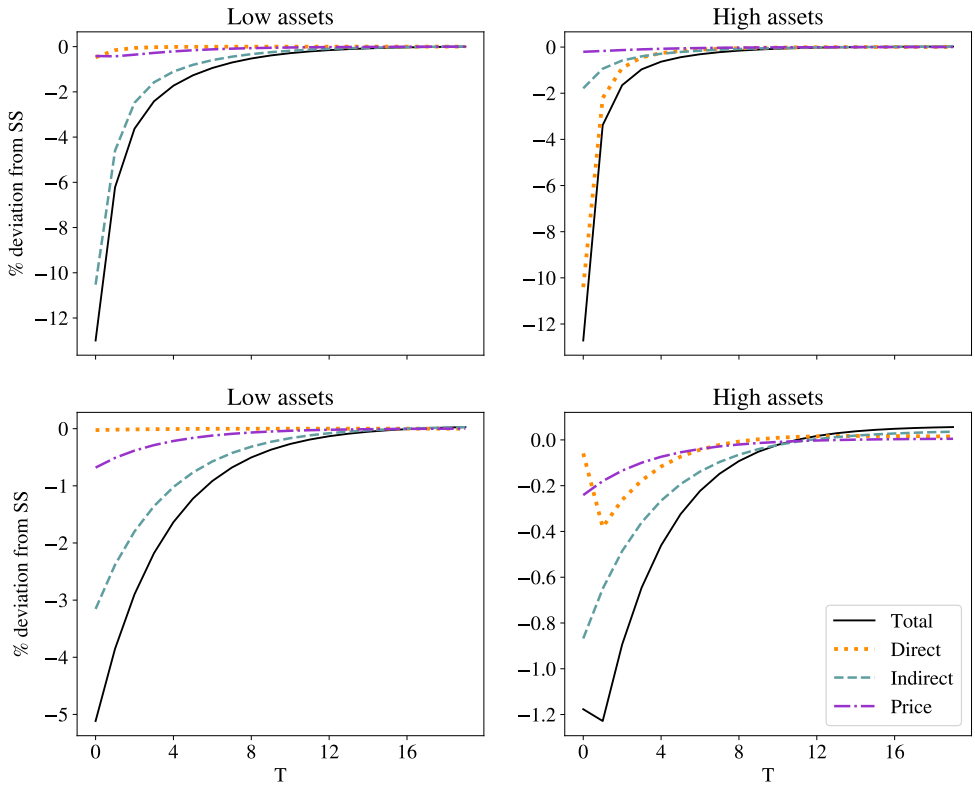
Note: On the top, we plot a comparison of the consumption response of low-wealth and high-wealth households under monetary policy rules reacting to contemporaneous measures of inflation. On the bottom panel, monetary policy reacts to forecast measures of inflation. Low-wealth refer to households in the lowest wealth quintile whereas high-wealth refer to households in the second highest wealth quintile.

Under a fixed real rate, the decline in consumption is larger for low-wealth households as compared to high-wealth households, while active rules mitigate the difference in consumption responses across low and high- wealth households (top panel). In the baseline, the consumption decline for low- and high-wealth households is around 6 and 2 percent, respectively. Active rules amplify the consumption response of low-wealth households twofold for headline and core targeting rules and more than threefold in case of energy inflation targeting, as compared to consumption response in the baseline rule. The

consumption response of the high-wealth households instead increases at least five-fold for active policy rules and can even be an order of magnitude larger in case of an energy rule. While both low-wealth and high-wealth households see a decline in consumption, the reasons for the decline are very different, as shown in Figure 9. Households with little wealth are reducing their consumption due to energy goods becoming more expensive and due to a fall in real income. High-wealth households instead reduce their consumption because higher real rates raise the return on assets thereby strongly incentivizing them to save more. A consumption decomposition across wealth quintiles shows that more than 80 percent of the consumption decline for the lowest wealth quintile is due the indirect effect of a declining labor income. Direct real rate effects and price effects instead play a similar and muted role. In contrast, the consumption decline of the highest wealth quintile is overwhelmingly driven by the direct real rate effect. A small fraction is also related to the indirect effect but is much smaller than for low-wealth households, whereas relative price effects are absent for wealthy households. Indeed, appendix Figure A8 shows that while the savings response of households with little wealth is almost nil, high-wealth households strongly increase their savings under active rules.

As forecast rules exhibit a very mitigated real rate response, their implications are similar to the baseline. In particular, they are beneficial to all households as they mitigate the decline in consumption. However, the negative consumption response of low-wealth households is still larger than that of high-wealth households (bottom panels of Figure 8). For both types of households the response is mostly driven by indirect effects, which however are smaller than under active rules. For low-wealth households, price effects also matter whereas for the wealthy is the direct effect that plays an additional role (bottom panels of Figure 9).

Figure 9: Consumption decomposition for low- and high-wealth households



Note: On the top, we plot a comparison of the consumption response of low- and high-wealth households under monetary policy rules reacting to contemporaneous measures of inflation. On the bottom panel, monetary policy reacts to forecast measures of inflation. Low-wealth refers to households in the lowest wealth quintile whereas high-wealth refers to households the second highest wealth quintile.

5 Conclusions

The surge in energy prices that began in mid-2021 impacted the Euro Area through various channels. Building upon the open economy HANK literature, we introduce non-homothetic preferences in consumption and incorporate energy into production. This framework enables a quantitative assessment of the channels and the aggregate and distributional effects of the an energy-induced inflation surge. We particularly focus on studying these implications in passive and active monetary policy frameworks under various rules specifications.

In what regards the aggregate effects, given significantly higher real rates, we find that with policy rules reacting to contemporaneous inflation, the decline in consumption and output is around four times greater compared to the baseline rule where real interest

rate is constant. We also find that policy rule reacting to energy prices has a substantial bigger recessionary effect, containing inflation rates in the short run at the expense of medium-term inflation. Then, we investigate the implications by employing monetary policy rules reacting to forecast measures of inflation. Model based impulse response functions indicate that forecast rules reacting to either headline or core inflation effectively "look through" the initial energy price increase. This results in a substantial dampening of the real rate increase, thereby mitigating adverse effects on aggregate demand. Notably, both the decline in consumption and labor income are somewhat less pronounced compared to a fixed rate rule with otherwise similar implications.

Finally, we investigate the distributional effects of the energy prices shock across the different monetary policy rules. In general, low-wealth households are disproportionately affected by an energy price shock, regardless of the monetary policy response. Contemporaneous monetary policies, whether headline or core rule based, exacerbate this consumption decline for low-wealth households. The higher real rates in the active policy response result in favourable returns on savings, benefiting wealthy households. This is also evident when investigating the consumption decomposition. The decline in consumption is observed across both low-wealth and wealthy households, yet the driving factors differ markedly. For households with little wealth, the reduction in consumption is attributable to the increased costs of energy goods and a decline in real income. Conversely, wealthier households curtail their consumption due to higher real rates, which enhance returns on assets, providing a strong incentive for increased savings. A decomposition of consumption across wealth quintiles reveals that more than 80 percent of the consumption decline in the lowest quintile results from the indirect impact of diminishing labor income. Direct effects via real rates and price changes play comparable roles. In contrast, the consumption decline in the highest wealth quintile is predominantly driven by the direct impact of real rates. Instead, passive policy responses that do not induce a large increase in the real rate also do not impose a larger drop in any households' consumption compared to the fixed interest rate rule.

A Appendix

A1 Derivation of New Keynesian Wage Philips Curve

In this section, we provide the analytical derivation of the wage Phillips Curve. At time t, the union sets its wage to maximize the utility of its average worker:

$$\sum_{\tau\geq 0}\beta^{t+\tau}\left[u(C_{t+\tau})-v(N_{t+\tau})-\frac{\psi_{nr}}{2}(\frac{W_{k,t+\tau}}{W_{k,t+\tau-1}}-1)^2-\frac{\zeta_{BG}}{2}(\epsilon-1)N^{\epsilon}u(C)/\frac{W}{P}(\frac{W_{k,t+\tau}}{P_{t+\tau}}-\frac{W}{P})^2\right]$$

where ψ_{nr} denotes the degree of nominal rigidity and ζ_{BG} denotes the real wage motive. The unions combine individual labor into tasks which face demand $N_{kt}=\left(\frac{W_{kt}}{W_t}\right)^{-\varepsilon_w}N_t$ where $W_t=\left(\int_0^1 W_{k,t}^{1-\varepsilon}dk\right)^{\frac{1}{1-\varepsilon}}$ is the price for aggregate employment services.
Households' real earnings are

$$Z_t=\frac{1}{P_t}\int_0^1 W_{kt}(\frac{W_{kt}}{W_t})^{-\epsilon}N_t d_k$$

Then $\frac{\partial C_t}{\partial W_{kt}}=\frac{\partial Z_t}{\partial W_{kt}}$ where $\frac{\partial Z_t}{\partial W_{kt}}=\frac{1}{P_t}N_{kt}(1-\epsilon)$.
Total hours worked by households (i) are:

$$N_{it}=\int_0^1 (W_{kt}/W_t)^{-\epsilon}N_t\,dk$$

Which falls when W_{kt} rises according to

$$\frac{\partial N_t}{\partial W_{kt}}=-\epsilon\frac{N_{kt}}{W_{kt}}$$

Therefore, the union's first order condition gives

$$\begin{aligned}\left(\frac{W_{k,t}}{W_{k,t-1}}-1\right)\frac{W_{k,t}}{W_{k,t-1}}=&\frac{\epsilon}{\psi_{nr}}(N_{kt}v(N_t)^{-\frac{\epsilon-1}{\epsilon}}(N_{k,t}W_{k,t})/(P_t)u(C_t)\\&-\zeta_{BG}N^{\frac{\epsilon}{\epsilon-1}}\frac{W}{P}u(C)\frac{W_{k,t}}{P_t}-\frac{W}{P}\frac{W_{k,t}}{P_t})+\beta(\frac{W_{k,t+1}}{W_{k,t}}-1)\end{aligned}$$

Define wage inflation as $\pi_w\equiv\frac{W_t}{W_{t-1}}-1$ and the wage markup $\mu_w=\frac{\epsilon}{\epsilon-1}$ yielding A(1) as follows:

$$\pi_{w,t}(1+\pi_{w,t})=(\epsilon/\psi_{nr})[N_t v(N_t)-\frac{1}{\mu_w}Z_t u(C_t)-\frac{\zeta_{BG}}{\mu_w}u(C)\frac{N}{N_t}(\frac{W_t}{P_t}-\frac{W}{P})\frac{W_t}{P_t}\frac{W}{P}]+\beta\pi_{w,t+1}(1+\pi_{w,t+1})$$

In the zero wage inflation steady state

$$v(N) = \frac{1}{\mu_w} u(C) \frac{W}{P}$$

Linearizing A(1) around the steady state yields:

$$d\pi_{w,t} = \epsilon \psi_{nr} N \, dv(N_t) - \frac{1}{\mu_w} du(C_t) \frac{W}{P} - \frac{(1 + \zeta BG)}{\mu_w} u(C) \, d\frac{W_t}{P_t} + \beta \, d\pi_{w,t+1}$$

A2 Further details on consumption decomposition

In this section we provide further details on the decomposition of the total consumption response to an energy price shock following the approach of Kaplan et al. (2018). Aggregate consumption can be written as a function of the sequence of equilibrium prices and quantities

$$\mathcal{C}_t \left(\{ r_t, w_t, N_t, p_{et} \} \right) = \int c_t(a, z; \{ r_t, w_t, N_t, p_{et} \}) d\Omega_t$$

where $c_t(a, z; \{ r_t, w_t, N_t, p_{et} \})$ are the individual policy functions explicitly written as a function of individual states and aggregate prices. Totally differentiating the aggregate consumption function we can decompose the consumption response at each time t as

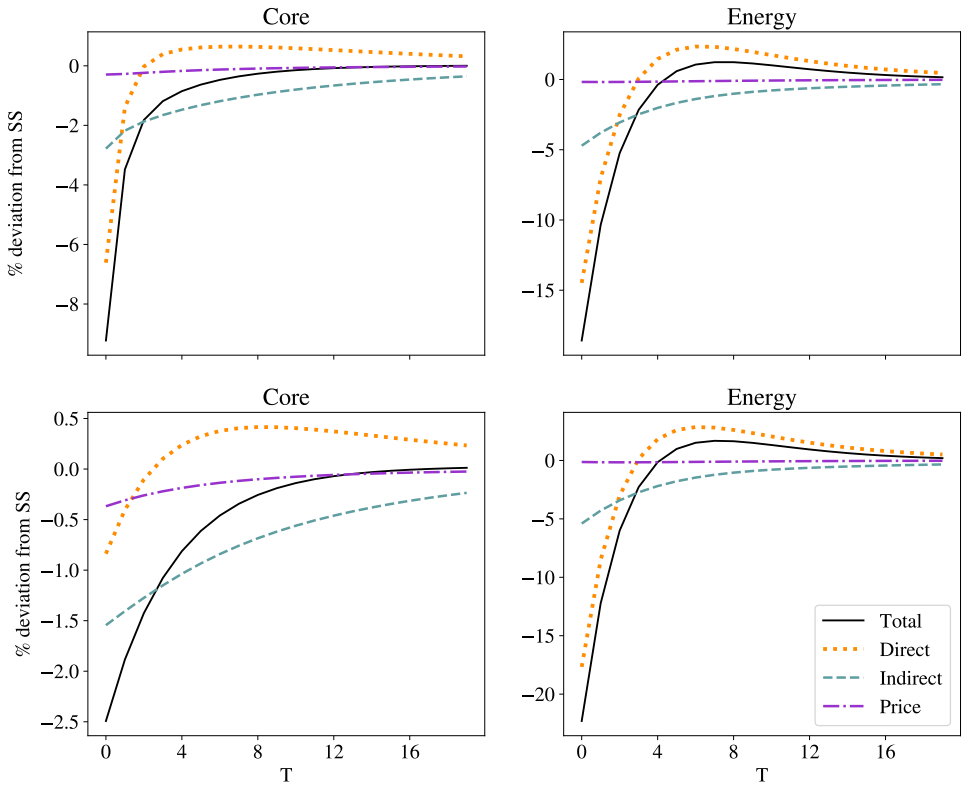
$$d\mathcal{C}_t \left(\{ r_t, w_t, N_t, p_{et} \} \right) = \underbrace{\sum_{s=0}^{\infty} \frac{\partial \mathcal{C}_{t+s}}{\partial r_{t+s}} dr_{t+s}}_{\text{direct effect}} + \underbrace{\sum_{s=0}^{\infty} \frac{\partial \mathcal{C}_{t+s}}{\partial w_{t+s}} dw_{t+s} + \frac{\partial \mathcal{C}_{t+s}}{\partial N_{t+s}} dN_{t+s}}_{\text{indirect effect}} + \underbrace{\sum_{s=0}^{\infty} \frac{\partial \mathcal{C}_{t+s}}{\partial p_{et+s}} dp_{et+s}}_{\text{price effect}}$$

The direct effect reflects changes in aggregate consumption resulting directly from changes in the path of real interest rates, whereas the indirect effect reflects consumption changes arising from changes in the path of real wages and labor hours. The price effect reflects any changes in consumption arising from a change in relative energy prices that raise the cost of subsistence consumption.

To numerically compute each effect we compute the respective partial derivate and multiply it with the equilibrium response arising from the specific monetary policy rule of interest.

The top panels of Figure A1 plots the consumption decomposition for the policy rules reacting to contemporaneous core and energy inflation. As was the case for the headline rule in Section 4, both rules see a consumption decline predominantly due to increasing real rates. Particularly, the strong decline in consumption under the energy rule is solely driven by the monetary policy response to energy prices.

Figure A1: Consumption decomposition for core and energy rules



Note: On the top, we plot a comparison of the aggregate consumption decomposition under monetary policy rules reacting to two contemporaneous measures of inflation (respectively core and energy). On the bottom panel, monetary policy reacts to forecast measures of inflation. The "direct" effect captures the contribution from a change in the real interest rate, the "indirect" effect captures income effects and the "price" effect captures relative price changes.

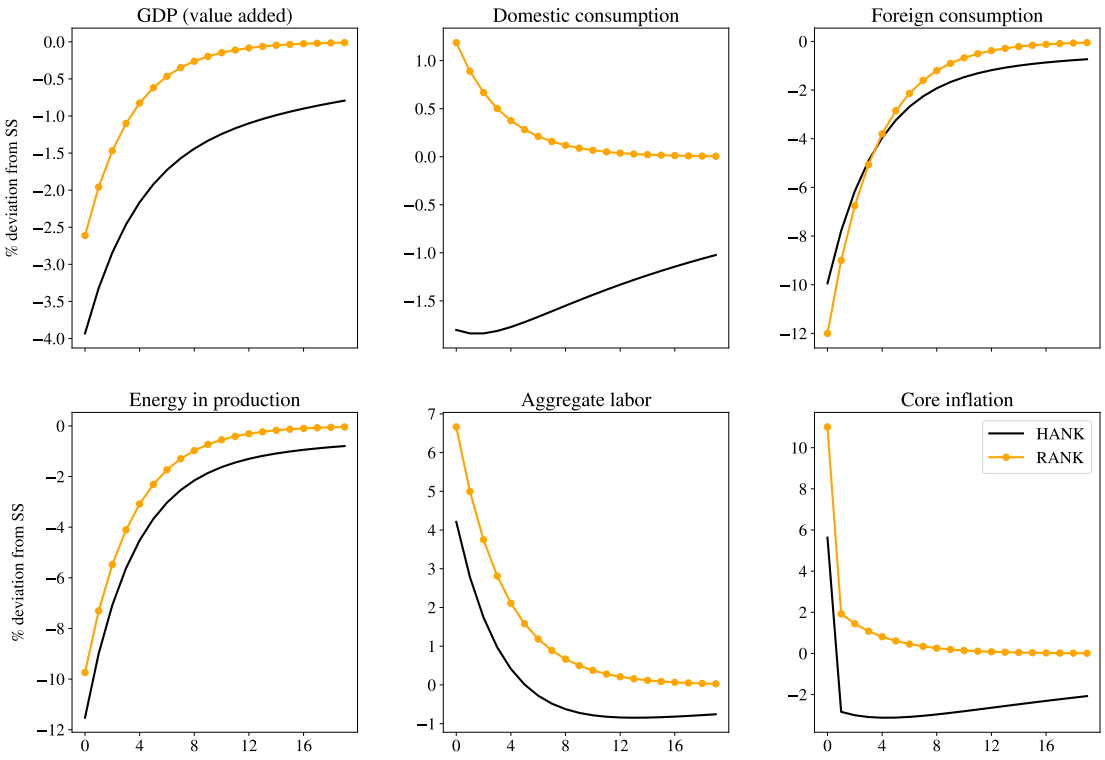
The bottom panels of Figure A1 plots the same consumption decomposition for policy rules reacting to the forecast of core or energy inflation. The core forecast rule has similar implications to the headline rule as discussed in the text, except for an initially slightly negative contribution of real rates. However, the energy forecast rule exerts a strong negative impact on consumption through the substantial rise in real rates. It thereby mimics contemporaneous policy rules albeit triggering a consumption decline twice the size.

A3 Comparison of HANK with RANK model

In this section, we solve a representative agent new Keynesian (RANK) model which we calibrate to be as close as possible to our baseline HANK model with a fixed interest rate rule for monetary

policy.[8] We then simulate the response of these two economies following the same energy price shock as in Section 4.2. The impulse response functions (IRFs) are displayed in Figure A2.

Figure A2: Comparison of HANK and RANK models



Note: GDP is computed as purchasing power parity adjusted ($\text{GDP}_t = P_{h,t}Y_t/P_t - P_{f,t}E_t/P_t$). The shock is a 30% increase in foreign energy prices. Monetary policy implements a fixed interest rate rule.

GDP drops relatively and significantly more in the HANK model (top left panel). This is due to a strong consumption expenditure channel at play for low-wealth households. On top of having a larger increase in expenditure, these households are unable to insure because they hold zero or little assets. The aggregate effect of these households is large, as we can infer from the top middle and right panel. The general equilibrium effects are stronger in the HANK model, with labor income and energy in production dropping relatively more than in the RANK model (bottom left and middle panels). Inflation instead reacts stronger on the spot in the RANK, although the shock is short-lived (bottom right panel). A key difference between the economies is that while

[8]The only difference between the two models is the discount factor β, which we adjust to be consistent with the steady state real interest rate.

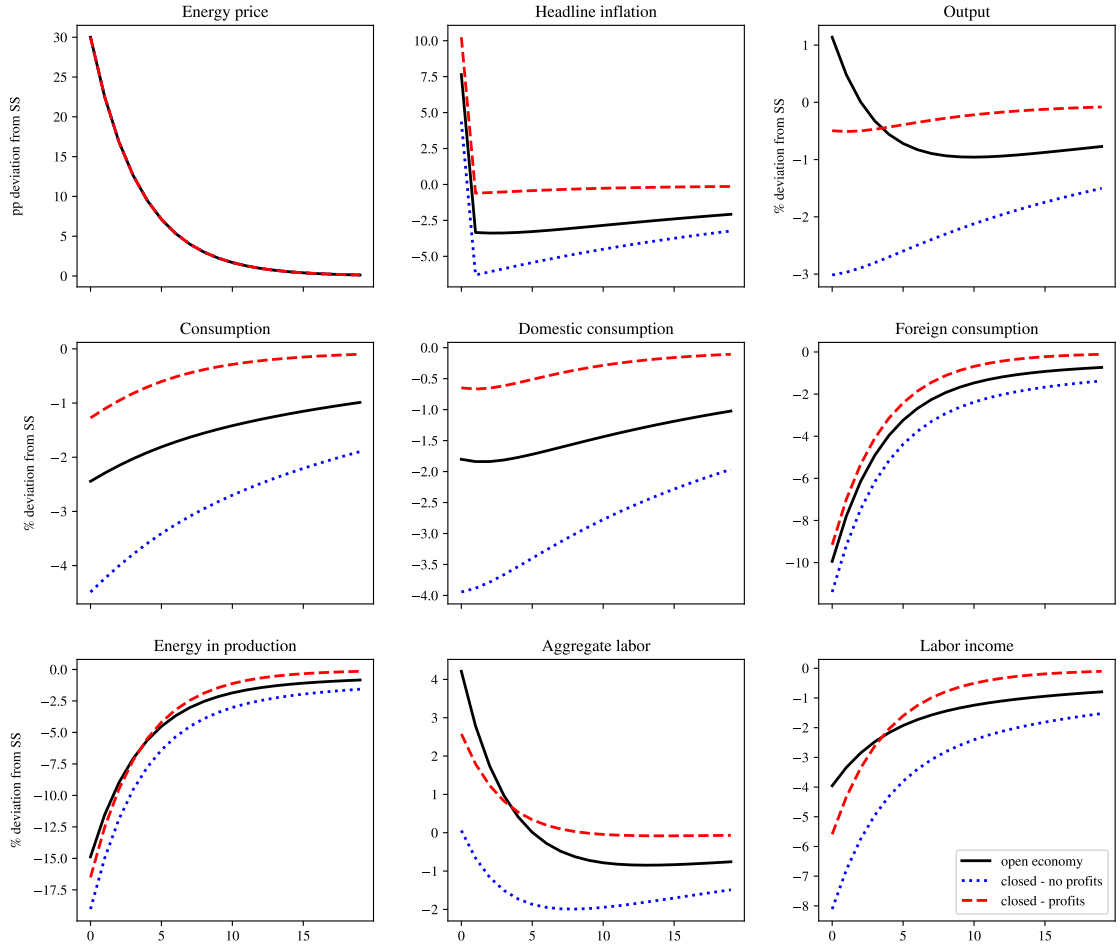
in RANK the variables go back to steady state relatively quickly, the HANK economy features much more persistence coming through the endogenous asset distribution.

A4 A closed economy setup

In this section we compare our small open economy setup to a closed economy version. To this end we shut down the terms of trade channel by setting the foreign demand elasticity to zero, enforcing a constant real exchange rate and requiring the mutual fund to only invest in the domestic economy. We then proceed with the same simulation as in the main text, a 30 percent increase in the price of energy goods.[9] We will entertain two assumptions related to the price of energy. First, we assume that the price increase is a deadweight loss to society, e.g. because the extraction of resources has become more costly. Second, we assume that the energy price increase raises profits of a domestic energy producer, who is owned by the mutual fund.
Figure A3 shows the differences between the open and the closed economy setup under constant real rates. In the closed economy the effects of an energy price shock are generally aggravated, when no profits arise from higher energy prices. As opposed to the open economy, there is no foreign demand for domestic goods that can increase in response to a deterioration of the terms of trade thereby mitigating negative effects. The negative consumption response is roughly twice the size and output and labor demand are negative in the closed economy, whereas they are positive initially in the open economy. Firms substitute labor for energy as an input as seen by the smaller decline in aggregate labor.

[9]Note, that in this setting the shock to energy prices is an exogenous change to relative prices that is *independent* of policy. To see this, recall that the price of domestic goods according to equation 3.16 can be written as a function of the now constant real exchange rate and the exogenous energy price increase.

Figure A3: Open versus closed economy



Note: The energy shock is a 30% increase in foreign energy prices, with persistence of 0.8. Monetary policy implements in all cases a fixed interest rate rule. The solid line is our baseline model; the dotted line corresponds to a closed economy model in which the energy price shock induces a dead weight loss to the domestic economy; and the dashed line is a model in which a local energy producer benefits from the increase in price.

The effects of an energy price shock are generally mitigated in the closed economy, if profits accrue to domestic owners of energy. Aggregate consumption falls less than in an open economy despite the absence of a mitigating foreign demand channel. As energy prices rise, the mutual receives higher profits from energy production raising the return on assets which benefits all households with positive savings. Thus, there is no wealth transfer from the domestic to the foreign economy. Nevertheless, rising energy prices constitutes a transfer from non-savers with high marginal propensities to consume to savers with lower marginal propensities to consume in this economy. The energy price shock therefore is still recessionary, as consumption and output

are falling.

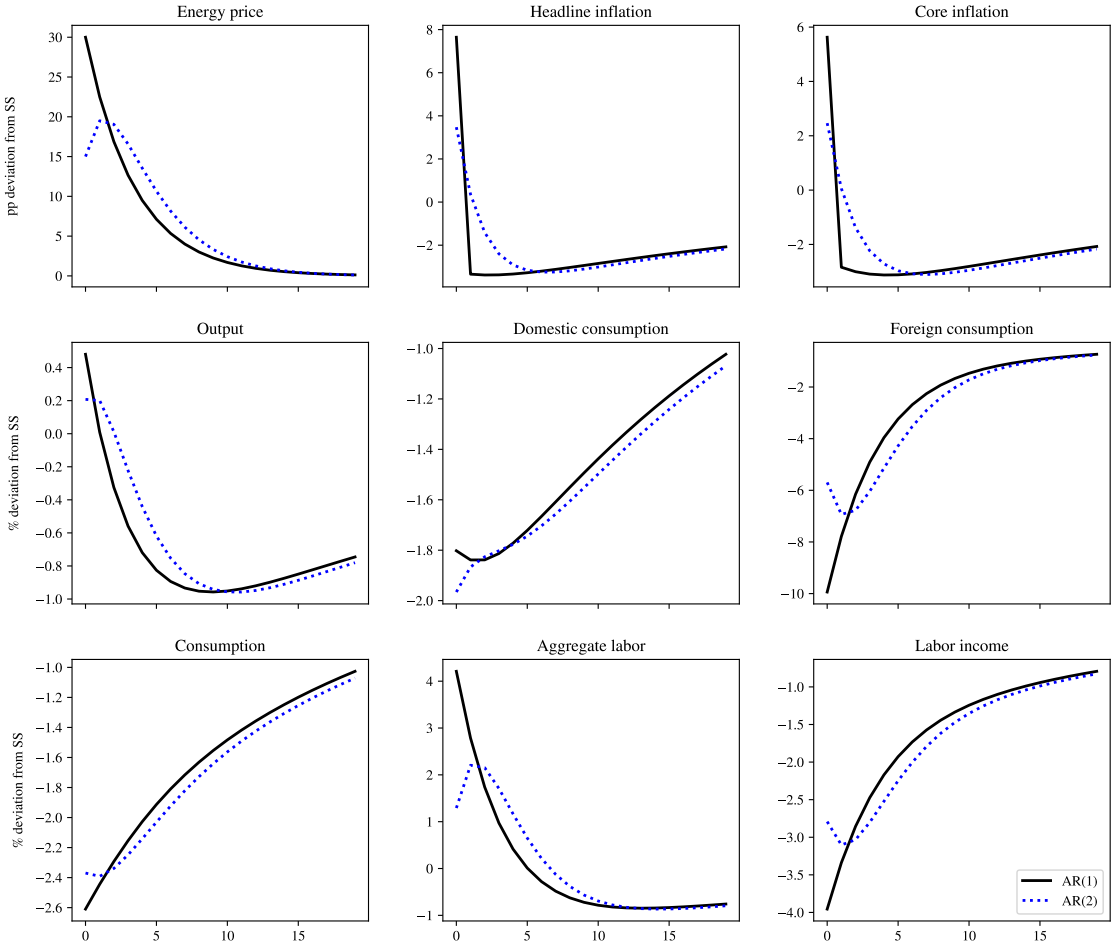
A5 Hump-shaped energy price shock

In this section, we study the effects of a hump-shaped energy price shock modelled as an AR(2) process. As Figure 1 shows, the energy price developments in the past two years can also be understood as an initial unexpected price increase with the anticipation of further price increases before energy prices eventually settled down.

In Figure A4 we contrast the baseline energy price shock to a hump-shaped shock. The top-left corner contrasts the two different processes. The hump-shaped shock has a lower initial magnitude, then increases until it levels off somewhat later but comparably to the AR(1) process. While the integral of both shocks is comparable, the reaction of aggregate variables is not. Especially the initial response is typically smaller and some variables like output, consumption and labor exhibit a similar hump-shaped profile peaking only a couple of quarters after the shock occurs. Once in the receding phase of the shock, aggregate variables exhibit similar patterns both qualitatively and quantitatively.

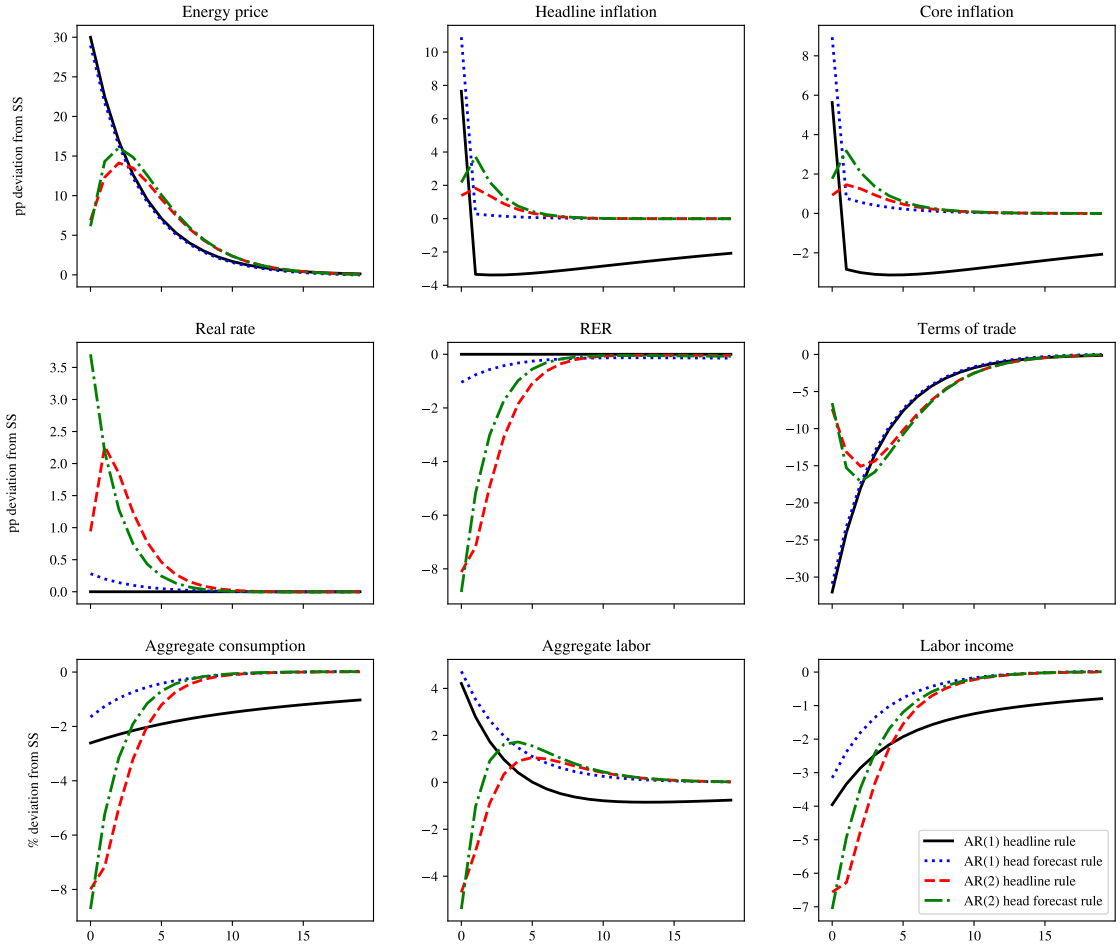
Given different shock profiles the natural question arises whether forecast rules are as advantageous in the case of energy price increases that can be expected to continue for some time. Figure A5 contrasts active monetary policy rules reacting to headline inflation for both profiles of an energy shock. Results for other active monetary policy rules are equivalent. Two main messages arise. First, forecast rules still perform better than rules reacting to contemporaneous inflation. While forecast rules lead to overall higher inflation rates, they stabilize aggregate real outcomes like consumption and labor better by partially looking through the energy price shock. Second however, these differences are by far not as pronounced as in the case of an immediately receding energy shock. Especially in the initial period headline rules yield comparable outcomes. Only in subsequent quarters does the headline rule imply slightly more adverse outcomes for real variables while at the same time leading to lower inflation.

Figure A4: Comparison of energy price shocks with different time profile



Note: The solid line plots a shock of 30% increase in foreign energy prices with persistence of 0.8. The dotted line plots a hump-shaped shock, chosen to have roughly similar overall impact on foreign energy prices. Monetary policy implements in all cases a fixed interest rate rule.

Figure A5: Comparison of policy rules for energy price shocks with different time profile



Note: The solid and dotted lines plot a shock of 30% increase in foreign energy prices with persistence of 0.8. The dashed and dot-dashed lines plot a hump-shaped shock, chosen to have roughly similar overall impact on foreign energy prices.

A6 Comparison across different supply shocks

This section aims to underline that modeling an energy price shock is significantly different from modeling standard productivity or cost-push shocks. While all constrain supply, these shocks transmit into the economy through different channels and therefore have different aggregate and distributional effects. In Figure A6, we compare the aggregate effects of our foreign energy price increase with those of an adverse TFP and mark-up shocks. We target the magnitude of the shocks to reach similar magnitudes of the core inflation response in period 0, while we leave the persistence equal. We compare the effects of these shocks under our baseline policy rule.

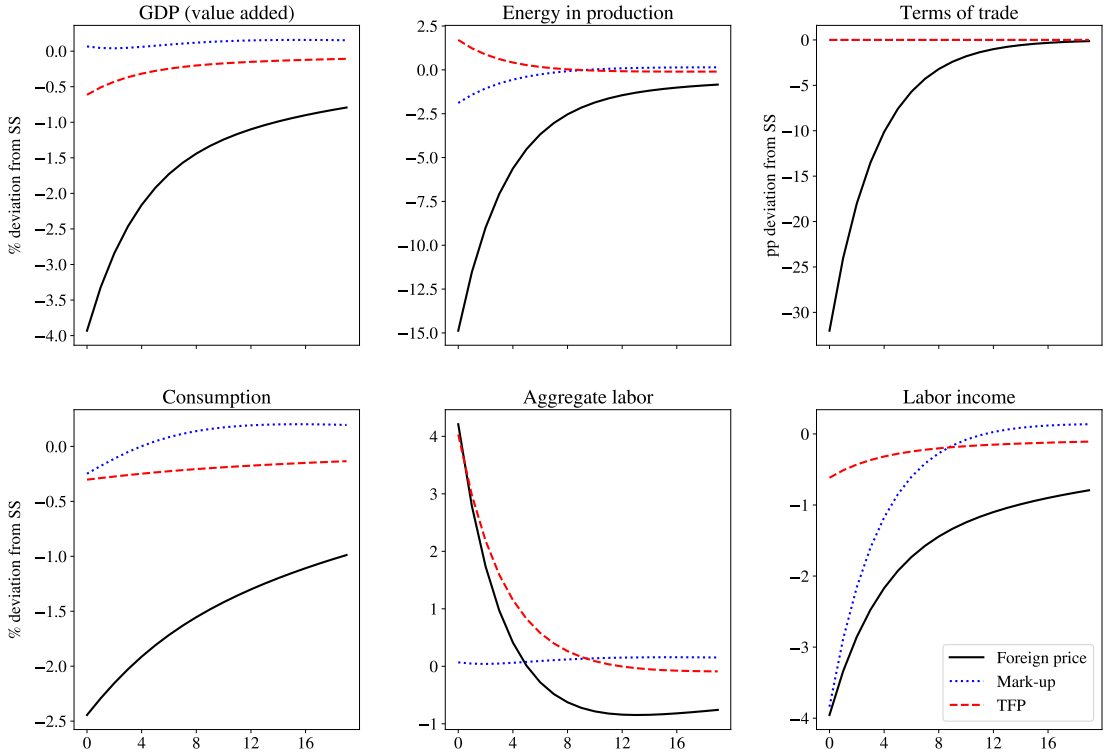
First, the TFP shock decreases the productivity of labor. Firms thus need to hire more labor to

produce the same output and labor demand increases. Instead, the energy price shock increases labor demand due to a substitution effect away from the imported energy good. The latter effect is more persistent, leading to a more persistently depressed labor income. Moreover, the TFP shock increases demand for the energy good, while the foreign price shock has the opposite effect – though both happen because of substitution effects. Furthermore, the TFP shock leads to a smaller decline in the terms of trade, implying a weaker foreign demand channel. The increase in energy demand of firms due to declining labor productivity implies far lower energy price increases as our energy price shock which together with a similar-sized initial response of domestic goods prices implies a smaller deterioration in the terms of trade.

Second, the mark-up shock generates a decrease in real wages and an increase in profits. The decrease in income leads to lower aggregate demand, translating into lower demand for factors of production, which further depresses labor income. The shock induces a redistribution from labor income towards asset income. In fact, low-wealth households witness a relatively higher drop in consumption, while all households with positive savings benefit from rising profits through the returns on the mutual fund. The shock is redistributive within the domestic economy, but all savers benefit from this.

Third, the foreign energy price shock overall entails the biggest output losses. It is also the only shock that generates a terms of trade depreciation, which actually dampens the effect of the shock over time. Importantly, the mark-up shock is redistributive within the economy, while the other shocks entail real economic costs, either because of lower productivity requiring more inputs (TFP) or because of a wealth transfer into the foreign economy (energy shock).

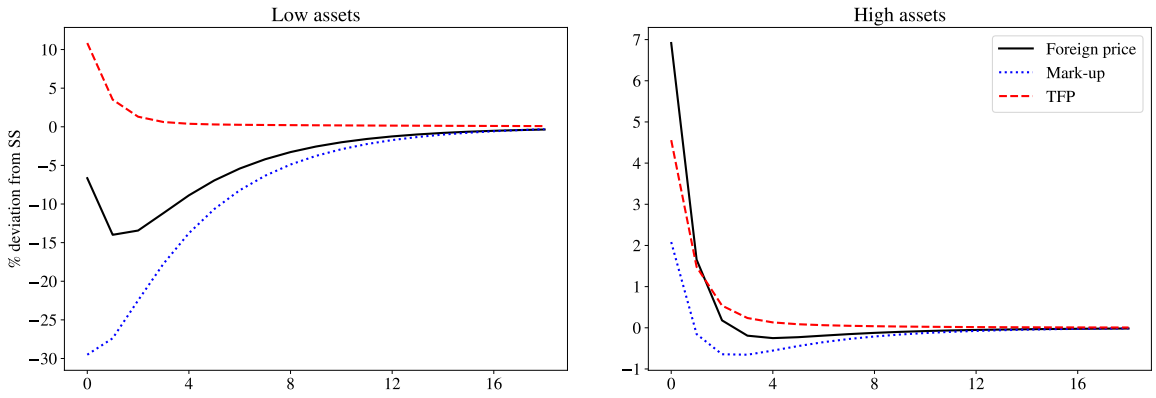
Figure A6: Comparison of the effects of the energy shock with those of a productivity and a price mark-up shock



Note: The energy shock is a 30% increase in foreign energy prices. The productivity shock and the price mark-up shock are calibrated to match the first period response of inflation as induced by the foreign energy price shock. All three shocks assume AR(1) processes with persistence of 0.8. Monetary policy implements in case of all three shocks a fixed interest rate rule.

Not only do the aggregates respond very differently to the three types of shocks, but also the effect on inequality depends on the nature of the shock. For illustration purposes of the heterogeneous effects, Figure A7 plots the savings response of low- and high-wealth households for the different shocks, and under a head monetary policy rule. The energy price shock weights negatively on low-wealth households' savings, while low-wealth households decide to increase savings as a response to the TFP shock. Savings of the low-wealth decrease most after a mark-up shock, consistently with the latter being a transfer from labor to capital earners.

Figure A7: Savings response to an energy, productivity and price mark-up shock

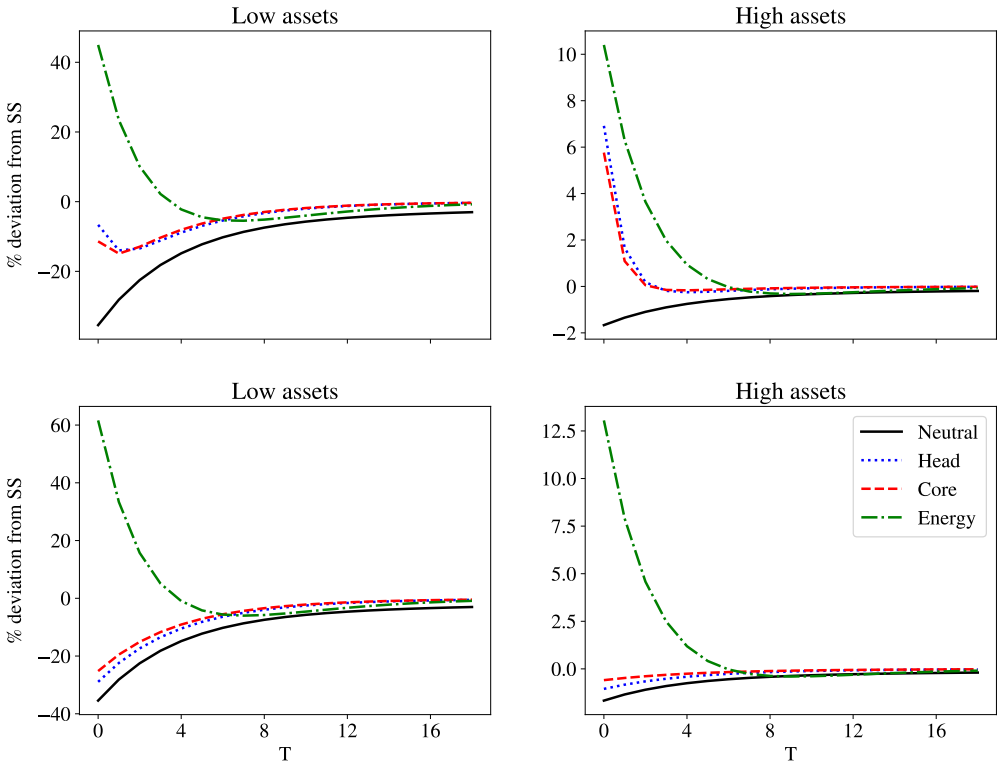


Note: The energy shock is a 30% increase in foreign energy prices. The productivity shock and the price mark-up shock are calibrated to match the first period response of inflation as induced by the foreign energy price shock. All three shocks assume AR(1) processes with persistence of 0.8. Monetary policy implements in case of all three shocks a head rule to contemporaneous inflation. The left panel plots the response of the lowest wealth quintile, while the right panel plots that of the second highest wealth quintile.

A7 Savings response for low- and high-wealth households

This section shows the savings response for low- and high-wealth households under monetary policy rules reacting either to contemporaneous or forecast measures of inflation. We define low-wealth households as those in the lowest wealth quintile and high-wealth households as those in the second highest wealth quintile. In our calibration, low-wealth households are also borrowing constrained without any savings to rely on.

Figure A8: Savings response under head monetary policy rules



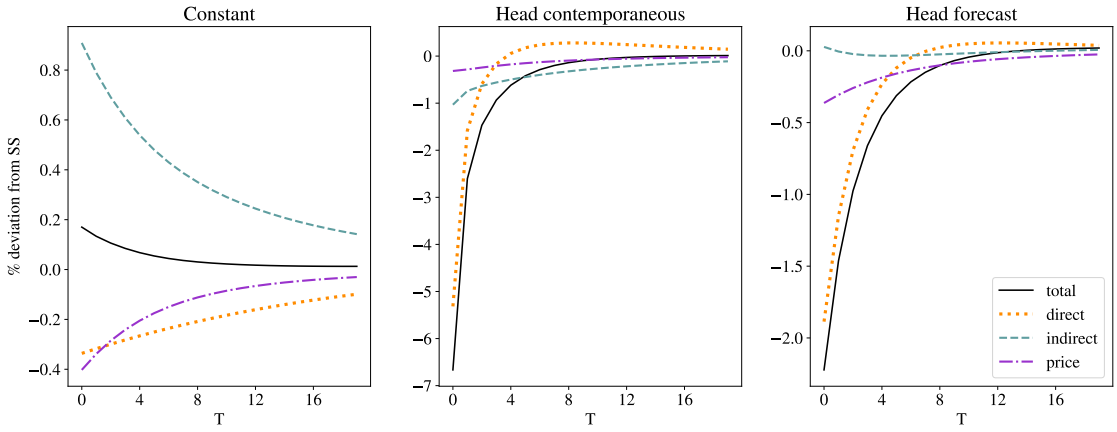
Note: On the top, we plot a comparison of the asset response of low- and high-wealth households under monetary policy rules reacting to contemporaneous measures of inflation. In the bottom panel, monetary policy reacts to forecast measures of inflation. Low-wealth households refer to the lowest wealth quintile whereas high-wealth households refer to the second highest wealth quintile.

A8 Incorporating a price Phillips Curve

Throughout the text we assume that wages are sticky but prices are perfectly flexible. In this appendix section we relax the latter assumption and introduce a price Philips curve. We introduce sticky prices by assuming that monopolistically domestic goods producers purchase intermediate goods and repackage them selling them to a final domestic goods bundler. This leads to a News Keynesian price Phillips curve of the form

$$\pi_t = \beta \pi_{t+1} + \kappa_p * \left(\frac{p_t^h}{p_t^i} - 1/\mu_p \right)$$

Figure A9: Drivers of aggregate consumption response across different monetary policy rules

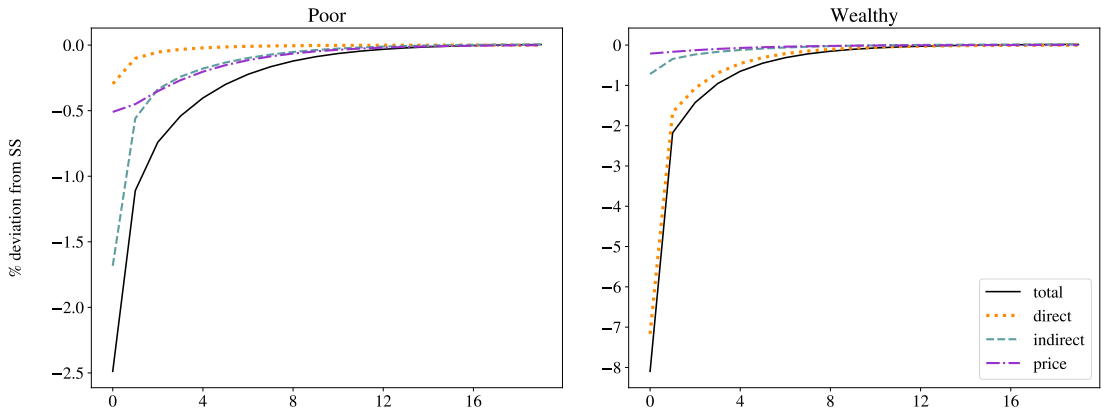


Note: Decomposition of the aggregate consumption response to an energy price shock. The "direct" effect captures the contribution from a change in the real interest rate, the "indirect" effect captures income effects and the "price" effect captures relative price changes as described in Appendix A2.

We calibrate the price Phillips curve to be twice as steep as the wage Phillips curve taking into account empirical evidence that prices seem more flexible than wages. In figure (A9) we show a decomposition of the aggregate consumption response similar to figure (7). Several results are evident. First, if prices are not perfectly flexible the aggregate effects of an energy price shock are not as severe. This is due to aggregate real wages not falling as strongly in response to the shock thereby sustaining aggregate demand. In case of a real rate rule the aggregate consumption response is even slightly positive (despite the overall shock causing a decline in aggregate ouput) because foreign demand for domestic goods and substitution away from energy inputs is sufficiently strong to maintain aggregate labor demand. Second, the aggregate consumption decomposition reveals that similar forces are at play as described in the main text. Active policy responses exacerbate aggregate effects through a strong real rate channel. Third, forecast rules have the potential to be less recessionary but in the case of sticky prices do not work as well compared to a baseline constant real rate rule.

Figure (A10) shows the same consumption decomposition for wealthy and less wealthy households for the headline Taylor rule. As in the main text the consumption response of the less wealthy is mainly driven by an indirect labor income effect. In contrast, consumption of the wealthy is predominantly driven by the direct effect as higher real rates incentivize them to save more. Notably, because sticky prices help sustain aggregate demand by avoiding as strong a fall in real wages, the consumption decline of the less wealthy is not as strong as that of the wealthy.

Figure A10: Consumption decomposition for low- and high-wealth households



Note: Comparison of the consumption response of low- and high-wealth households under monetary policy rules reacting to contemporaneous measures of inflation. Low-wealth refers to households in the lowest wealth quintile whereas high-wealth refers to households the second highest wealth quintile.

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